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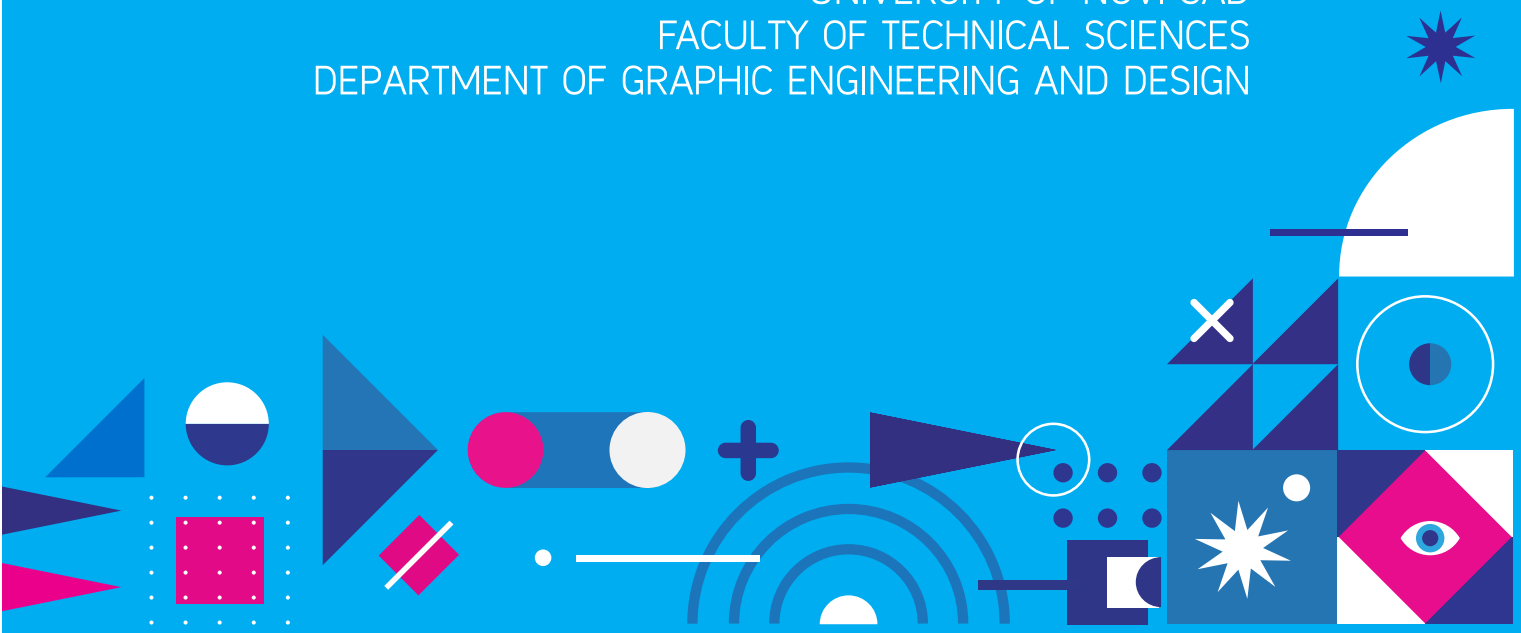
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12th INTERNATIONAL SYMPOSIUM ON GRAPHIC ENGINEERING AND DESIGN

UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF GRAPHIC ENGINEERING AND DESIGN



University of Novi Sad
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DEPARTMENT OF GRAPHIC
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Foreword

Dear readers,

It is my great pleasure to introduce You the research papers of the Twelfth Symposium on Graphic Engineering and Design. With this proceeding we continue the works of previous symposiums which have been held biennial since year 2002.

We're delighted that this international symposium has once again gathered a great number of participants from many countries as it became a tradition over the past 22 years.

The papers include the achievements of researches in the field of technology and scientific areas relevant to graphic technology and graphic design. Through the work of the symposium GRID, we continued significant scientific cooperation with educational institutions all over the world. With them we are continuing good cooperation which is the driving force for the creation and display of new developments, both individual and common.
I want to thank everyone who participated with their paper and presentation in the Symposium. Your contribution is significant for the improvement of the Symposium on Graphic Engineering and Design GRID 24. The research achievements presented here are also valuable to the scientific and professional community and are highly appreciated.

Editor

INVITED LECTURES



UNVEILING INNOVATIONS, CONFRONTING CHALLENGES, AND SHAPING THE FUTURE OF SUSTAINABLE PACKAGING SOLUTIONS IN THE EPOCH OF ENVIRONMENTAL TRANSFORMATION

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Abstract: *In response to escalating environmental concerns and the global push for sustainability, the packaging industry is undergoing a significant transformation. Traditional packaging methods, heavily reliant on single-use plastics, are no longer viable due to their detrimental impact on ecosystems and contribution to climate change. As consumer preferences shift towards eco-friendly products and stricter regulations emerge, industries are compelled to adopt sustainable packaging solutions. This shift not only addresses environmental challenges but also redefines the future of packaging in a rapidly evolving ecological and regulatory landscape. This paper provides a comprehensive analysis of the innovations in sustainable packaging in the broader context of global ecological change. Alongside these advances, the paper also identifies significant challenges to widespread adoption, such as economic barriers, consumer misconceptions and infrastructure limitations. The study examines both regulatory frameworks and industry initiatives and proposes strategies to overcome these barriers, emphasizing the importance of collaboration, policy innovation and continued investment in research and development. The aim is to outline a way forward for the packaging industry that is aligned with global sustainability goals and the circular economy.*

Key words: Packaging, sustainability, environmental issues, consumer behaviour, economic barriers

1. INTRODUCTION

The increasing awareness of environmental degradation and the urgent need to mitigate climate change have put unprecedented pressure on industry to adopt sustainable practices. Packaging, a fundamental component of various sectors, has become a focal point in this sustainability discourse due to its significant contribution to global plastic pollution and resource consumption (Jestratijević & Vrabič-Brodnjak, 2022). Conventional packaging materials, especially single-use plastics, are derived from non-renewable fossil fuels and remain in the environment for centuries, leading to negative impacts on the environment and human health. Therefore, the need for innovative and sustainable packaging solutions has become a key priority for policy makers and industry leaders. The impact of packaging waste, especially plastics, on the environment is serious. An estimated 8 million tons of plastic waste enter the oceans every year, posing a major threat to marine life and disrupting ecosystems (Pilapitiya et al., 2024). In addition, the production and disposal of conventional packaging materials contribute significantly to greenhouse gas emissions, further exacerbating the global climate crisis. Considering these facts, sustainable packaging has proven to be an essential element in reducing the environmental footprint of industrial activities. Namely, the sustainable packaging encompasses a range of strategies aimed at minimizing the environmental impact of packaging throughout its life cycle. These include the development of materials that are renewable, biodegradable or compostable, as well as design innovations that reduce material consumption and improve recyclability. In addition, sustainable packaging is in line with the principles of the circular economy, which aims to create closed loops in which materials are reused, recycled or returned to the environment in a harmless form.

1.2 The era of ecological change

The current era of ecological change is characterized by a global shift towards sustainability, driven by international climate agreements, regulatory frameworks and changing consumer behaviour. The Paris Agreement and the United Nations Sustainable Development Goals (SDGs) emphasize the importance of reducing waste and promoting sustainable production and consumption patterns (Ghufran et al., 2024). Against this backdrop, the packaging industry is at a crucial turning point. Environmental regulations such as the EU Single Use Plastics Directive and national bans on plastic bags and straws are forcing the industry to re-evaluate its reliance on traditional packaging materials (Kiessling et al., 2023). At the same

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time, consumers are increasingly prioritizing sustainability in their purchasing decisions and demanding more transparency from companies regarding the environmental impact of their products.

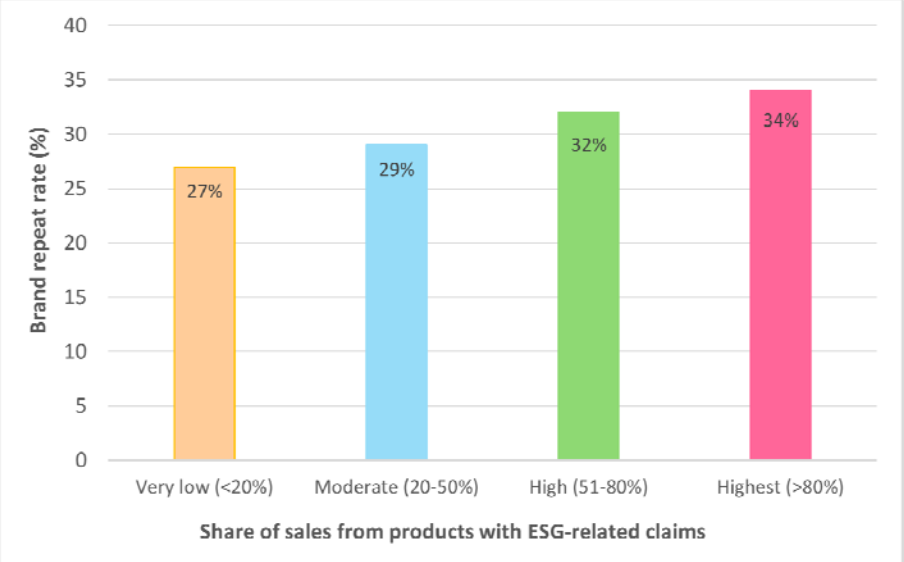


Figure 1: Brand repeat rate by sales from ESG-related claims (US) (McKinsey Global Institute, 2024)

Figure 1 shows data focused on ESG claims in the United States, regarding product offerings that can directly benefit brands through increased customer loyalty (McKinsey Global Institute report, 2023). This trend highlights the role of ESG integration as a key strategy not only for environmental and social responsibility but also for achieving sustainable business growth. The scientific implication is that companies focusing on circular economy principles, reducing carbon footprints, or enhancing social governance standards are likely to be rewarded with increased consumer engagement and loyalty over time.

The confluence of these forces is accelerating the development and adoption of sustainable packaging solutions, making it a key focus area for both industry and research. In this era, environmental degradation has accelerated dramatically, driven by industrialization, urbanization and the overconsumption of natural resources. Global environmental changes such as rising levels of carbon dioxide in the atmosphere, loss of biodiversity and scarcity of natural habitats have led to profound challenges that threaten the stability of ecosystems and the well-being of future generations. In response, it is increasingly recognized that a systemic shift towards more sustainable practices is required in all sectors of the economy, including packaging. In this context, the packaging industry faces challenges. Packaging materials, particularly single-use plastics, are ubiquitous in modern life and fulfil important functions in protecting products, preserving food and enabling global supply chains. However, the environmental costs of traditional packaging systems are becoming increasingly unsustainable. The global production of plastics reached 367 million tons in 2020 (Figure 2). A large proportion of this ends up in landfill, in the oceans or is incinerated, releasing harmful pollutants and greenhouse gases. The persistence of plastic waste in the environment has become a visible symbol of the wider ecological crisis and has prompted calls for a fundamental change in the way packaging is designed, produced and disposed of.

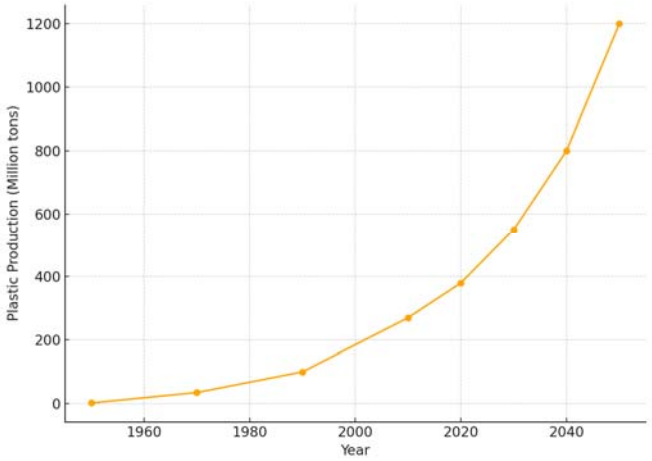


Figure 2: Global plastic production and accumulation over time, from 1950 to projected values in 2050 (Coalition Clean Baltic, 2024)

As mentioned, the era of ecological change, defined by significant human impact on the environment, poses both challenges and opportunities for sustainable packaging. Key drivers of this transformation include climate change, resource depletion, biodiversity loss, and the need for a circular economy:

a) Climate change necessitates a shift towards low-carbon packaging solutions, as traditional production methods contribute to greenhouse gas emissions through energy-intensive manufacturing and waste disposal. Transitioning to renewable and biodegradable materials is crucial for mitigating climate impacts and addressing food waste, which significantly contributes to methane emissions.
b) Resource depletion highlights the reliance on non-renewable resources, particularly fossil fuels, in conventional plastic production. This raises sustainability concerns and drives the move towards bio-based alternatives, such as polylactic acid (PLA). While these materials offer renewable options, challenges related to production scalability and environmental trade-offs remain.
c) Biodiversity loss and pollution are critical issues, as packaging waste, especially plastics, has severely degraded ecosystems. Plastic pollution in oceans leads to microplastic contamination, affecting marine life and human health. Addressing this requires the development of biodegradable and recyclable materials, along with effective waste management systems.
d) The concept of a circular economy emerges as a response to the traditional linear model of "take-make-dispose," which is inherently unsustainable. A circular economy promotes resource reuse and waste reduction by designing durable, recyclable products and establishing infrastructure for closed-loop systems.

The recognition of packaging's environmental impact has prompted regulatory initiatives aimed at reducing plastic pollution and promoting sustainable materials. Governments, particularly in the European Union and North America, are phasing out single-use plastics and encouraging biodegradable alternatives (Dhiman et al., 2022). The European Green Deal aims to make Europe climate-neutral by 2050, emphasizing sustainable product design and implementing measures like the Single-Use Plastics Directive, which bans specific plastic products and establishes Extended Producer Responsibility (EPR) schemes to hold manufacturers accountable for end-of-life management (European Commission, 2024).
On the other hand, public awareness has significantly increased, leading to growing consumer demands for sustainable products. This shift in behaviour pressures industries to align with environmental values and drives innovation in packaging solutions. However, the transition to sustainable packaging presents challenges. Technical challenges include the performance limitations of biodegradable and compostable materials compared to traditional plastics, necessitating further innovation to meet industry needs. There is economic viability, which remains a barrier, as developing sustainable materials can be cost-prohibitive, especially for small and medium enterprises. Yet, rising consumer demand and regulatory pressures may lower costs over time, making sustainable options more feasible. Additionally, infrastructure limitations hinder progress, as many regions lack adequate recycling and composting facilities, underscoring the need for investment in systems that support a circular economy. Therefore, the era of ecological change is reshaping the packaging industry, highlighting the critical need for innovation, collaboration, and

regulatory support. Developing sustainable packaging solutions is essential for reducing the environmental footprint of industrial activities, requiring concerted efforts from governments, businesses, and consumers to ensure a sustainable future.
This paper aims to provide an examination of the challenges and future directions of sustainable packaging in the context of this environmental transition, with three objectives:

- To examine the advances that are driving the development of sustainable packaging, with a focus on biodegradable, compostable, reusable materials and smart packaging technologies.
- Critically assess the barriers to widespread adoption of these innovations, including economic, regulatory and behavioural challenges.
- Propose strategies to overcome these barriers, emphasizing the role of collaboration between governments, industry and consumers, alongside the need for a robust regulatory framework and continuous research and development.

By addressing these areas, the paper aims to contribute to the scientific understanding of sustainable packaging, which is a critical component of global efforts to achieve environmental sustainability and reduce the environmental impact of industrial activities.

2. SUSTAINABLE PACKAGING SOLUTIONS AND INNOVATIONS

The transition to sustainable packaging necessitates a multidisciplinary approach, involving material science, engineering, and environmental policy. In 2024, the sustainable packaging landscape continues to evolve with several cutting-edge innovations addressing both environmental impact and consumer demand.
Notable trends and solutions shaping the future of packaging include (Patel, 2023):

a) Edible packaging: companies like Loliware are developing biodegradable, edible materials made from natural ingredients like seaweed. These can serve as a replacement for traditional plastic in food packaging, drastically reducing waste.
b) Mushroom/Mycelium packaging: mycelium-based packaging, derived from the root structure of mushrooms, is emerging as a sustainable alternative to polystyrene. It's biodegradable, lightweight, and made from agricultural waste, with applications in electronics and insulation.
c) Bio-based materials: replacing fossil fuel-derived plastics, plant-based plastics made from corn, sugarcane or similar materials are biodegradable and compostable, offering a more sustainable option for food and consumer goods packaging.
d) Recyclable, flexible packaging: innovations in mono-material flexible packaging are making these materials easier to recycle, addressing the traditional challenge of multi-layer packaging. Companies like Dow and Amcor are leading efforts in this area.
e) Compostable packaging: compostable materials, such as packaging made from beech tree pulp for citrus fruits or mycelium, are gaining traction. These materials degrade naturally, reducing the burden on landfills.

As already mentioned, biodegradable materials have become the most important response to the limitations of conventional petroleum-based plastics. They are developed as eco-friendly alternatives to traditional plastics, typically derived from renewable biological sources. They can degrade naturally without producing harmful residues. There are several bio-based packaging materials that are being developed as sustainable alternatives to conventional plastics. Biopolymer films made from cellulose nanocrystals (CNC), nano-fibrils (CNF), and bacterial nanocellulose (BNC) in combination with chitosan and alginate have shown potential for food packaging applications (Lavrič et al., 2021). The addition of CNC enhances the hydrophobicity, as well as the water and oxygen barrier properties of these materials. These biopolymer films exhibit improved mechanical performance, making them a promising substitute for conventional plastic packaging. Polylactic acid (PLA), which is derived from renewable sources such as corn starch or sugar cane, is a biodegradable material used for food packaging, utensils and containers. Polyhydroxyalkanoates (PHA), which are produced by microorganisms, are fully biodegradable and are suitable for packaging, bags and medical applications. Starch-based plastics, made from sources such as potato or corn starch, are often used for films, bags and other disposable products. Chitosan, which is derived from the chitin of crustacean shells, has strong antimicrobial properties and is ideal for food packaging films. Agar and carrageenan, which are obtained from algae, are also used to produce biodegradable films with good oxygen barrier properties. Lignin, a by-product of the paper industry, is

also being researched to produce biodegradable plastics with strong mechanical properties (Lavrič et al., 2021). These materials, as well as cellulose nanocrystals (CNC) and cellulose nanofibrils (CNF), aim to reduce environmental impact while providing effective packaging solutions.

An important approach to sustainable packaging solutions is also the possibility and shift towards reusable and refillable systems, which are central to the circular economy model. This approach aims to minimize waste by keeping materials in continuous circulation, replacing single-use packaging with durable, returnable containers. Several refill and reuse solutions are gaining prominence as part of the shift toward a circular economy (Vrabič-Brodnjak & Jestratijević, 2024). Examples include Algramo, a system that offers smart packaging for refilling household products like cleaning supplies and food, allowing customers to refill containers at vending machines or via delivery services. The Body Shop has introduced refill stations in stores where customers can refill reusable containers with personal care products, while Unilever is testing refill stations in supermarkets for shampoos and cleaning agents. Lush offers no packaging products, such as solid shampoos and soaps, which eliminate packaging, along with reusable tins for storage. Albéa provides refillable solutions for cosmetics, enabling consumers to purchase refills rather than new containers. Muuse focuses on the food and beverage industry, offering reusable containers for take-out meals, which can be returned, cleaned, and reused. These solutions play a vital role in reducing single-use packaging waste and promoting sustainable resource use (Vrabič-Brodnjak & Jestratijević, 2024).

These solutions demonstrate how technology and natural resources are converging to create more sustainable packaging, driven by both regulatory changes and consumer preferences for eco-friendly options.

3. ECONOMIC BARRIERS REGARDING COSTS AND SCALABILITY

The production of sustainable packaging, especially biodegradable and compostable alternatives, is often more expensive than conventional plastics due to high raw material costs and specialized manufacturing processes, which is a challenge for small and medium-sized enterprises (SMEs). In addition, consumers are often unaware of the correct disposal methods, resulting in lower environmental benefits. Compostable materials, for example, require industrial facilities that are not available in all regions, and confusion over "biodegradable", "compostable" and "recyclable" labelling makes disposal difficult. The global recycling infrastructure remains underdeveloped, particularly in developing countries, which limits the effectiveness of sustainable packaging. The supply chains for bio-based materials are still being established, which leads to supply bottlenecks and higher costs. Performance issues, such as reduced shelf life or moisture resistance, also pose a challenge for sectors such as food and pharmaceuticals. On the other hand, there are government measures such as the European Green Deal and the Single Use Plastics Directive are key to promoting sustainable packaging. In the US, bans on plastic bags and polystyrene foam are gaining momentum at state level. EPR is forcing manufacturers to take responsibility for the entire life cycle of their products. Industry initiatives such as the Sustainable Packaging Coalition and certifications such as “Cradle to Cradle” also play an important role in setting standards and helping consumers make environmentally friendly choices.

4. STRATEGIES FOR OVERCOMING BARRIERS TO SUSTAINABLE PACKAGING

To address the challenges outlined, a multifaceted strategy is required, incorporating technological, regulatory, and educational approaches. Overcoming barriers to sustainable packaging requires a comprehensive strategy that addresses technological, economic, and consumer challenges. One critical approach is the development of innovative materials, such as biodegradable, compostable, and recyclable alternatives. These materials must be improved to match the performance of traditional plastics, particularly in terms of barrier properties and durability. Scaling production and reducing the costs of sustainable materials through investment in supply chains and economies of scale is another vital step, making these options more economically viable. Government intervention through policies and incentives can accelerate this shift, with measures such as taxes on single-use plastics, EPR programs, and financial incentives for companies adopting sustainable packaging. Equally important is the improvement of recycling infrastructure, expanding facilities, and incorporating better sorting technologies and standardized labelling to increase recovery rates and minimize contamination. Adopting circular economy models is another key strategy, where packaging is designed for reuse, recycling, or composting. Initiatives like Loop’s refillable systems or Coca-Cola’s Universal Bottle illustrate how closed-loop systems

can keep packaging materials in continuous circulation. Consumer behaviour plays a significant role in sustainable packaging adoption, making consumer education and engagement essential. Raising awareness about environmental impacts, providing clear recycling labels, and implementing incentive programs like deposit return schemes can influence more responsible consumer choices. Collaboration across the supply chain is crucial for ensuring that packaging solutions are not only environmentally friendly but also compatible with existing recycling systems. Lastly, lifecycle assessments (LCA) and eco-design principles encourage companies to minimize packaging material use and reduce environmental impact across the entire product lifecycle. By integrating these strategies, the industry can overcome the barriers to sustainable packaging, promoting a shift toward eco-friendly solutions that replace traditional plastics.

5. CONCLUSIONS

The era of ecological change requires a transformative approach to packaging, characterized by innovation, regulatory adaptation and active consumer engagement. The future of sustainable packaging lies in a multi-pronged approach that integrates biodegradability, recyclability, and intelligent design with circular economy principles. Continued research, innovation, and collaboration between industries, governments, and consumers will be essential in driving this environmental transition. As sustainable packaging becomes mainstream, it has the potential to significantly reduce the environmental impact of one of the most pervasive aspects of modern consumption.

Future research should focus on optimizing the performance of sustainable materials, exploring novel recycling technologies and assessing the life cycle impact of different packaging options. In addition, collaborative frameworks that engage stakeholders along the entire supply chain are critical to overcoming barriers to the adoption and long-term viability of sustainable packaging solutions. Ultimately, the transition to sustainable packaging is not just a regulatory measure, but a strategic imperative for companies that want to align themselves with global sustainability goals. By fostering innovation, improving regulatory frameworks and engaging consumers, the packaging industry can play a critical role in mitigating environmental impacts and shaping a sustainable future. This collective effort will be critical to building a resilient economy that prioritizes environmental protection and social responsibility. The transition to sustainable packaging in the context of ecological change represents a complex interplay of innovation, legal framework conditions, consumer behaviour and ecological necessities.

6. ACKNOWLEDGMENTS

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CURRENT TRENDS IN PACKAGING

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Abstract: *The basic duties of packaging include protecting the product, providing information about the product, and facilitating transportation. With developing technology, decreasing resources, and increasing population, extra duties have been needed in addition to the basic duties of the packaging, such as protecting the life and freshness of the product, providing information about the product inside, improving the usage areas of the product, ensuring its correct use, and ensuring sustainability conditions. In this sense, sustainable, smart, and active packaging technologies are increasing day by day. The use of these functionalized packages is generally more common in the healthcare, food, and logistics industries. This study examines how active, sustainable, smart packaging can revolutionize packaging. The research aims to provide specific insights into the potential of functional packaging technologies. The study also discusses the promising future of functional packaging, with technological development and consumer needs ecological for friendly products. In conclusion, this work reveals how functional packaging can transform packaging industry accomplish limitations and compensation consumer demands, supply advanced product safety, quality, and sustainability.*

Key words: active packaging, smart packaging, traceability, food safety, functional packaging

1. INTRODUCTION

Packaging has an important and critical role in the product supply chain. The main task of packaging is to contain the product, keep it in its content, transport the product efficiently in all logistics stages, prevent physical damage that may occur during supply and transportation, and resist deception. In addition, packaging prevents undesirable chemical and biological changes in the product and ensures the quality and safety of the product in the process from production to consumption (Rahmawati et al., 2024). As can be understood from here, packaging has a barrier feature that protects the product from external factors, chemicals, and microbiological pollution such as oxygen, moisture, light, dust, pests, volatile substances, etc.

Packaging generally provides passive protection. That is, the packaging acts as a barrier between the in-package environment and the out-of-package environment around the product. However, sometimes gas-permeable packaging materials can also be used in the packaging of fresh products. This second type of packaging can protect the life of the product for a limited time (Pirsa, 2024). Nowadays, people do not want to increase the usage and shelf life of the product by adding additives to it (Bodie et al., 2024). The undesirable side effects that added additives may cause on the body of the user of the product cause concern in end consumers. In this sense, the fact that the products are produced with minimum processing and fewer or no additives (clean content) attracts the attention of conscious consumers. This interest has made the product protection feature of the packaging more important. Nowadays, new packaging technologies such as modified atmosphere packaging (MAP), active packaging (AP), smart and intelligent packaging (SP/IP) and nanomaterial applications are being developed day by day in order to improve the protective properties of the packaging (Mahapatra et al., 2024).

In addition, in the last fifty years, the advantages of plastic packaging such as cost, lightness, ease of production, perfect compatibility with the product, and ease of processability have enabled it to be used more than other traditional packaging materials (glass, metal, paper and cardboard, etc.). However, the fact that most plastics used in the packaging industry are produced from petroleum, the difficulty and long time it takes to break down these petroleum-based plastics, the microplastics that emerge when they break down, the pollution and energy requirements that occur in the cycle from their production to waste, make consumers concerned about the use of plastic packaging. To overcome this problem, the packaging industry is paying more attention to packaging made from biodegradable bioplastics produced from biomass (Mohapatra & Singh, 2024).

Innovative packaging solutions have emerged because of increasing population, conscious consumer demands, decreasing resources, increasing environmental awareness and developing technologies (Francis et al., 2024). Innovative packaging trends include smart, active, and sustainable packaging (Khandeparkar et al., 2024). While these packaging technologies increase efficiency in the supply chain of products, they ensure product safety, reduce product loss, and eliminate product waste, and ensure the

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communication of the product with the consumer. The increasing diversity of publications on innovative packaging in recent years proves that the subject has attracted attention from both the academic and industrial environments.

Packaging that offers "something extra" in addition to wrapping, protecting, and transporting the product is called smart packaging. Said "extras" can include anything from improving the freshness of the food, monitoring its conditions, or extending its shelf life, etc. Smart packaging technology is a technology that enables the product inside the package to communicate with the consumer. If we compare traditional and smart packaging applications, traditional packaging provides limited information, basic protection, manual monitoring, while smart packaging has features such as enhanced protection, traceability and safety, real-time monitoring, interactive features (Li et al., 2024).

Even though smart packaging systems have early applications, they have found many areas for themselves. These include monitoring the freshness of the food, sharing the data with the end user, and keeping the stocks of the products trackable and traceable. Smart packaging analyzes the storage conditions, quality, and internal/external environment of the product with the help of various sensors, indicators and devices. Smart packaging uses sensors, indicators, and monitoring systems to monitor and communicate the status of the product. Sensors added to the packaging, or its design are the most important component of smart packaging. With sensors, parameters such as temperature, humidity, gas composition, microorganism rate and pH levels of the internal environment of the package can be determined and shared with the consumer (Hasanin et al., 2024). Smart packaging can constantly monitor one or more of the above features and constantly inform consumers about the quality of the product. For example, smart packaging technologies are used to prevent problems that may occur if the cold chain of the vaccine packaging is broken (Figure 1).

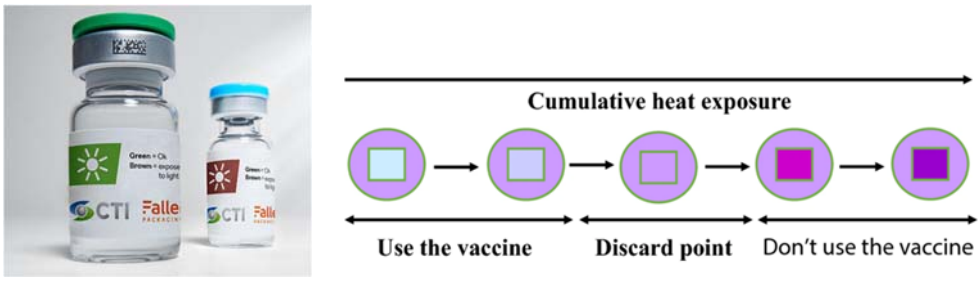


Figure 1: Examples of smart tags used in vaccines (Smart Labels, 2015; Ramakanth et al., 2021).

Another example of the use of smart packaging applications is thermochromic inks (Figure 2). Thermochromic inks are materials that change colour depending on temperature changes. Smart packaging systems are used to share with the consumer the ideal drinking temperature of a beverage or whether a canned food that needs to be heated has reached the ideal eating temperature. By choosing appropriate colours, hidden messages such as "DRINK NOW" or "TOO HOT" can become visible and provide a visual cue to the consumer.



Figure 2: Thermochromic smart labels and packaging items (Intelligent Packaging, 2024)

Time temperature indicators (TTI) are one of the most well-known smart packages. It is a design embedded in a label or packaging that communicates with visuals or data showing whether the product has deviated from the specified temperature in its storage and logistics, whether it has been exposed to adverse conditions, and whether there has been a loss of quality as a result (Figure 3) (Ahmed et al., 2018). TTIs

allow product tracking from producer to consumer, allowing informed decisions to be made. TTIs have advantages such as ensuring the protection of the product by allowing real-time information transfer about temperature increases or decreases during the logistics and storage of the product, warning the relevant parties in case products that can be affected by temperature such as medicines, vaccines, or food encounter undesirable conditions, and reducing the risk of consuming spoiled food depending on the information provided. It also has disadvantages such as not being concerned with other quality factors of the product as it only allows temperature monitoring, and the need to apply an additional sensor to the packaging, which increases the cost.

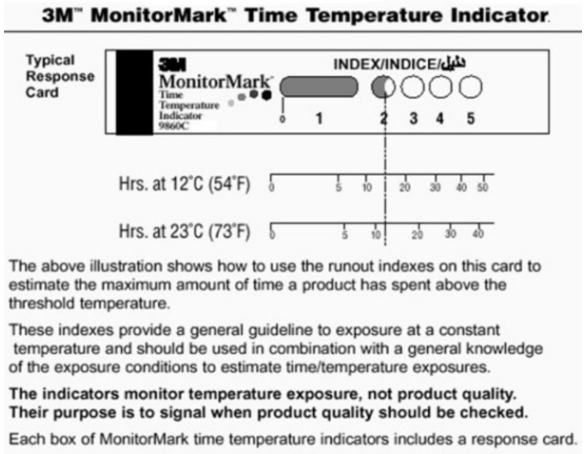


Figure 3: Monitor Mark™ time temperature indicators (Wang et al., 2015).

Technologies such as Radio Frequency Identification (RFID) and Near Field Communication (NFC) are also used as smart packaging components that enable tracking and tracing of the product from production to consumption. Information about the product's location, temperature, etc. can be monitored instantly with RFID tags or NFC-enabled tags added to the packaging (Athauda & Karmakar, 2019). In this way, theft and counterfeiting are reduced, while product safety is increased by quickly recalling the product in case of damage, etc (Figure 4).



Figure 4: RFID / NFC Labels (RFID / NFC Labels, 2024)

Another technology used in smart packaging technologies is gas sensors that can determine oxygen, carbon dioxide, ethylene levels, humidity, pH, and other volatile components in the packaging. With the information obtained from these sensors, the freshness, ripeness, and quality of the product can be determined (Hasanin & Abdelkhalek, 2024). For example, with the ethylene gas sensor (Figure 5), it can be determined whether an unripe fruit is ripe or not. Some of the fruits release ethylene gas as they ripen, and ethylene gas sensors can give us information about the ripeness of the product depending on the presence and amount of ethylene gas. Smart packaging using gas sensors can be used to continuously monitor the freshness of products that are likely to deteriorate quickly and spoil (fruits, vegetables, and dairy products), to inform the end user more easily about the expiry date and freshness, to raise the awareness of the end user and to reduce waste by consuming products that are about to deteriorate earlier. While it has advantages, it also has disadvantages such as increased cost due to the addition of additional packaging members, and in some cases, the complexity of the design in case of energy requirements such as batteries (Matindoust et al., 2016).



Figure 5: Ethylene gas sensor (RipeSense) for ripening of fruit (Label to Sense Ripening of Fruits, 2024)

Another type of smart packaging uses interactive elements to attract the attention of the end user and enable them to use the product better and more effectively. For example, with the element added to the packaging design, additional information such as recipes for different dishes to be made with the purchased product or the nutritional values of the product can be added. QR codes or quick response codes provide access to product information, market promotions or market loyalty programs in the packaging (Figure 6) (Elkhattat & Medhat, 2022).



Figure 6: QR code embedded smart package (Epacflexibles, 2024)

A large part of smart packaging research is related to bio-based sensors, where the sensors to be used in product packaging are natural substances and biopolymers. In this type of smart packaging, the sensor notifies the end user of changes in the product or the environment where the product is located (inside the packaging), thus ensuring that the consumer has precise information about the condition of the product. Such sensors are also called freshness indicators. Freshness indicators generally work by determining the metabolites or microbiological materials released as a result of chemical reactions occurring in the structure of the food. For example, nitrogen derivatives may be released because of spoilage in food, which causes a change in pH, so information about freshness can be easily obtained by using substances that change colour with pH change. Freshness indicators can operate directly or indirectly. Direct freshness indicators work by detecting the freshness of the product using a specific analyte directly from the fruit. Indirect freshness indicators work by detecting the deterioration of the product based on the spoilage reaction products due to effects of temperature and/or time, etc. (Liu et al., 2022).
Depending on the development of microorganisms in the product, food may spoil or lose its freshness. With the help of freshness indicators, the released metabolites (volatile nitrogen molecules, carbon dioxide, biogenic amines, ethanol or sulfur compounds) can be determined. In order to perceive quality in perishable products, harmful metabolites released during food spoilage must be minimized. Even if these metabolites cannot be minimized, determining the number of metabolites is important. While acetic acid, n-butyrate and biogenic amines released by microbial growth should be determined as freshness indicators to be used in meat, total volatile basic nitrogen (TVB-N) and biogenic amines should be determined in fish and shellfish. Ethyl alcohol and carbon dioxide released during the decay of food accelerate the decay. If these metabolites can be determined with the freshness sensor, food waste can be prevented (Panjagari et al., 2021).

pH-sensitive sensors are sensitive to changes in acidity or alkalinity occurring in the product's environment and can warn the consumer by showing different reactions in case of a change. Some substances used in these sensors not only change pH-sensitive colour but also provide the packaging material with the ability to protect the product against different bacteria, fungi, or viruses (Motelica et al., 2020). However, it should not be forgotten that any substance added to the film may change the properties of the films (mechanical, barrier and optical, etc.). Therefore, the quantities of substances used must be precisely adjusted and optimized (Riahi et al., 2024).

Although synthetic colorants provide very effective results in freshness indicators, caution should be exercised in their use in food applications as they may have toxic properties. Colorants obtained from natural sources (plants and fruits) are preferred instead of synthetic colorants in freshness indicators. Natural colorants have positive properties such as being easily biodegradable in nature and in the human body, low toxicity and very low environmental impact, and negative properties such as low colouring ability and low light fastness (Chiu & Yang, 2024).

Anthocyanins are one of the colorants used to create pH-sensitive biosensors in smart packaging applications (Figure 7). Anthocyanins are known to be antioxidant, antibacterial and pH sensitive. One of the biggest disadvantages of anthocyanins is that they are not stable against light and heat. For this reason, low temperatures must be used in the preparation of the polymeric matrix used in smart packaging design. In addition, the smart packaging materials produced are either exposed to less light on the inside of the package. Forming a two-layer film with substances such as ZnO will facilitate its use. Due to the low observability of colour capacity at low concentrations, the polymer matrix to be used is expected to be colourless so that the colour of the anthocyanin is easier to detect. Some colour differences may occur depending on the pH of anthocyanins from different sources. In addition, the use of excessive amounts of anthocyanins will create aggregation problems and have a negative effect on the mechanical properties of the film. Plasticizers can be added as reinforcements to increase the mechanical and barrier properties of the films.

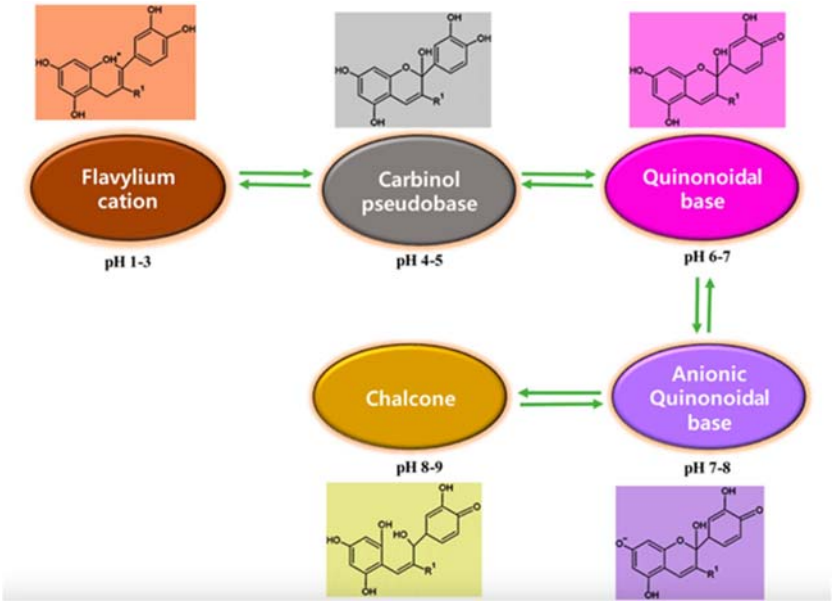


Figure 7: pH-dependent chemical structures of anthocyanin (Roy & Rhim, 2021).

Curcumin obtained from turmeric is also used in studies on smart packaging application (Figure 8). It has been determined that the addition of curcumin in smart packages, in addition to its colour change against pH, has a high level of antibacterial activity against foodborne pathogens such as *Escherichia coli*, *Salmonella spp* and *Listeria monocytogenes* etc. in films made from pectin/chitosan mixtures and chitosan-based materials. In addition, it has been concluded that curcumin is a good candidate material for smart packaging systems because the films added to curcumin do not lose their transparency and improve their properties such as mechanical, barrier, hydrophobic and thermal stability. Apart from these, there are studies on the usability of carotenoids and chlorophyll in smart packaging applications (Zheng et al., 2022).

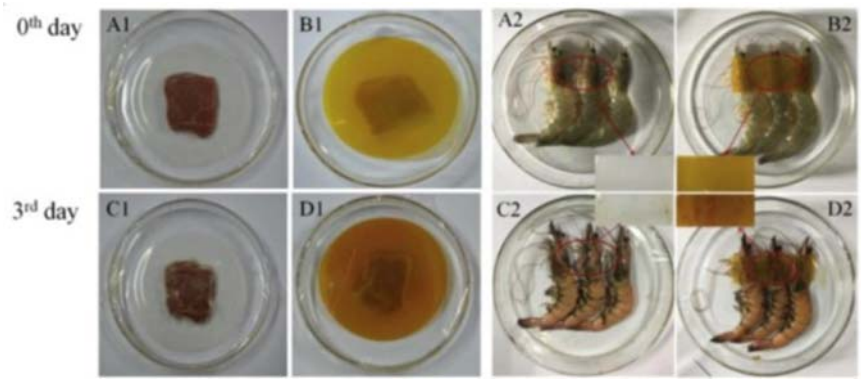


Figure 8: Curcumin based smart label (Roy et al., 2022).

Smart packaging methods provide valuable insights and information to both consumers and supply chain stakeholders. It enhances user experience, improves product safety, and reduces waste. However, the choice of smart packaging method should be compatible with the specific needs and characteristics of the product, and the advantages and disadvantages should be carefully considered to ensure effective application.

Another new generation packaging application can be considered active packaging. Active packaging works by incorporating active materials into the packaging to provide features such as extending the shelf life of the products and maintaining their current quality (Nian et al., 2024). For example, oxygen scavengers can be added to packaging material to prevent oxidative degradation. Another example is humectants. These prevent mould formation by reducing the water vapor in the food. The most used types of active packaging include oxygen scavengers, carbon dioxide scavengers, ethylene scavengers, self-heating or cooling cans and antioxidant releaser films (Rani et al., 2024). In order to remove harmful and unwanted gases contained in the packaging, various gas regulators such as absorbent sachets, absorbent porous pads, dust types placed in paper/cardboard, semi-permeable membranes, strips and self-adhesive labels can be used to contain the gas content. Although sachets are the most used active packaging type, alternative approaches such as adding functional materials to polymer matrices attract attention due to high packaging costs and safety concerns.

Oxygen scavengers aim to remove oxygen from the packaging environment and thus prevent problems that may occur in the product (Figure 9). Iron powder, ascorbic acid, enzymes, unsaturated fatty acids and yeasts can be used as oxygen scavengers (Gupta, 2024). When the literature is examined, it is seen that most studies are based on iron oxidation. The risk of swallowing oxygen scavengers, which are usually added to the packaging in small packets, is one of the biggest usage restrictions. In addition, possible package explosions and contamination of food with iron dust are other factors that need to be taken into consideration. Another problem encountered when sachet oxygen scavenger is added to the packaging is that there is difficulty in capturing oxygen due to the lack of air flow. For this purpose, integrating oxygen scavengers into the packaging material will overcome the problems. Oxygen scavengers have advantages such as extending the shelf life of food, medicine, etc. that are spoiled by oxygen, slowing down the decomposition by inhibiting aerobic bacteria, but also have disadvantages such as accelerating the decomposition of fresh products that require oxygen and being costly (Vermeiren et al., 2003).



Figure 9: Oxygen scavenger sachet (What is modified atmosphere packaging, 2024)

Ethylene gas is a plant-based chemical that affects some fruits and vegetables (Figure 10). Breathing ethylene gas accelerates ripening, thus causing food to rot earlier. To extend the shelf life of food products and slow down decay, ethylene must be restricted or removed from the environment. Potassium permanganate is the most used ethylene scavenger (Kumar et al., 2024). Potassium permanganate is reduced by reacting with ethylene; thus, ethylene is removed from the environment, and with the reduction, the colour of the permanganate changes from purple to brown, which gives us information about the lifespan of the scavenger. Ethylene scavengers can be useful in packaging foods with high usage areas such as apples, apricots, mangoes, bananas, tomatoes, avocados, carrots, potatoes and similar (John et al., 2024).

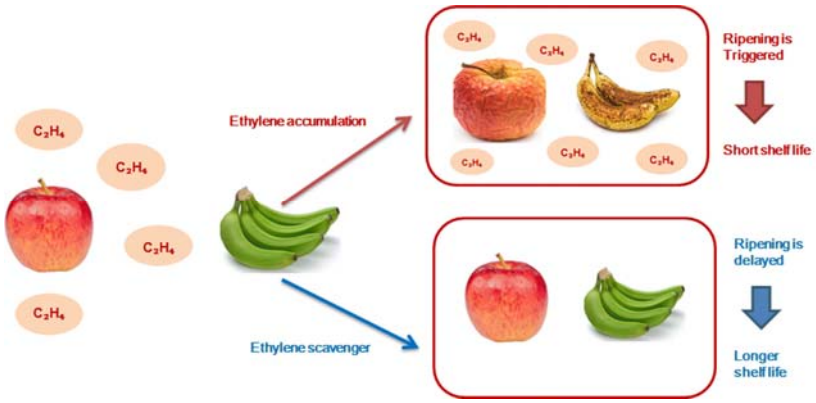


Figure 10: Ethylene scavenger working principal diagram (Gaikwad et al., 2020)

Carbon dioxide (CO_2) is released as a result of spoilage and respiratory reactions in some foods (Figure 11). This gas released causes both the food to deteriorate faster and the packaging to swell and explode. For this reason, this gas accumulated in the packaging must be removed. The most common way to remove carbon dioxide is to react it with calcium hydroxide. As a result, calcium carbonate and water are released. The problem can be eliminated by collecting the resulting water in the pad (Rani et al., 2024).

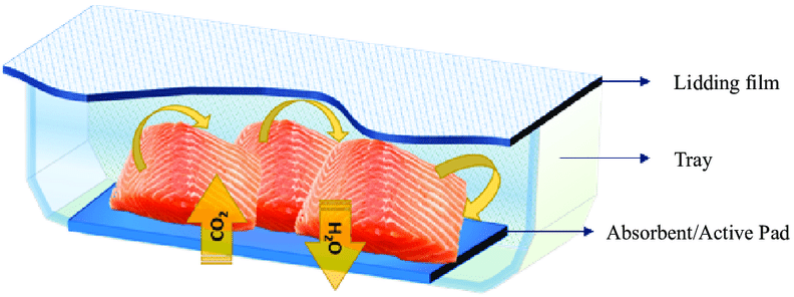


Figure 11: CO_2 scavenger sachet (Boz et al., 2018)

When recent studies are examined, improving the capabilities of materials in new generation packaging attracts attention. Bio nanocomposites are used to improve the thermal properties of materials and provide barrier properties. While providing these properties, an antimicrobial effect can be achieved by adding nanoparticles. While providing these features, there are factors such as the cost of the material produced, the safety of bio-nano composites in contact with food and compliance with health/safety regulations in order for the new generation packaging to be commercially applicable. Although biosensors used in smart packaging are an interesting component, their adaptation to the packaging poses some difficulties. Microstructures, sensitivities, specificities, and detection limits of biosensors, and ensuring consistent sensitivity over time are some of these. Despite all their positive capabilities, the commercialization of new generation packaging technologies is still in its infancy. In this sense, more research is needed on new generation packaging technologies. A comprehensive understanding of next-generation packaging technologies is crucial to creating sustainable and affordable smart packaging materials.

In order for smart packaging systems to be used in the market, strict regulations must be established

regarding the materials used and the labeling to be done. For example, care should be taken to clearly label products that should not be eaten, such as oxygen-scavenging sachets. To eliminate such problems, studies are being carried out on the development of packaging-integrated systems.
Promoting sustainability in the packaging industry requires considering issues such as the type of packaging material used, recycling, reusable products and the environmental damage caused by packaging waste. In addition, the resistance that antimicrobial materials used in new generation packaging technologies will create on bacteria should not be ignored. Even though smart and active packaging technologies try to meet market demands, the positive properties of synthetic polymers still make them preferred in use. However, studies continue at full speed to ensure that sustainable and environmentally friendly bioplastics, which emerge with evolving personal and social perceptions, provide the desired properties. Even though most of the currently developed materials are at laboratory size, it is thought that food-contact packaging will increase the safety of food in the future. Going back to nature is not only about polymers, but studies on selecting active ingredients from natural sources are continuing rapidly. The development of new naturally compatible bioplastics and the modifications of the resulting biofilms are promising in new generation packaging. In addition, there is a need for more research, scaling and evaluation specific to products, so that new regulations can be introduced, and the most appropriate packaging systems can be implemented. With the regulations in the light of these developments, consumers' trust in new generation packaging systems and thus the packaging market will develop.

2. CONCLUSIONS

As a result, new generation packaging systems have enabled us to take significant steps into the market by increasing food safety, shelf life, quality and sustainability. Real-time monitoring, sensors, indicators, and tracking systems have reduced product waste, ensuring consumer awareness and better experience. Integration with IoT platforms has opened the doors to supply chain management, traceability and correct use of products. The concept of sustainability has become more prevalent in our lives with environmentally friendly, recyclable and reusable packaging. It is clear that these technologies will develop further in the future when more conscious consumers, higher quality products and less waste will be provided by using new generation approaches in the packaging industry.

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TRANSFORMING THE CLASSROOM WITH DESIGN THINKING

Charles Weiss
Clemson University, South Carolina, USA

Abstract: *Design thinking is not a new concept, but it is a tool that could potentially be very useful in the classroom. It is deeply rooted in the scientific method and works well with the concepts of problem solving as well as critical thinking. It is an especially worthwhile learning method in conjunction with project-based learning. Traditionally the term design thinking might be associated with business and industry, but it is a process that can be practiced in all educational disciplines. Just as with other existing concepts, design thinking is a worthwhile tool that educators can use to help their students be successful in the classroom.*
The core tenets of design thinking are Empathy, Define, Ideate, Prototype, and Test. Each stage of the process allows students to work through a project step by step thereby allowing students to skillfully master a learning process can be used for a variety of projects, in all their classes.
Today's college students are very adept at creating a final project, but many are not aware of the design thinking process and how it can potentially help them be more successful. Far too often students simply go with their first idea to create a project and don't take the time to analyze the steps needed to create a worthwhile project. By sharing the design thinking process as part of a class students will then be able to transfer the five tenets of the process into creating a higher quality final project.
This study began by including the design thinking process in a sophomore level Graphic Communication course and then moved onto including the design thinking process in a senior level Graphic Communication course. Students in both classes were surveyed on their past experiences with the design thinking process, as well as their experience with the five tenets of the process. Both class formats were traditional in-person courses. Students were instructed on how they could use the design thinking process in a classroom project. Upon completion of the project students were then surveyed to find out their overall experiences with the design thinking process. Certain areas of the design thinking process including critique and reflection were emphasized as part of the project in both classes.
This paper will explore the design thinking process though a literature review and how the process was implemented in two university level courses. Student's prior experience with the design thinking process will be examined and student's will be surveyed upon completion of a project based on the design thinking process to explore what elements they enjoyed of the overall process.

Key words: Design Thinking, Project-Based Learning, Critical Thinking, Scientific Method

1. INTRODUCTION

Students enrolled in undergraduate Graphic Communication courses at Clemson University are very aware of the traditional graphic design process. This established process involves three stages of design: thumbnails, roughs, and comprehensives, (Arntson, 2007; & Appiah & Cronjé, 2012). This three-step design process is used throughout the world of art and graphic design, and Graphic Communication students are usually very familiar with using this process when creating a design-based project. Students enrolled in the same undergraduate courses do not appear to be as familiar with the design thinking process and a study was conducted to survey Graphic Communication undergraduate students in two different classes at both the sophomore and senior levels to determine student familiarity with the design thinking process, and to examine how the students enjoyed using the design thinking process to complete a major project.
Pre-project and post-project anonymous online surveys were given to two different classes of students to determine first what their familiarity was with the design thinking process, and then after the projects were completed to get a better understanding of how they enjoyed using the design thinking process, and what stages of the design thinking process were their most liked stages, and if they would use design thinking again for future projects.
The design thinking process includes five core tenets: Empathy, Define, Ideate, Protype, and Test (Figure 1). As part of this learning activity students were provided lecture material and an online module to learn about each of the stages in the process. The online module included links to helpful websites and videos. Classroom discussion was also a major part of the learning process for the students.



Figure 1: Design Thinking Process

Each stage in the design thinking process has a distinct role, though there is often overlap and revisitation of roles throughout the process. During the Empathy stage the best outcome, product, or service is decided upon. In the case of a classroom project, the best project solution is determined. The next stage is the define stage in which the problem is clearly defined and evaluated. During the ideate stage a wide variety of solutions are determined with lots of brainstorming. In the prototype stage the final creative solution to the problem is created or implemented, and in the final stage of testing, the solution is tested, and feedback is gathered to address any possible revisions (Boguda & Shailaja, 2019). Design thinking is not always linear, and the stages in the process can often be moved here and there, and the process can be repeated until a proper solution is acquired.

2. REVIEW OF LITERATURE

Design thinking is a process used in education and business to create better projects and better products and it has been part of the discussion in academic circles for more than thirty years (Gronman & Lindfors, 2021). It is identified by the five different stages (Figure 1) of Empathy, Define, Ideate, Prototype, and Test (Yilmaz, 2022). Design thinking is an approach to formulating ideas and projects utilizing various stages of development.

The core concept of design thinking is based upon design itself. In order to create better artifacts and better things various stages of design need to be utilized (Koh et al., 2015). The design thinking process takes this idea of design and breaks it into five stages. These five stages allow designers to engage in various interactions to better formulate a final design. For instance, the Empathy stage allows designers the chance to better understand and observe the problem at hand, while the Define stage allows the designer to frame the problem, the Ideate stage allows the designer to explore the possibilities, the Prototype stage allows the designer to make and iterate the problem, and the Test stage allows the designer to gain feedback and implement the final solution (Vanada, 2014).

Design thinking has demonstrated its ability to cross over disciplines and to help create trust between collaborators, foster problem-solving skills, and increase the quality of solutions being generated in the classroom (McLaughlin et al., 2022) Design thinking has also proven to be a valid process across various disciplines and universities.

Educators across disciplines have various levels of familiarity with the design thinking process, though research suggests that integrating design thinking into the curriculum can help achieve competencies like critical thinking, student collaboration, and global awareness (Hennessey & Mueller, 2020). Design thinking has the potential to create collaboration between various disciplines such as art, science, mathematics, and social studies. Educators also perceive the process as a way they could solve problems incorporating a combination of previously acquired skills, learning outcomes, and existing knowledge.

Students in an undergraduate business class were exposed to the design thinking principles through an adaptation of an undergraduate design project (Armstrong, 2016). In this case students followed a nine-step process: (1) Gain initial insights, (2) Build on initial insights, (3) Capture findings and reframe the problem, (4) Craft the problem statement, (5) Ideate solutions to the problem, (6) Share solutions and record feedback, (7) Reflect and generate a new solution to the problem, (8) Create a prototype and record feedback, and (9) Record final feedback. In this manner the five-stages of the design thinking process were broken out into more manageable steps for the students. By following these steps students were exposed to a full cycle of the design process and were able to develop more critical thinking skills that are more in tune with “real-world” applications.

Empathy, holistic view, problem reframing, and team working were all areas of research that were enhanced using the design thinking process (Thi-Huyen, Xuan-Lam & Thanh Tu, 2021). Engineering students were presented with the design thinking process during a month of their course to determine how design thinking could aid in the growth of problem solving and teamwork mindsets. At the end of the month students recognized the importance of developing the best possible solutions, viewing the problems from a holistic view, addressing problems in a new manner, and encouraged students to creatively think of solutions that allowed them to identify the true problem and create possible solutions.

Design thinking can also be broken into four different processes; (1) Creative Problem Solving, (2) Sprint Execution, (3) Creative Confidence, and (4) Innovation of Meaning (Dell'Era et al., 2020). Each of these categories allow individual to better engage in the design thinking process. The first kind, Creative Problem Solving, allows the designer to solve a problem using creative solutions to the known problem. The second category, Sprint Execution, allows the designer to quickly accelerate the development process and allow solutions to be completed faster. The third, Creative Confidence, promotes an approach that aims at promoting a new innovative mindset that fosters a new set of approaches and practices that foster innovation. The fourth kind, Innovation of Meaning, supports new innovative design strategies that support new, and strategic directions that are pursued by the clients. Each of these four kinds of design thinking allows a new framework to be put in place to help foster solutions using the existing design thinking process.

The 5-step IDEAS critical thinking process can also be a part of the design thinking process. The first step, represented by "I", of this process is to "Identify Problems and Set Priorities", the second step represented by "D" is to "Determine Relevant Information and Deepen Understanding." Step three is represented by "E" and is "Enumerate Options and Anticipate Consequences." Step Four is represented "A" and is "Assess the Situation and Make a Preliminary Decision", and step five is represented by "S" and is "Scrutinize the Process and Self-Correct as Needed." It is clear from this five-step critical thinking problem-solving process that design thinking is clearly following a very similar path through its process, (Facione & Gittens, 2016). The design thinking process allows creators the chance to critically think about solutions throughout the entire process.

From a business perspective design thinking has also been shown to be a useful process in project management, (Lahiri, Cormican & Sampaio, 2021). Design thinking allows the designers to emphasize with the customer needs and better understand what the customer wants or desires. Design thinking adopts a user centric process that allows designers to better understand the needs of the customer. Design thinking is also focused on communication as part of the process that allows the customer to communicate more efficiently with the designer.

An interesting take on design thinking is teaching learners how to fail better. The current climate in education is to be successful and doesn't really address the concept of failure. Students need the ability to test ideas in a way that it is messy and a way that can include failure. Design thinking allows students to come up with concepts that may inherently be failures but may be successes when feedback is received from their peers and they are given the chance to create a successful concept that has been tested, revised, and edited based upon feedback from their peers and their teachers, (Long, 2012).

Related methods to design thinking include participatory design, bricolage or tinkering, making, and Lego Serious Play (LSP). All of these methods also include a system of discovery though each approaches the process differently from design thinking (Panke, 2019).

3. METHODOLOGY

A research study was created to examine the extent to which undergraduate students, enrolled in classes within the Department of Graphic Communication, were familiar with the design thinking process and to determine what they thought of using the design thinking process to complete a major project. In addition to quantitatively surveying the students anonymously on the design thinking process, an online module and lecture material were created and shared with students to help inform them of the design thinking process.

Two different undergraduate classes within the Department of Graphic Communication were selected to be a part of this study. The researcher worked with the Institutional Review Board (IRB) at Clemson University to design a valid study that provided anonymity to all students who took the surveys. The IRB reviewed the pre and post surveys and approved the use of human subjects as part of this study.

The first step in conducting this study was to give the pre-design thinking project survey to the students enrolled in a sophomore level Graphic Communication course, GC 2070. This pre- survey was given to the students before any mention of the terms design thinking process. Upon completion of this pre-project survey students were informed that the class would be using the design thinking process to complete a portfolio project that highlighted student design work. The students were given a lecture on the process and provided an online module within the Course Management System that provided additional information on the design thinking process. This additional online information included website links and video links. After reviewing the process, students then completed their portfolio project using the five stages of the design thinking process. Students engaged in discussion with their classmates during each of

the five design thinking stages and used feedback from their classmates to make a better project. The professor did not provide any feedback on the projects during this aspect of the project. Upon completion of the portfolio project students took a post-project survey to analyze their basic thoughts on the use of the design thinking process to complete their portfolio project.

The second step in conducting this study was to give the pre-design thinking project survey to the students enrolled in a senior level Graphic Communication course, GC 4440. Just as the students did in the sophomore class, students in the senior class took the initial pre-project survey without any introduction to the design thinking process. For the senior level class, students utilized the design thinking process to complete a portfolio project focused on creating sustainable packaging. After completing the pre-project survey, students in GC 4440 were given a lecture on the design thinking process and then provided an electronic module of information covering the design thinking process. This material also included websites and videos just like what was shared with the lower-level course. Upon completion of this portfolio project, students completed a post-project survey.

Both of the classes took the same pre and post surveys. Each class was also given the same lecture material and provided the same information in an online module provided within Canvas, the Course Management System for each class. Since the classes were at the sophomore level and the senior level it was decided not to give each class the same project, so a design portfolio project was designed for the sophomore level class, while a sustainable package portfolio project was created for the senior level class. While this did have each class create different final projects, they both followed the same learning process.

The surveys were administered to the sophomore level class in the Fall of 2021, while the surveys for the senior level class were administered in the Fall of 2022. Each class consisted of unique students and there were no students who took the sophomore class and completed the study, and then went onto to complete the study in the senior level class a year later.

Data for this survey was collected via Canvas, the online classroom portal provided by Clemson University. Students had to be enrolled in the course in order to access the surveys within the course management system. Students were not required to take this survey during class but could take the survey on their own time. Because of the anonymity of the survey responses, no student names were tied to survey responses, though the instructor could see the total number of respondents, and how the responses from each respondent.

4. RESULTS

Results of this study indicated the majority of students in both courses were not familiar with the design thinking process (Figure 2 and Figure 3) The study also found that the majority of students in both classes were open to using the design theory process for future projects. Detailed analysis of the survey responses is included below.

In the sophomore level class (GC 2070), 72% of the students had never heard of the design thinking process (Figure 2), while in the senior level class (GC 4440), 71% of the students (Figure 3) had never heard of the design thinking process. There were 47 respondents for GC 2070 there were 28 respondents for GC 4440).

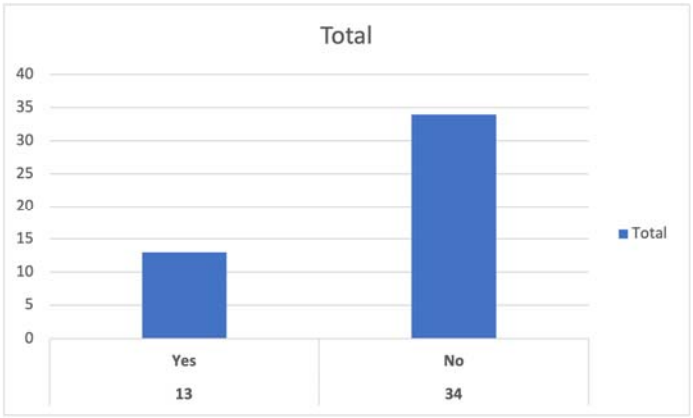


Figure 2: Have you ever heard of the design thinking process? (GC 2070 Responses)

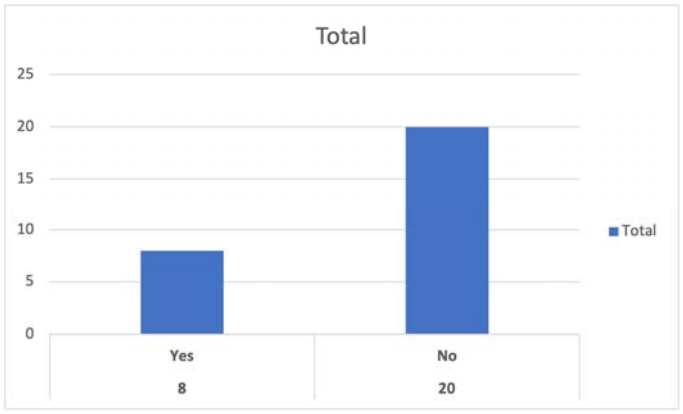


Figure 3: Have you ever heard of the design thinking process? (GC 4440 Responses)

Upon completion of the project that utilized the design thinking process students were again surveyed using the same online survey system. In the sophomore level class (GC 2070) 92% of the respondents where either satisfied or very satisfied with the process (Figure 4). Only two respondents were neutral to the process while only one was very unsatisfied with the process.

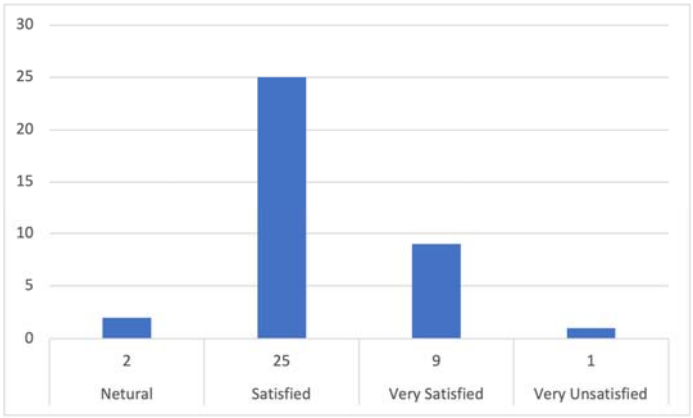


Figure 4: Overall, how satisfied were you with using the design thinking process to complete your portfolio project? (GC 2070 Responses)

Students in the senior level course (GC 4440) were also satisfied with using the design thinking process. 65% of the respondents indicated they were either satisfied or very satisfied with the process (Figure5). Seven students were neutral to the process. In the senior level course, no students responded to be unsatisfied in the process.

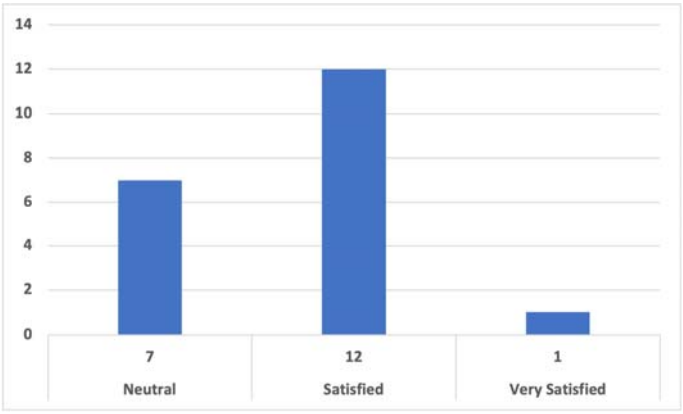


Figure 5: Overall, how satisfied were you with using the design thinking process to complete your portfolio project? (GC 4440 Responses)

Students were also asked if they would use the complete design thinking process for future projects. 74% of the respondents in GC 2070 indicated they were likely or most likely to use the complete overall design thinking process for future projects (Figure 6.). Respondents in the GC 4440 also indicated they would likely or most likely use the complete process with 60% of the respondents indicated they would likely or most likely use the complete process for future projects (Figure 7). Six students were neutral to using the complete process in the future in the sophomore level class, while five students were neutral to using the complete process in the senior level class. One respondent stated they would unlikely use the complete process in the GC 2070 course, while three respondents indicated they would not likely use the complete process in the GC 4440 course.

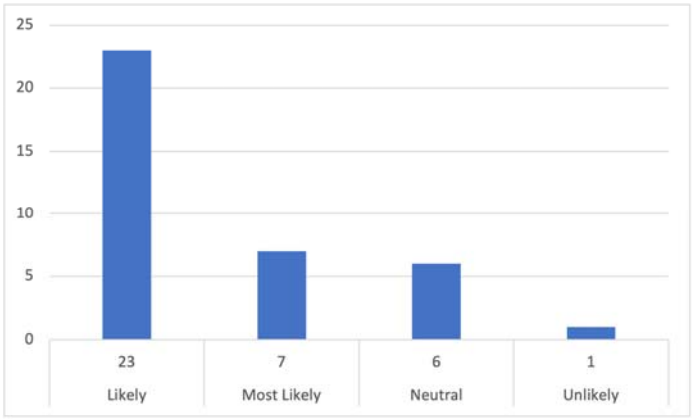


Figure 6: How likely are you to use the complete overall design thinking process to complete future projects? (GC 2070 Responses)

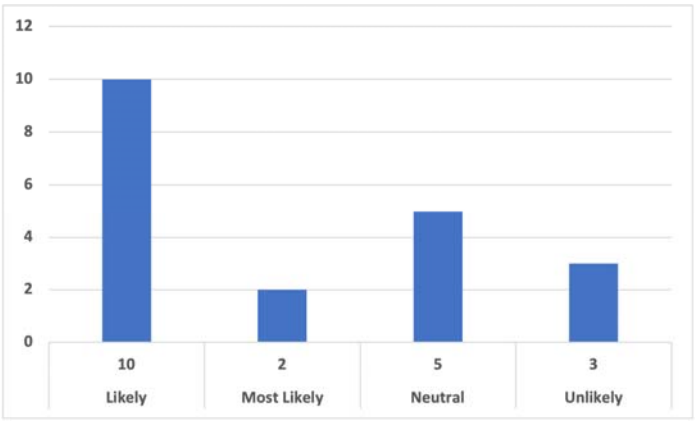


Figure 7: How likely are you to use the complete overall design thinking process to complete future projects? (GC 4440 Responses)

When asked about using parts of the design thinking process for future projects both classes overwhelmingly indicated they would be open to using parts of the process. 95% of the respondents in the GC 2070 course indicated they would be open to using parts of the process (Figure 8) while 80% of the respondents indicated they would be open to using parts of the process in the GC 4440 course (Figure 9). No students in either class reported they would unlikely or least likely to use elements of the overall design thinking process.

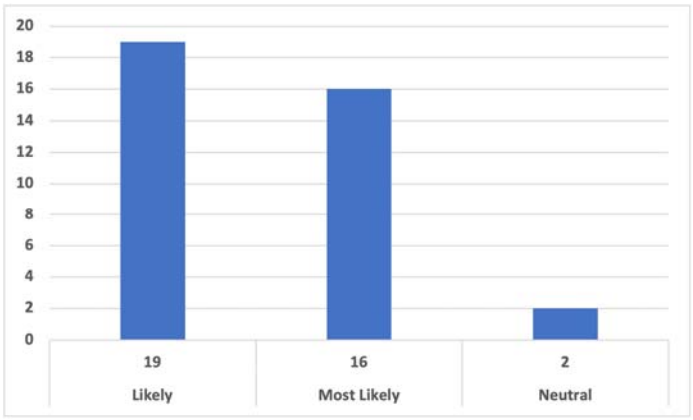


Figure 8: How likely are you to use parts of the design thinking process to complete future projects? (GC 2070 Responses)

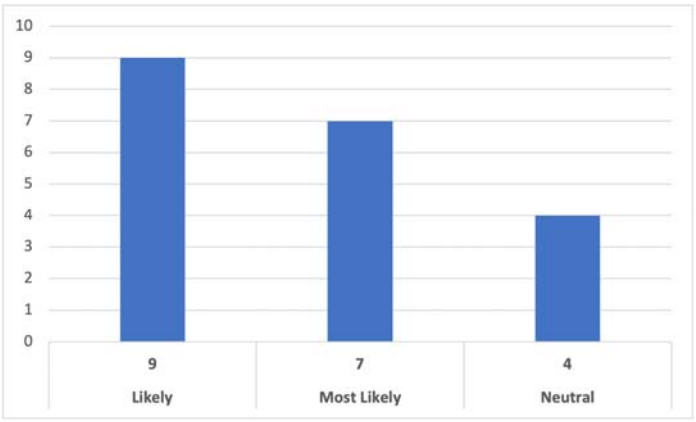


Figure 9: How likely are you to use parts of the design thinking process to complete future projects? (GC 4440 Responses)

Respondents in both courses had different opinions about what part of the design thinking process they liked the most, though both classes indicated their favourite two processes were Ideate and Prototype. In GC 2070, the majority of respondents (Figure 10) indicated they liked the Ideate stage the most, while in the GC 4440 the equal number of students liked the Ideate and Prototype stages (Figure 11). The Prototype stage was second in responses in the GC 2070 course. The least liked stage in the GC 2070 course was the Test stage, while Define and Emphasis were the least liked in the GC 4440 course.

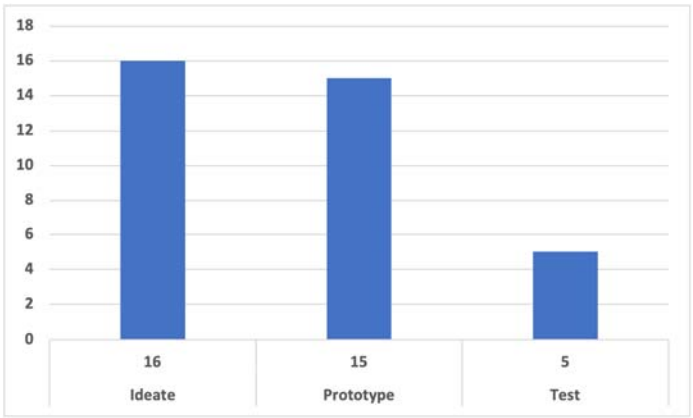


Figure 10: Which part of the design thinking process did you like the most? (GC 2070 Responses)

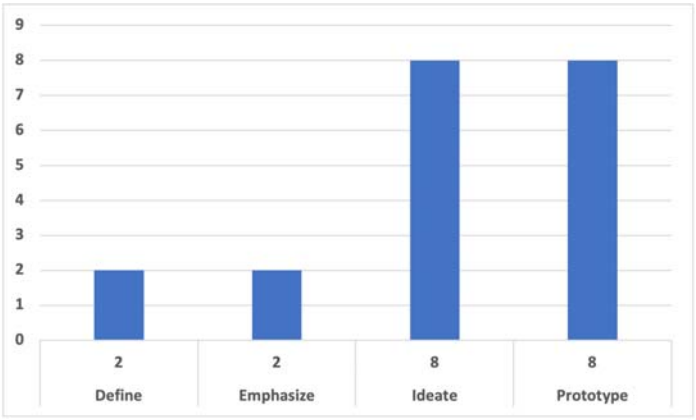


Figure 11: Which part of the design thinking process did you like the most? (GC 4440 Responses)

Students in the GC 2070 course overwhelmingly (73%) indicated their least liked part of the process was the Define and Emphasize (Figure 12). While students in the GC 4440 course indicated the least liked part of the process was the Define stage, followed closely by the Emphasize and the Prototype stages (Figure 13).

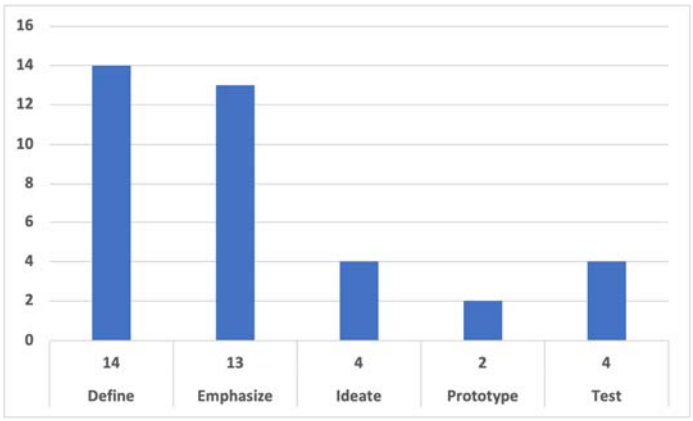


Figure 12: Which part of the design thinking process did you like the least? (GC 2070 Responses)

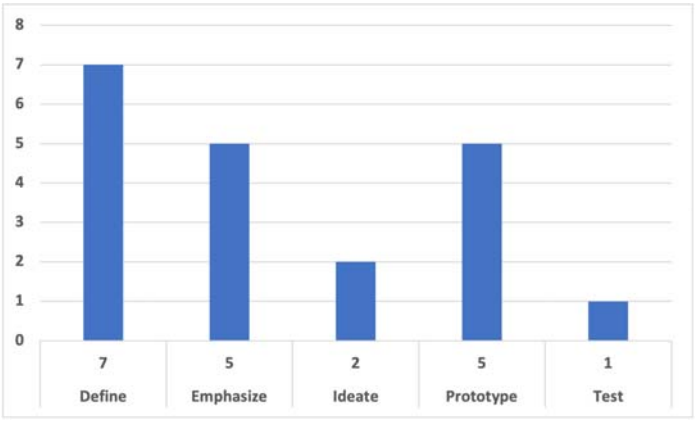


Figure 13: Which part of the design thinking process did you like the least (GC 4440 Responses)

In examining the data from the survey questions regarding most liked and least liked stages, it is interesting to note that while both classes had similar responses, they also had differing experiences with the design thinking process, and what their least favourite part of process was.

Results of this study indicate most students surveyed were not aware of the design thinking process to begin with but are open to using the entire design thinking process or at least parts of the process for future projects.

5. LIMITATIONS

This study is limited in scope to undergraduate students that were enrolled in a sophomore and a senior level course within the Department of Graphic Communications that were taught by Dr. Charles Weiss. The findings of this study are therefore limited to students enrolled in these two courses and should not be applied to other classes directly. It is possible however to take these results as an indicator that the design thinking process can be used to enhance the curriculum of other undergraduate courses, in other departments and other universities, but further research will need to be completed in order to find the experiences of students in other classes and other Departments on campus.

6. CONCLUSIONS

The design thinking process has been a part of the educational curriculum for the past thirty years, but this study clearly indicates the majority of undergraduate students who participated in this study were not aware of, nor had heard of the process. This also indicates other teachers the students may have had in high school and university have not been incorporating this concept as part of the learning process. So, while the design thinking process has the potential to provide positive benefits to the curriculum for any class that utilizes project-based learning, it is essential for educators to teach students more about the process and to do what they can to incorporate it as part of classroom projects.

If the design thinking process is going to play a larger part in the curriculum within the Department of Graphic Communication, and potentially other departments or other universities, more projects need to be created that incorporate the design thinking process. More time needs to be spent showing students the details of using the design thinking process, and the potential of using the complete or even aspects of the process as part of their learning journey.

Students also need to learn that their first idea is not always their best idea. Critique and feedback are part of life and that is the same for classroom projects. The design thinking process allows students the chance to fail and to make something stronger based on feedback from their peers.

7. RECOMMENDATIONS

The design thinking process can transform project-based learning in the classroom, and help students create better projects, while also teaching students the benefits of constructive feedback shared in a dynamic process that is focused on success. Educators and students need to understand the process and start to explore the benefits of the five core tenets.

While the design thinking process is generally made up of five different stages it is important for educators to define each of those stages for their own classroom. Some educators may choose to only use some of the tenets while other educators use all. The adoption of this process is up to the educator, and they must be able to adopt it in a way that works for their classroom. This is also evidenced by some of the reviewed literature as it is easily possible to modify those five stages to create a better fit for the curriculum model being used for a specific project, or in a specific field or classroom.

Design thinking is not a new concept, but it is a concept that seems to be underutilized in the classroom. Educators and students alike could benefit from incorporating more design thinking into projects and curriculum initiatives. More research needs to be conducted so that more information, and suggestions, on design thinking can be shared with a larger academic population.

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CORRELATION OF INK PENETRATION WITHIN THE PRINTING SUBSTRATE AND PRINT-THROUGH EFFECTS IN OFFSET, GRAVURE AND SCREEN SUSTAINABLE PRINTS

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Abstract: *The drying process of printing ink on absorbent substrates in conventional printing techniques essentially takes place in two steps: the penetration of the ink within the printing substrate and the oxidation or oxy-polymerization process. The process of ink penetration within the printing substrate itself begins immediately after the ink is transferred using the impression cylinder, while the oxidation or oxy-polymerization process lasts up to several hours. In this research, the correlation between the value of ink penetration within the printing substrate and the print-through effect on prints produced using three different printing techniques was observed. In this analysis prints made on sustainable printing substrates were produced with a 30% share of non-wood cellulose pulp were observed in order to reduce the consumption of wood raw materials worldwide. The results of the research prove that the degree of ink penetration within the printing substrate correlates with the print-through effect in all analysed black prints (printed with one ink layer), while no correlation was found in the prints that were printed with three ink layers (cyan, magenta and yellow). That is the print-through effect is very low compared to the values obtained for ink penetration within the printing substrate. It was also found that the lowest values for ink penetration inside the printing substrate was achieved with offset printing process, and thus the lowest values for the print-through effect. Sustainable printing substrates achieve very low deviations compared to reference substrates made only from recycled wood pulp, which confirms the possibility of using these substrates for both secondary packaging and publications.*

Key words: gravure printing, ink penetration, offset printing, print-through effect, screen printing, sustainable printing substrates

1. INTRODUCTION

Today, commercial printing techniques are still on the market for the mass production of printed products that serve the multiple purposes of labelling, marketing, advertising, brand promotion and the dissemination of regulated information. The most common printing technique is offset printing, followed by flexographic printing, screen printing and gravure printing, whereby only the conventional printing techniques are considered (KBV Research, 2022).

Each printing technique is suitable for a specific graphic product. The choice of printing technique depends on the substrate, the printing ink and the intended use of the product. They differ in the way the ink is transferred from the inking unit to the printing substrate and in the way the printing form itself holds the ink. In the case of offset inks, the drying process can be described in the steps of penetration and oxidation/polymerization. In the first stage, the printed ink film penetrates between the fibres of the substrate, whereby the thickness of the ink layer must not be greater than the absorbency of the printing substrate. In this phase, the rapid setting/phase separation takes place, and the type of resin plays an important role once the ink has hardened and stopped transferring to other sheets within the print run. The final drying takes place via the mechanism of oxidation or polymerization of the ink. Oxidation, in which oxygen initiates the polymerization of free radicals from unsaturated oils, completes the drying of the ink on the printing substrate (Leach, 2008).

Gravure printing is a very old printing technique with low-viscosity inks that offers high quality reproduction on printing substrates, which is achieved by rapid drying of the ink. With conventional gravure inks, the drying process itself takes place through ink absorption and evaporation of the solvent (water or toluene). Inks with a dynamic viscosity of 0.05 to 0.2 Pa·s are used, compared to conventional offset printing inks, which contain a dynamic viscosity of 40 to 100 Pa·s (Kipphan, 2001; Leach, 2008). The possible applications are diverse and range from high-circulation magazines, catalogues and advertising brochures to the production of film packaging for food, snacks, sweets and medicines to decorative paper for laminate flooring and furniture.

There are around 1,200 gravure printing presses in Europe, which print over 1.2 million gravure cylinders

ORCID numbers are provided at the end of the paper.

every year. By far the largest number of gravure printing machines is in Germany, with a total of 119 machines (Silver, 2021).
The screen printing technique is the most versatile method of ink transfer. This printing technique is used to transfer ink on many different substrates such as paper, textiles, ceramics, plastic, glass, wood and metal. When printing on absorbent printing substrates, the ink dries by absorption and evaporation of solvents, as in the gravure printing process, and the dynamic viscosity of the ink depends on the printing substrate, so it can range from 1.5 to 2.0 Pa·s (Leach, 2008).
With all three conventional printing techniques, it is possible to use water-based inks, which are more environmentally friendly. The gravure printing process also uses heavy metals such as copper, nickel and chromium. These metals are toxic and contaminate the environment if improperly disposed in contact with soil and water. The production process requires high energy consumption, particularly for drying the inks and running the machines, which increases carbon dioxide emissions that contribute to global warming. The amount of waste from engraving the cylinders has also increased, resulting in metal shavings that should be disposed of properly (Gravure Education Foundation, 2003). Today, more and more manufacturers are setting themselves new goals and challenges due to legal regulations and their own sustainability on the market. The most common goals are: carbon-neutral production; 100% recyclable, compostable or reusable products; a greater proportion of raw materials based on non-wood fibres or recycled wood fibres in printing material or from certified sources; 100% of energy from renewable energy sources; and more than 90% of non-hazardous waste which can be recycled or composted (Wessendorf, 2021). Due to the war in Ukraine and restrictions on the import of paper and cardboard from Russia, Europe is currently struggling with paper shortages (Fast Markets, 2022). Unfortunately, the usage rate of recycled paper varies greatly, as the final use changes depending on the desired quality of the original raw material. The use of recycled paper in Europe is highest in the printed packaging sector with 63.7%, for publications only 26.0% (18.6% for newsprint and 7.4% for other graphic products), and for household and sanitary products 6.9%, while other types of paper account for 3.4% (Blanco et al., 2013).
Since crop straw is treated as waste every year after harvest and large quantities remain in the fields, crop straw is becoming a potential source of fibre due to its global availability. Based on previous research, it was found that the addition of straw pulp from wheat or barley or triticale up to 30% of the content within the recycled fibre pulp creates a printing substrate with which various printing technologies achieve high quality printing (Plazonic et al., 2016; Bates et al., 2020; Plazonić et al., 2022; Bates et al., 2022; Cassel et al., 2023; Rudolf et al., 2023; Bates et al., 2024). In this study, samples printed according to the ISO 12647 standard using three printing techniques on printing substrates obtained with a 30% share of wheat or barley or triticale were analysed (International Organisation for Standardisation, 2013). The aim of this research was to observe the degree of ink penetration into the printing substrate in correlation with the print-through effect in black prints (printed with one layer of black) and in prints printed with three inks (printed with one cyan, one magenta and one yellow layer, which should achieve black coloration according to the theory of subtractive colour mixing) (Field, 1999).

2. MATERIALS AND METHODS

The experimental part of this research was performed in the following steps: 1. production of laboratory paper substrates; 2. printing of paper substrates; 3. ink penetration depth analysis; 4. analysis of print-through effect; 5. analysis of spectrophotometric values of prints.

2.1 Production of laboratory paper substrates

Straw of wheat (*Triticum spp*.), barley (*Hordeum vulgare L*.), and triticale (*Triticale sp*.), the most abundant crops in Croatia, was collected after harvest and manually cut into 3 cm long pieces with scissors. The cleaned straw was processed into semichemical pulp using the soda-pulp method.
The composition of laboratory-produced papers with a weight of about 42.5 g/m^2 was 30% unbleached wheat, barley or triticale pulp and 70% recycled wood pulp (Plazonić, 2016). They were formed using a Rapid-Köthen sheet former (FRANK-PTI) according to the standard EN ISO 5269-2:2004 (International Organisation for Standardisation, 2004).
The reference printing substrate (R) was made at the same laboratory procedure from 100% recycled wood pulp. Table 1 shows the abbreviations and composition of all paper substrates included in this research. The control paper (K), which is commercial paper made from 100% recycled wood pulp, was used to confirm the similarity of the properties of commercial paper with produced laboratory papers.

Table 1: Composition and marks of paper substrates

Paper substrate	Composition (%)	
K	0% straw pulp	100% recycled wood pulp
R	0% straw pulp	100% recycled wood pulp
30W70R	30% wheat straw pulp	70% recycled wood pulp
30B70R	30% barley straw pulp	70% recycled wood pulp
30T70R	30% triticale straw pulp	70% recycled wood pulp

2.2 Printing of paper substrates

Three main printing techniques commonly utilized for printing on absorbent substrates were used in this research. Offset printing is the predominant printing technique for publications and packaging, gravure printing is used for printing luxury products, publications and packaging in very long runs, while screen printing is used for products with special effects.

For all printing techniques, the printing substrates were printed in full tone with one layer of black and in full tone with three layers (cyan, magenta, yellow) according to the standard conditions of ISO 12647. As the printing sequence of the printing inks depends on the properties of the surface of the printing substrate and the rheological and transparent properties of the printing ink, sequential printing of inks was chosen in accordance with the standards, which means that the printing sequence for offset printing is cyan+magenta+yellow, for gravure printing is yellow+magenta+cyan and for screen printing is yellow+cyan+magenta (International Organisation for Standardisation, 2013; International Organisation for Standardisation, 2014; International Organisation for Standardisation, 2015).

Offset printing was carried out with conventional black Express ink (manufactured by Sun Chemicals) using a Prüfbau multipurpose test machine at a temperature of 23°C and a relative humidity of 50%. All samples were printed at a speed of 0.5 m/s and a pressure of 600N.

Gravure printing was done with a KPP laboratory gravure printing system using a printing cylinder with a mechanical hardness (HS) of 65 per Shore and an engraved printing plate at an angle of 37° with a diamond needle at an angle of 130° with a screen of 100 lines/inch, i.e. 40 lines/cm. The prints were made with Sunprop black ink (manufactured by Sun Chemicals) at a speed of 20 m/min, a temperature of 23°C and a relative humidity of 52%.

Screen printing was carried out with Epta Hi-Gloss inks from KIIAN S.p.A. on a semi-automatic machine from Shenzhen Juisun using a wiper with a mechanical hardness of 75 Shore and a mesh size of 120lin/cm at a temperature of 23°C and a relative humidity of 50%. After printing, the prints were moderately dried in the tunnel of the NP-2413 (380V) device from HIX corporation with warm air at a temperature of 55°C.

2.3 Ink penetration depth analysis

The surface topography plays a decisive role in the adhesion and transfer of ink, especially on laboratory paper that is not additionally industrially calendered and has a rough surface structure. Several factors influence the penetration of the ink into the substrate, including the printing pressure, whether it is a single or multi-layer print, the properties of the ink, the substrate properties, and the environmental conditions during the printing process.

The penetration depth of the ink (*Hp*) was determined by surface analysis using a non-destructive method of reflectance values based on the Kubelka-Munk theory (Equation 1) (Pauler, 2012; Yang et al., 2005; Yang et al., 2011). The ink penetration depth was determined from an average reflectance value of 50 spectrophotometric measurements measured by a spectrophotometer eXact, X-Rite with a measurement geometry of 45°/0° (D65/10°) at 457 nm (brightness) according to the Tappi T452 standard.

$$Hp = \frac{ln\frac{(1-R_0 \times R_\infty)(1-R_p \times R_\infty)(1-R_q/R_\infty)}{(1-R_0/R_\infty)(1-R_p/R_\infty)(1-R_q \times R_\infty)}}{ln\frac{1-R_0 \times R_\infty}{1-R_0/R_\infty}} \times D \quad (1)$$

where R_∞ is the reflectance value of unprinted paper substrate over opaque pad of unprinted papers, R_o is the reflectance value of unprinted paper substrate over a standard black background, R_p is the reflectance value of printed paper substrate over opaque pad of unprinted papers, R_q is the reflectance value of the reverse side of printed paper substrate placed over opaque pad of unprinted papers and D is an average value of unprinted paper thickness.

2.4 Analysis of print-through effect

The print-through is a qualitative measure that describes the visibility of the ink on the reverse side of the printed paper substrate. This phenomenon occurs when the opacity of the paper substrate itself is reduced by the infiltration of the ink carrier after printing, the penetration of the ink pigments into the paper, and the inherent transparency of the paper. The print-through is precisely defined as the appearance of a thin layer of ink on a paper substrate that is visible through a white background (Eriksen et al., 2005; Eriksen et al., 2006).

The colour difference (ΔE^*_{00}) between the CIE colorimetric values L*, a* and b* on the reverse side of the printed paper substrate and the white background of the unprinted paper substrate was used to calculate the print-through effect. These colorimetric values were determined using a spectrophotometer (X-Rite Exact, D50/2°), and Equation (2) was used to calculate the colour difference, thereby revealing the print-through effect.

$$\Delta E^*_{00} = \left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_c S_c}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_C S_H} \quad (2)$$

where $\Delta L'$ represents the transformed lightness difference, $\Delta C'$ represents the transformed chroma difference, $\Delta H'$ represents the transformed hue difference, R_T is the rotation function; k_L, k_C, and k_H represent the factors for the variation in the experimental conditions; and S_L, S_C, and S_H are the weighting functions. The definition of tolerance colour difference (ΔE^*_{00}) is presented in Table 2 (Yang et al., 2012); (Kumar, 2003).

Table 2: Tolerances of colour difference

Euclidean difference value	Euclidean difference tolerance
< 0.2	Average human eye does not see the difference
0.2- 1	Average human eye sees negligible difference
1- 3	Very small difference – optimal ΔE^*_{00}=2
3- 6	Clearly visible
6- 12	Difference, extremely large
> 12	Great difference, unacceptable

2.5 Analysis of spectrophotometric values of prints

Spectrophotometry is the science that forms the basis for colour measurement. Colour perception is a connection between physics and physiology that was recognized very early on when the physicist Isaac Newton contributed to spectrophotometry and colorimetry in 1704 with his attempts to divide white light into spectral colours.

However, the colour perception of the human eye itself was defined by the physician Thomas Young in 1802. Young is considered to be the first to describe how colour is perceived in the eye with the help of the three receptors red, green and blue. Today we know that every colour experience can be fully described with three numerical values (L*, a*, b*) (Young, 1802; Heesen, 2015).

In this research, the colorimetric values of obtained samples with three different printing techniques were considered in the CIELAB colour space. CIELAB is a colour space that was defined in the 1976 by the International Commission on Lighting was created to represent colours more faithfully than the CIEXYZ colour space and enables the numerical definition of all colours visible to the human eye (Field, 1999).

3. RESULTS AND DISCUSSIONS

To observe the correlation between the ink penetration depth inside the ink into the paper substrate and the print-through effect, prints produced using three printing processes (offset printing (o), gravure printing (g), screen printing (s)) were analyzed. In this paper, samples printed with only one layer of black ink and samples printed with three layers of ink were compared, which create a dark brown colour that should theoretically be black (cyan+magenta+yellow). The colorimetric values of the single-layer and three-layers prints were additionally placed in the CIELAB colour space to observe the difference between the colours obtained on the prints with the three different printing techniques.

The correlation results between the ink penetration depth within the printing substrate and the print-through effect on prints obtained with three printing techniques are shown in Figure 1.

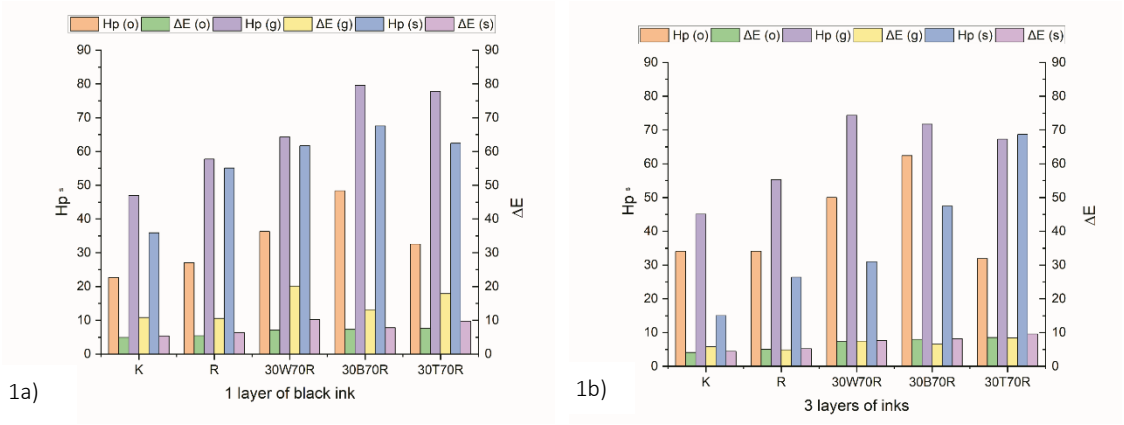


Figure 1: Correlation between the ink penetration depth within the printing substrate (Hp) and the print-through effect (ΔE^*_{00}) for prints obtained with the offset printing process (o), gravure printing process (g) and screen printing process (s) with: a) one layer of black ink and b) three layers of cyan, magenta and yellow ink

Figure 1a shows the correlation between the ink penetration depth and the print-through effect, where the highest ink penetration depth was achieved in the gravure printed samples on sample 30B70R and sample 30T70R, while the highest print-through effect was obtained with samples 30W70R and 30T70R using the gravure printing process.

Observing the printing techniques it is evident that the lowest values for ink penetration depth for all paper substrates were achieved with offset printing ($Hp_{(o)}$ = 22.71 - 48.33), while the highest values for ink penetration depth were achieved with gravure printing ($Hp_{(g)}$ = 47.05 - 79.56). These results are directly related to the dynamic viscosity of the ink. Inks with a high viscosity create a lower ink penetration depth, while inks with a low viscosity in relation to high fluidity result in a high ink penetration depth when used on the same paper substrates. From the results of the print-through effect, it can be seen that the values are greater than ΔE^*_{00} = 4.94, which is considered a clearly visible difference between the colours. This is to be expected as the table is used for the tolerance of colour differences when comparing very similar shades or prints, whereas in this analysis a comparison of the reverse side of the print and the unprinted paper substrate was used.

Figure 1b does not show the correlation between ink penetration depth and the print-through effect. The values of all samples for the print-through effect were very similar or equal, while the highest values for the ink penetration depth were calculated for samples 30W70R and 30B70R. The print-through effect is significantly lower for these samples than for prints with a single ink layer. For these prints, the print-through effect is a maximum of ΔE^*_{00} = 8.52, whereas it is a maximum of ΔE^*_{00} = 20.11 for prints with only one layer of black. It can therefore be concluded that these substrates are more suitable for multi-colour printing than for mono-colour printing with only black ink. The relationship between dynamic viscosity and ink penetration depth is also observed when printing three layers of ink, which are printed in different sequences to achieve a theoretical black colour or dark brown coloration. The highest values of ink penetration depth were achieved in the gravure printing process ($Hp_{(g)}$ = 44.05 - 74.34), while the lowest values were obtained when printing with the offset printing process ($Hp_{(o)}$ = 31.91 - 62.24).

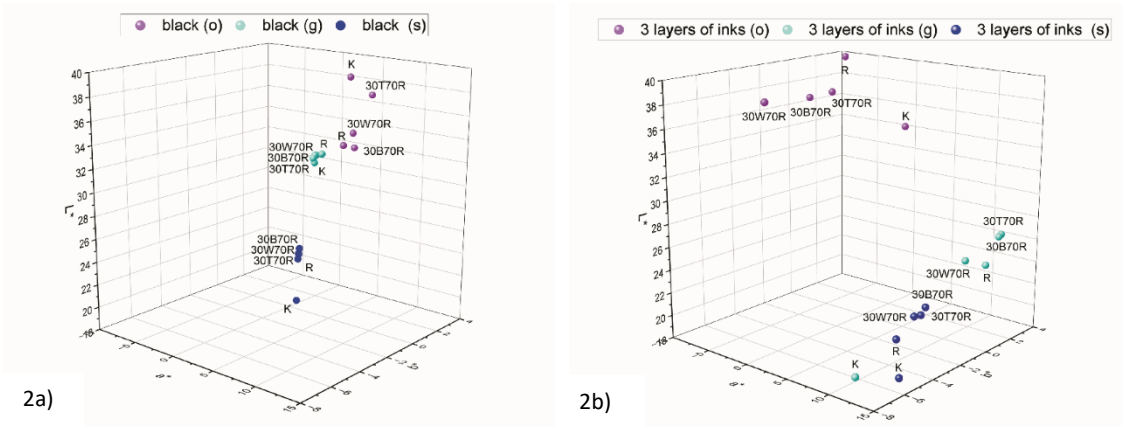


Figure 2: Colorimetric values of prints with single ink layer (black) (2a) and 3 layers of ink (brown)(2b) produced with the offset printing process (o), gravure printing process (g) and screen printing process (s)

By observing the colorimetric values of black prints with a single ink layer (2a) and three ink layers (2b), a strong scattering of colours can be observed in Figure 2b, while in Figure 2a very similar colours were printed with gravure and screen printing techniques, while a lower colour scattering is visible in offset prints. The largest colour differences between the prints depending on the printing technique used can be observed in the L* coordinate (Figure 2a). Figure 2b shows the largest differences between the placement in the CIELAB colour space of offset prints on the one side and gravure and screen prints on the other. Offset prints are located at much higher L* values (L* = 33.82- 39.56) than other prints (L* = 18.07- 25.87), which is most likely due to the sequence of ink printing, where the yellow ink is printed last in offset printing, while gravure and screen printing techniques are used as the first printing ink. Comparing the prints produced using gravure and screen printing techniques with three layers of ink, differences in the b* coordinate can be observed, most likely due to the last ink printed, i.e. cyan in gravure and magenta in screen printing.

4. CONCLUSIONS

The results of the research prove that the degree of ink penetration within the printing substrate correlates with the print-through effect in all analysed black prints (printed with one ink layer), while no correlation was found in the prints that were printed with three ink layers (cyan, magenta and yellow). Meaning the print-through effect is very low compared to the values obtained for ink penetration within the printing substrate. It was also found that the lowest values for ink penetration inside the printing substrate was achieved with offset printing process, and thus the lowest values for the print-through effect.
It has been confirmed that the dynamic viscosity of the ink is directly related to the penetration depth of the ink. It was proven that the analyzed paper substrates are more suitable for multi-colour printing than for mono-colour printing with only black ink if a lower print-through effect is to be achieved.
It is confirmed that the printing sequence of inks is a very important factor in achieving uniform coloration of prints produced with different printing techniques. Sustainable printing substrates with a 30% straw pulp content achieve very low deviations compared to reference substrates made only from recycled wood pulp, which confirms the possibility of using these paper substrates in all three printing processes.

5. ACKNOWLEDGMENTS

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STABILITY OF UV CURABLE INKS APPLIED IN THREE LAYERS ON PAPERS CONTAINING STRAW PULP AFTER ARTIFICIAL AGEING

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Abstract: *In order for prints to be considered high quality, regardless of the type of printing substrate, they must retain the initial optical quality achieved during printing and years after the printed product has been used or stored. The rate at which print quality deteriorates over time depends on several factors. The composition of the printing substrate, the composition of the printing ink, the technique of applying the ink to the substrate, and the interaction between the ink and the substrate have the greatest influence on the initial quality. In addition to the listed influences on the durability of the print quality, the conditions under which the print was used or stored, such as humidity, temperature, microorganisms, and air quality, also have an effect. Paper is the most commonly used printing substrate, and considering the favourable ecological components of this material, it will be used more and more in the future. The need for alternative raw materials to wood in its production will also become more pronounced. Precisely because of the cellulose fibres that make up its basis, paper is subject to many degradation changes. In this research, the optical and colorimetric stability of prints on paper with straw pulp from different cereals were monitored after two cycles of accelerated ageing of 48 hours, performed according to the ASTM D 6789-02 standard. As the stability of prints in which UV curable inks were applied in three layers on laboratory paper by screen and gravure printing techniques was monitored in parallel, it was determined that screen prints have better colorimetric stability compared to gravure prints. It was also observed that for both types of inks, the most significant degradation occurs in the first 48 hours of accelerated ageing, while further prolonging the exposure time of the prints irradiance through the daylight filter does not show any significant continuation of the degradation.*

Key words: Artificial ageing, gravure printing, paper, straw pulp, screen printing, UV curable inks

1. INTRODUCTION

Paper is one of the most traditional and commonly used printing substrates (Schmidt, Martorana & Jocher, 2022). On the market today we find papers in a variety of compositions, weights, finishes and textures, meeting a wide range of printing needs. Therefore, the choice of paper can affect the absorption of the ink and the clarity of the printed text and image (Dong et al., 2020), and it is crucial to match the type of paper with the intended use. Printing techniques are the methods by which ink is transferred to paper, and the type of technique selected depends on the required quantity, the desired quality, and the intended use of the final product. Printing techniques differ in their cost, complexity, and print quality. The use of UV curable ink, compared to more traditional alternatives, is becoming an increasingly popular option due to the simplicity of the printing technology and the more environmentally friendly composition (Robert, 2015). The advantage of these specially formulated inks is that, after being printed on the substrate, they dry onto the surface under intense UV light. The print drying mechanism takes place in seconds because, as soon as the print head applies the ink to the substrate, the UV light that is built into the printing mechanism meets the printed design to instantly cure it. In this way, high resolution prints are obtained. The curing process itself affects the properties of the print, making it less susceptible to fading or damage over time. Due to the drying process, there is no risk of smearing or smudging. The composition of the UV curable inks does not contain any a solvent that evaporates, so the print is the result of 100% ink deposition on the surface of the substrate. There is no absorption of the ink into the substrate, resulting in a more intense colour. According to the composition UV curable inks are a mixture of monomers, oligomers, colorants, photo initiators and other additives that are activated by ultraviolet (UV) light. Namely, when exposed to UV light, the monomers and oligomers in the ink will polymerize and, by forming strong bonds between the ink particles (Hakeim et al., 2018), they will form a strong coloured layer on the surface, which results in printing with a long service life (Havlínová et al., 2002). In general, printing with

ORCID numbers are provided at the end of the paper.

UV curing inks has a significantly longer lifespan compared to traditional inks, as they are not prone to fading or other damage over time (Karlovits & Gregor-Svetec, 2011).
In this paper, the optical stability of UV prints obtained by two printing techniques where UV curable inks were applied in three layers was studied. Accelerated ageing was performed as a simulation of natural ageing to determine the multicolour print quality deteriorates over time to evaluate the long-term behaviour of prints on papers with cereal pulp under the expected conditions of use. It is known that the conditions under which the prints were used or stored, such as humidity, temperature, microorganisms, pollutants and air quality, have a significant effect on the surface of printed products as well as a paper as a cellulose based porous printing substrate.

2. METHODS

This research is divided into the following steps: laboratory production of straw pulp containing papers; gravure and screen printing with UV curing inks; accelerated ageing of multicolour prints (C+Y+M) and evaluation of the stability of prints upon ageing.
First step for producing laboratory papers with straw pulp was collecting the straw after harvesting field crops of wheat, barley, and triticale. The collected straw was prepared for processing into semichemical pulp by purification and cutting into pieces ranging from 1 to 3 cm. This unbleached straw pulp obtained by the soda method (Plazonic, Bates & Barbaric-Mikocevic, 2016) was added into the pulp of recycled wood fibres in a proportion of 30% during laboratory production of paper at the Rapid Köthen sheet former (FRANK-PTI GmbH, Birkenau, Germany) according to EN ISO 526 9-2:2004 standard (Table 1).

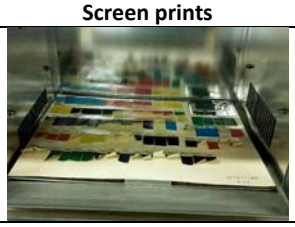
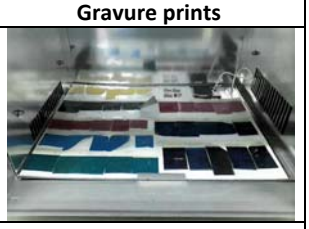
Table 1: Abbreviations used for marking laboratory-made papers

Abbreviation	Pulp composition	Paper production	Paper grammage, g/m²
K	100% recycled wood pulp	commercial	42.5
100N	100% recycled wood pulp	laboratory	42.5 ± 2.6
70N30W, 70N30B, 70N30TR	70% recycled wood pulp + 30% straw pulp	laboratory	
* W = wheat pulp; B = barley pulp; TR = triticale pulp			

To achieve multicolour prints on produced laboratory paper substrates, printing was performed with yellow, cyan and magenta inks applied in layers in specific order regarding the printing technique used. For gravure printing, the UV Solarflex curing inks (Sun Chemical) were applied to laboratory papers using the laboratory equipment KPP Gravure System with an impression cylinder of mechanical hardness (HS) 65 Shore and an engraved printing plate at an angle of 37° with a diamond needle at an angle of 130°, with a screen of 40 lines/cm. First applied ink was yellow and after its curing, with a Technigraf Aktiprint L 10-1 dryer containing a UV-C tube with ultraviolet light from 100 nm to 380 nm with a source power of 120 W/cm and an intensity of 60%, the magenta ink was applied and cured at same conditions and the cyan ink was last applied and cured at the same conditions.
Screen printing of the samples was performed using Ultragraph UVAR UV inks from Maragraph GR on a Shenzhen Juisun semi-automatic machine using squeegee with a mechanical hardness of 75 Shore and a mesh size of 120 lines/cm. The desired multicolour print was obtained by multiple application of three colours (Y+C+M). The prints were dried in a TM -UV750L (380V/12.5 kW) produced by Tamprinter with two 5.6kW UV lamps.
Artificial ageing was performed in a Suntest XLS+ test chamber which emits diffused light and near-ultraviolet electromagnetic radiation in the wavelength range from 290 nm to 800 nm through a daylight filter where the prints previously cut in strips (20 mm × 50 mm) were placed. According to ASTM D 6789-02 standard, the artificial ageing procedure in two cycles of 48 hours was carried out (Table 2). In accelerated ageing device, most often controlled parameters are light, heat and humidity. Xenon arc spectrum modified with specific filters used in this test chamber gives a good simulation of sunlight. The ultraviolet part of the solar spectrum is very often responsible for the initiation of weathering degradation of material. A material must absorb light in order to affect that material. Fading of an ink is caused by the light, i.e. by the motion of the energy it carries. The energy is inversely proportional to the wavelength (Aydemir & Yenidoğan, 2018). The shorter wavelengths possessing higher photon energies are more

strongly absorbed in most polymeric materials and have a greater potential to break chemical bonds in that material (Jacques, 2000).

Table 2: Accelerated ageing procedure

Accelerated ageing procedure	Screen prints	Gravure prints
Samples in test chamber		
Equipment	Suntest XLS+ test chamber	
Standard	ASTM D 6789-02	
Wavelength (nm)	300 - 800	
Irradiance (W/m^2)	765 ± 50	
Filter	daylight	
Relative humidity (%)	47	48
Temperature of ambient (°C)	21.2	21.5
Total duration of process (h)	96 (2 cycles of 48 h)	

The stability of UV curable inks applied in three layers on papers containing straw pulp after artificial ageing was evaluated based on optical stability by measuring spectrophotometric values of each print and by the colour difference (ΔE^*_{00}) calculation. The colorimetric values of prints were determined using an X-Rite SpectroEye spectrophotometer. Colour data were measured under illuminant D50, 2° standard observer. The colour difference between the colorimetric values of the prints before and after artificial ageing was calculated according to Equation 1 (Luo, Ciu & Rigg, 2001):

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (1)$$

Where: ΔE_{00}^* – total colour difference, the Euclidean colour difference; $\Delta L'$ – the transformed lightness difference between prints before and after accelerated ageing; $\Delta C'$ – the transformed chroma difference between prints before and after accelerated ageing; $\Delta H'$ – the transformed hue difference between prints before and after accelerated ageing; R_T – the rotation function; k_L, k_C, k_H – the parametric factors for variation in the experimental conditions; S_L, S_C, S_H – the weighting functions.
The colour difference threshold differs in ΔE value depending on the area of application and formula used for calculation of colour difference. In graphic arts and printing industry, for most demanding products, the maximum acceptable ΔE colour difference is 1.5 (Dedijer et al., 2018).

3. RESULTS AND DISCUSSION

From the results of the Euclidean colour difference (Figures 1 and 2), it is visible that the multicolour brown prints show different optical stability regarding the used paper substrate and technique of applying UV curable inks. If we look at the composition of the paper as a printing substrate, the greater stability of the prints was noticed in paper without the addition of cereal straw pulp. With the addition of cereal straw to paper pulp, the colorimetric stability of the multicolour prints on such printing substrates after exposing to conditions of accelerated ageing decreases. It has been noticed that the prints obtained by the screen printing technique (Figure 1) show far greater optical stability of multicolour brown prints compared to prints obtained by gravure printing (Figure 2). After artificial ageing the observed change in colour, ΔE^*_{00}, of screen prints ranged from 1.16 to 1.96, while the changes for gravure prints were greater (ΔE^*_{00} = 2.34 - 4.19). If the colour difference value is above 5, a standard observer can recognize the print before and after ageing as prints with two different colours indicating that the print has low optical ageing stability (Mokrzycki & Tatol, 2011).

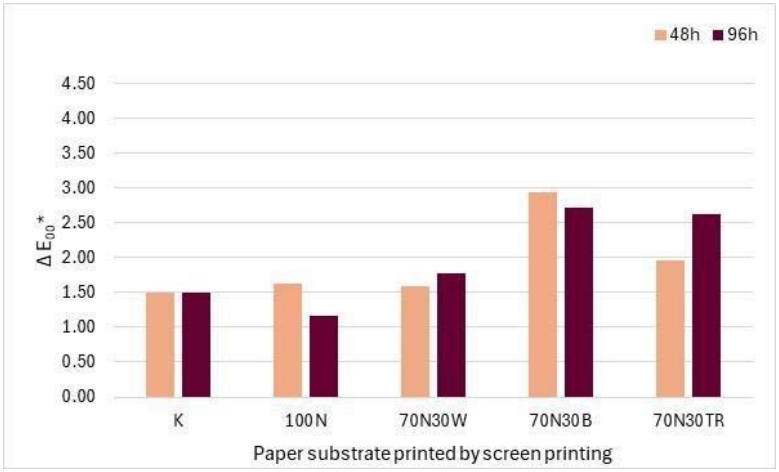


Figure 1: The Euclidean colour difference of UV curable inks applied by screen printing on paper substrates after artificial ageing

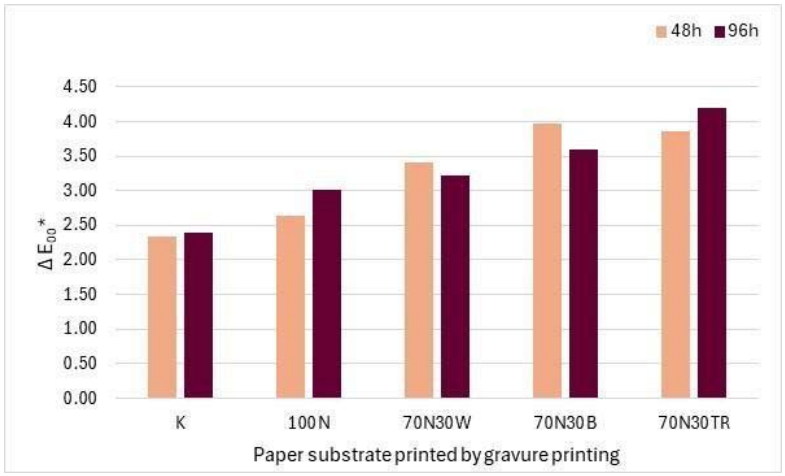


Figure 2: The Euclidean colour difference of UV curable inks applied by gravure printing on paper substrates after artificial ageing

From Figures 1 and 2 it is visible that optically more stable brown prints were achieved by screen printing on papers with the addition of straw pulp up to 30% (70N30W, 70N30B, 70N30TR) than by gravure printing on papers without the addition of straw pulp (N). Regarding the cereal type mixed in the paper pulp, best results are shown in the papers with added wheat pulp (70N30W) for both printing techniques. Papers with added barley pulp (70N30B) show slightly better results for gravure printing than screen printing in comparison with papers with triticale added pulp (70N30TR). This difference in the stability of gravure and screen multicolour prints achieved with three layers of inks applied one over the other is interesting as the results of previous study (Bates et al., 2023) showed that monocolour prints made with the gravure and screen printing processes after accelerated ageing of 48 hours reach a colorimetric difference of up to $\Delta E_{00}^* \leq 2$. In that study it was noticed that from all analysed monocolour prints gained by gravure and screen printing technique, the most colour difference was in cyan prints. As the cyan ink is the last printed ink brown prints printed made by gravure printing and in screen printing the last applied ink was magenta that could be the reason for lower optical stability of gravure print.

It was also observed that for both printing techniques of applying UV curable inks, regardless of the composition of the paper printing substrate, the most significant colour degradation occurs in the first 48 hours of accelerated ageing, while further prolonging the exposure time of the prints irradiance through the daylight filter does not show any significant continuation of the colour degradation. The only different colour change after 96 hours was observed on paper substrates with 30 % triticale pulp (70N30TR) when

printed with both printing techniques. It is therefore very important to know the desired lifetime of the printed graphic product.

4. CONCLUSIONS

The colour changes that occur on printed paper containing straw pulp upon ageing were analysed. As the colour stability of brown prints in which UV curable inks were applied in three layers on laboratory paper substrates by screen and gravure printing techniques was monitored in parallel, it was determined that screen prints have better colorimetric stability compared to gravure prints regardless of the composition of paper substrate. Of all the cereal straw pulps, the addition of wheat pulp to the recycled pulp provides the paper substrates for obtaining the most stable prints after ageing. The conclusion is that when choosing a printing substrate, it is very important to consider the desired lifetime of the graphic product and choose a paper substrate on this basis.

5. ACKNOWLEDGMENTS

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PROPERTIES OF SCREEN-PRINTED FLUORESCENT MOTIVE IN A FLEXO-SCREEN COMBINED REPRODUCTION ON RECYCLED PAPER SUBSTRATES

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Abstract: *Fluorescent printing inks are utilized in graphic reproduction for their special visual impression. Because of their vividness, they are used for printing decorative elements and information that needs to be noticeable. In this research, the fluorescent motive was printed by screen printing technique on recycled paper substrates and a preprinted flexographic ink layer. Because of the importance of introducing eco-friendly and sustainable options and alternatives to all segments of graphic reproduction, the possibility of using recycled paper substrates for printing a special-effect ink initiated the research with specific materials presented in this paper. Two types of flexographic printing plates (one solvent-washable and one eco-friendly water-washable) with different surface properties and screen printing plates with different mesh counts were used. This research aimed to determine the influence of the basic flexographic and screen printing plate parameters on the reproduction quality of fluorescent prints on recycled paper substrates. Spectrophotometric measurements of prints, measurements of the thickness of screen-printed and flexographic layers, microscopy of details on fluorescent prints and the width of the fluorescent printed fine lines were analyzed. Furthermore, adhesion parameters were calculated between the paper substrates, printed flexographic ink and fluorescent screen-printed ink. The results of this research provide information on the interaction, compatibility and properties of layers printed by a combination of flexography and screen printing on recycled paper substrates.*

Key words: fluorescent inks, flexography, screen-printing, recycled paper

1. INTRODUCTION

Fluorescent inks are a type of material that can absorb UV radiation and then re-emit it at longer wavelengths. These inks are used for various printing techniques such as offset printing, flexographic printing, gravure printing, inkjet, and screen printing (Koutsioukis, Belessi & Georgakilas, 2019; Xu, Yang & Sun, 2011). When printed on a light or white surface, the fluorescence effect is enhanced (Morović et al., 2019). Fluorescent pigments are highly visible and are commonly used for safety applications like roadwork signage, safety vests, helmets, and construction materials. They are also used in various products such as sporting gear, toys, textiles, and packaging. Fluorescent inks can be activated by visible light as well, which significantly expands the range of colors achievable beyond traditional printing capabilities. They can be formulated using rare-earth elements or organic fluorescent pigments. These inks contain binders like acrylic and epoxy resins, ensuring good viscosity, adhesion fastness, light resistance, heat resistance, and corrosion resistance. They are frequently applied in security printing (Muthamma et al., 2023; Rossier & Hersch, 2011; Varatharajan et al., 2023).

Research on fluorescent materials involves studying their interactions with different printing substrates to meet specific requirements and ensure optimal functionality (Muthamma et al., 2023; Tomašegović et al., 2021). Additionally, a combination of different printing techniques, such as flexographic printing and screen printing, is often used to achieve specific visual and tactile effects in products. By combining various printing techniques, interesting production options could be obtained, with a high degree of economy for printers and added value for the customer. Different technologies can be combined with different hybrid systems, i.e. conventional printing techniques can be combined with digital technologies, or different conventional techniques can be used to print the same product (Eshkeiti et al., 2015; Cazac et al., 2018) When using hybrid printing systems, the characteristics of the printing substrate, expectations of print quality and adhesion between the printed layers are of particular importance. The combined technologies must meet the qualitative requirements and be compatible in terms of the used materials and production technology (Krzemiński et al., 2023).

In this study, three types of recycled paper printing substrates were used, and fluorescent ink was screen-printed on plain substrates and substrates preprinted with black flexographic UV-curable printing ink. The

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research aimed to determine the influence of the screen printing plate's mesh count on the reproduction of fluorescent ink on recycled paper substrates, with and without the layer preprinted using flexographic printing and UV-curable ink. Furthermore, the influence of the preprinted flexographic ink layer on the optical and interfacial properties of the fluorescent ink layer was investigated.

2. MATERIALS AND METHODS

2.1 Preparation of the samples

For this study, three different types of recycled papers were utilized as printing substrates. Each substrate was certified by the Forest Stewardship Council, promoting environmentally sound, socially beneficial, and economically sustainable forest management. All substrates were uncoated types of papers, and were denoted A, B, and C. Their properties are presented in Table 1.

Table 1: Properties of the used paper substrates

	A	B	C
Brand	MOHAWK	FLORA	SCHOELLERS
Grammage (g/m²)	220	130	140
Caliper (µm)	200	140	155
Bekk smoothness (s)	52.00	3.80	4.10
Surface free energy (mJ/m²)	29.20	29.76	22.38

Papers were cut to dimensions of 5 x 70 cm and conditioned 24 hours before printing. The flexographic printing process was carried out using IGT Printability Tester F1 in the laboratory conditions, at a relative humidity of 55% and 23±2˚C. Anilox roller of 90 l/cm and 18 ml/m^2 was used. Anilox pressure was set to 300 N, and printing speed was 0.3m/s. For the flexographic printing, UV-curable ink, Solarflex Integra SINT 46 process black was used. The printing pressure was set to 300 N. Kodak Flexcel NX printing plate, with the micro-pattern on the surface for improving the ink transfer was used, as well as a water-washable and therefore environmentally friendlier printing plate, Toyobo Cosmolight QS. Full-tone flexographic prints were cured using the Technigraph Aktiprint L 10-1 device.
Screen printing was carried out using fluorescent ink Sebastar neon pink from SEBEK inks, and two polyester screens with different mesh counts: 60 l/cm and 100 l/cm. In that way, different amounts of the ink were transferred to the substrates, affecting the qualitative properties of the fluorescent prints. Screen printing was carried out on plain papers, as well as on the papers preprinted using flexography. The details on the prints are presented in Figure 1.

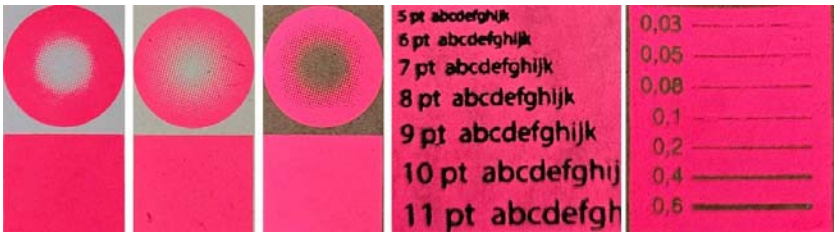


Figure 1: Details on the fluorescent prints (screen 60 l/cm), from left to right: on paper A, on paper B, on paper C, on pre-printed paper C and on plain paper C

2.2 Measurement and analysis

Paper smoothness was measured using the Bekk method on a PTI-Line Bekk device, following the TAPPI standard T 479. Samples were placed on a glass plate, and a measuring head pressed the sample with a 10 kg weight. The pressure between the paper surface and the glass plate was adjusted to 50.7 kPa and then released until it reached 48.0 kPa. The time it took for 10 mL of air to reach 48.0 kPa provided the smoothness value in seconds. Smoothness was measured five times on each printed paper side, and the average values were presented.
Printed ink thickness was measured using the SaluTron D4-Fe, which works based on magnetic induction to measure nonmagnetic layers. Measurements were conducted ten times on each paper, and average

values were presented. The paper caliper values (200 µm for paper A, 140 µm for paper B, and 155 µm for paper C) were subtracted from the measured average thickness values of the paper with print.
Spectral reflectance of the printed coatings was measured using the Ocean Optics USB 2000+ spectrometer and Deuterium-Tungsten Halogen UV light source DH-2000. This allowed observation of the reflectance of fluorescent inks when exposed to UV and daylight radiation.
Microscopy of the printed lines with a nominal width of 600 µm was performed using an Olympus BX51 microscope. Microscopic images were captured at a 50× magnification, and the Stream Motion program was used to measure the width of the fine lines from the captured images.
The contact angles of the reference liquids and consequently the surface free energy (SFE) of the samples were analyzed using the Data Physics OCA 30 goniometer. Three reference liquids with known SFE (water, diiodomethane, and glycerol) were applied on the paper substrates and prints. The SFE of the reference liquids and their contact angles on the samples were used to calculate the SFE of the solid substrates. Contact angles were measured using the sessile drop method, ten times on each sample at different positions. The shape of the drop was a spherical cap, and the volume of the drop was 1 µl. All measurements of the contact angles were performed at 0.4 s (10 frames) after the drop had touched the sample surface, due to the fast absorption of the liquids on unprinted papers. The SFE was calculated using the OWRK method. From the calculated SFE components, the adhesion parameters between the layers in the contact were calculated. Interfacial tension (γ_{12}), work of adhesion (W_{12}), and wetting coefficient (S_{12}) between the layers in contact were defined to assess the strength of interfacial interactions (Mahović Poljaček et al., 2023).

3. RESULTS AND DISCUSSION

3.1 Spectral reflectance of substrates and fluorescent prints

The results of spectral reflectance of the papers A, B, C; and of fluorescent prints on plain and preprinted papers, are presented in Figure 2 "F_" denotes the fluorescent print, "Bl_" denotes the black flexographic print, and "60" or "100" denotes the mesh count.
In Figure 2a, spectral reflectance of paper A and the corresponding prints can be seen. The reflectance over 100% for paper A in the area between 400 and 520 nm could be assigned to the optical brighteners in the paper (Mahović Poljaček et al., 2021; Mustalish, 2000). Furthermore, the reflectance over 100% is also usual for the spectra of fluorescent inks (Tomašegović et al., 2021).

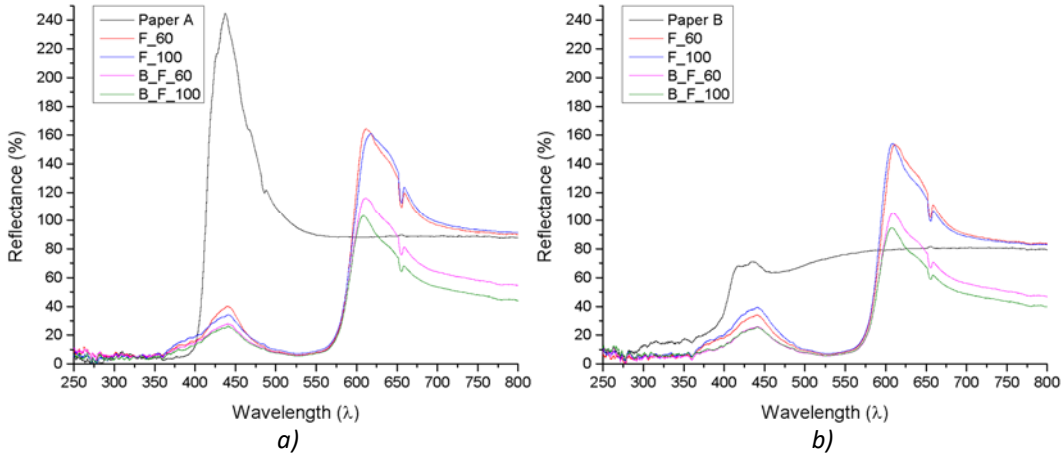


Figure 2 (part 1): Spectral reflectance of paper substrates and fluorescent prints: a) paper A, b) paper B

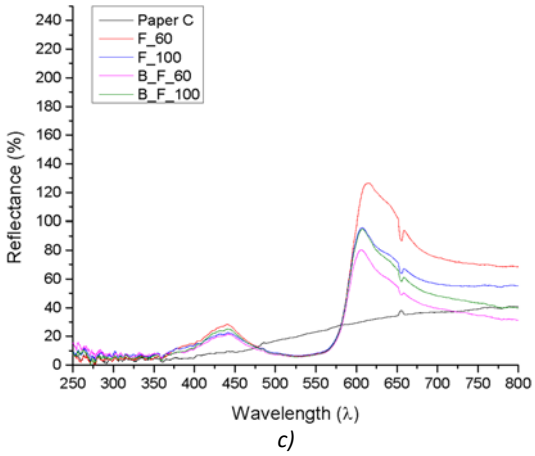


Figure 2 (part 2): Spectral reflectance of paper substrates and fluorescent prints: c) paper C

Two wavelength regions associated with the reflectance of the fluorescent pink ink utilized in this study are evident on all spectra of fluorescent prints, regardless of the used printing substrates (Figure 2a – c): one between 400 and 500 nm peaking at approximately 440 nm, and the other above 550 nm, peaking at around 620 nm. This leads to the conclusion that the fluorescent ink layer is opaque and has completely covered all substrates. However, the spectral reflectance of the fluorescent prints was influenced by the different optical properties of the papers. Darker paper C (Figure 2c) caused a reduction in the reflectance of the fluorescent print compared to prints on papers A and B (Figures 2a - 2b). Additionally, the mesh count also affected the reflectance - a higher mesh count resulted in a thinner ink layer on the substrate and therefore lower reflectance. Furthermore, the existence of the black flexographic ink layer under the fluorescent prints resulted in decreased reflectance, as well. This is particularly true for the fluorescent prints obtained using a 100 l/cm mesh: the effect of the black flexographic ink on the reflectance was significant due to the thin fluorescent print.

3.2 Thickness of the printed ink layers

In Figure 3 the thicknesses of the black and fluorescent layers printed on all substrates (papers A, B, and C) are presented.

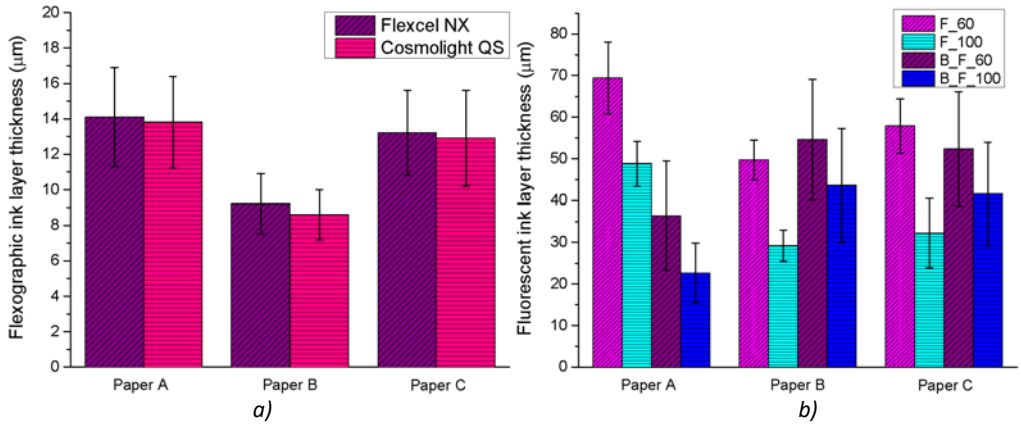


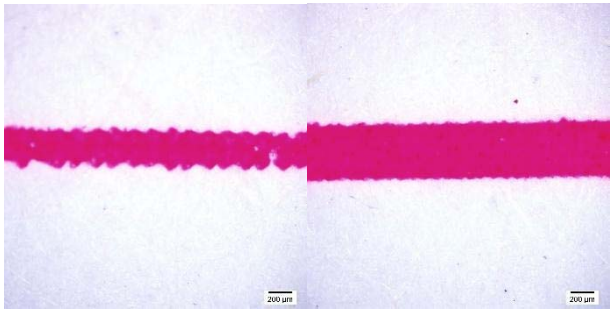
Figure 3: Thickness of the printed ink layers on different paper substrates: a) flexographic ink, b) fluorescent ink on plain and preprinted papers

The thickness of the black flexographic ink layer (Figure 3a) did not present with any significant differences as a result of different flexographic printing plate used. Although the Flexcel NX printing plate should transfer more ink to the substrate than the conventional flexographic printing plate due to the micro-patterned surface, water-washable Cosmolight QS plate performed similarly. It can be concluded that water-washable printing plate used in this research can be utilized to preprint a UV-curable ink layer on the recycled paper substrates rather than the solvent-washable plate due to its ecological favourability.

The fluorescent ink layer thickness was highest at an average value of 69.4 µm on paper A using a 60 l/cm screen and lowest at 22.6 µm on preprinted paper A using a 100 l/cm screen (Figure 3a). The mesh count had an impact on the thickness of the printed layers on all substrates, and an influence of the preprinted flexographic ink layer was discernible only on paper A. As expected, the relationship between ink layer thickness and mesh count was inversely proportional.
When fluorescent ink was directly printed onto paper, the prints on paper A had the highest thickness among the prints on different substrates. The preprinted black flexographic layer also significantly affected the thickness of the printed fluorescent ink layer on paper A. Compared to the fluorescent layers printed directly on the papers, prints on the black flexographic ink layer had a lower thickness. This can be attributed to the smoothness of the paper A - a significantly smoother substrate than papers B and C (Table 1). The flexographic ink filled out the pores of the paper A, which led to less fluorescent ink being transferred to the substrate due to reduced substrate roughness. However, due to the deviations in the printed layer thicknesses, resulting from the substrate roughness, fluorescent ink consistency, mesh structure and fast ink drying, the influence of the black flexographic ink layer on the thickness of the fluorescent ink on papers B and C could not be precisely defined.

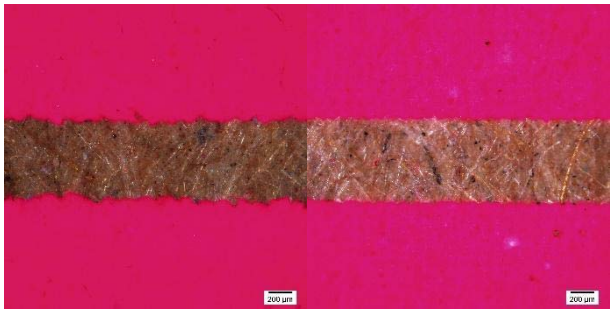
3.3 Width of the printed lines

Figures 4-7 present microscopic images of the lines on the print (nominal width of 600 µm). Image magnification was 50×. Figure 4 presents a clear difference in the width of the lines printed on paper A using different mesh counts. The line printed using the 60 l/cm mesh has irregular edges and is thinner than the line printed using the 100 l/cm mesh. Differences in the width can be attributed to less pronounced deformation during the production of the printing plate occurring due to the incidence and scattering of the light in the emulsion layer, and to the usual irregularity of the line edge in screen printing at lower l/cm. In Figure 5, there is a less pronounced difference between the printed lines in the negative on paper C.



a) *b)*

Figure 4: Microscopic images of the fluorescent printed lines (positive) on paper A: a) 60 l/cm, b) 100 l/cm



a) *b)*

Figure 5: Microscopic images of the fluorescent printed lines (negative) on paper C: a) 60 l/cm, b) 100 l/cm

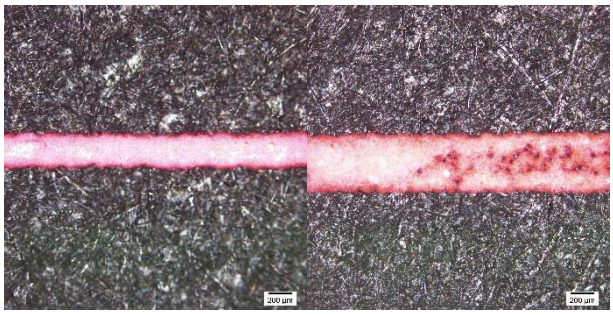


Figure 6: Microscopic images of the fluorescent printed lines (positive) on preprinted paper B: a) 60 l/cm, b) 100 l/cm



Figure 7: Microscopic images of the fluorescent printed lines (negative) on preprinted paper A: a) 60 l/cm, b) 100 l/cm

In Figure 6, fluorescent lines that were printed on the flexographic ink layer (on paper B) can be seen. An obvious difference between these two lines is visible; again, the line printed using a 100 l/cm mesh is wider than the line printed using a 60 l/cm mesh.

Both lines in Figure 7 are somewhat irregular with an uneven edge. They are printed on a flexographic ink layer on paper A and are in negative. The line printed using a mesh of 60 l/cm has a more irregular edge and is wider than that printed using a mesh of 100 l/cm, which corresponds to the negative deformation present during the printing plate production. It can be concluded that the adjustment of the film, and/or shortening the exposure should be performed, in order to increase the width of the lines printed in positive, especially for the motives on the 60 l/cm screen.

In Figure 8, the diagrams present the width of the printed lines in micrometres. Their nominal width was 600 µm. Figure 8a presents the lines printed in the positive. It can be seen that the lines printed using a mesh of 100 l/cm are generally wider. The scattering of light inside the emulsion during the exposure of the screen, as well as the effect of the incidence of light rays, proved to be more pronounced on a thicker layer of emulsion, i.e., the one with 60 l/cm.

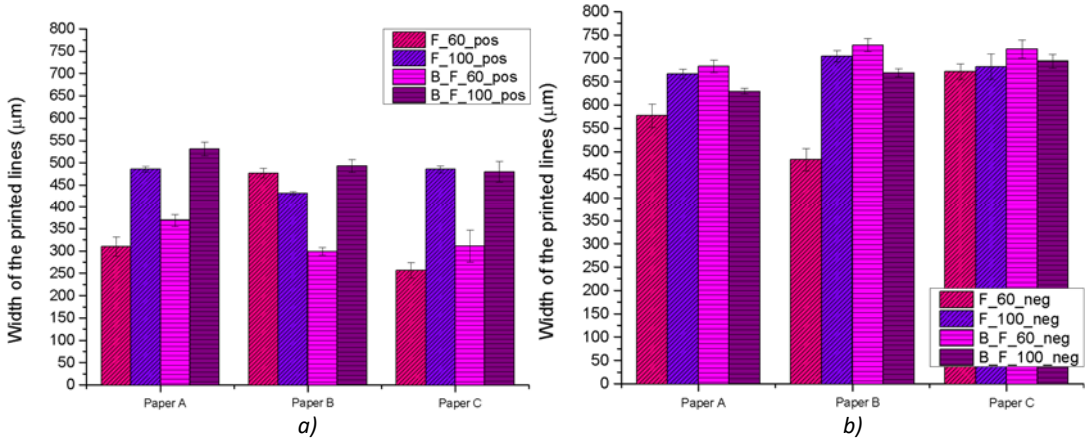


Figure 8: Width of the printed fluorescent lines (nominal width of 600 µm): a) positive, b) negative

In Figure 8b, the lines printed in the negative are shown. It can be seen that most lines exceeded the nominal width of 600 µm, with the exceptions being the lines printed directly onto papers A and B, using a 60 l/mesh. Generally, the variations in the line thickness among the samples are significantly lower than for the lines printed in positive. The adjustment of the motive on the film would be needed for achieving the intended printed line width (600 µm).

3.4 Adhesion between the printing substrates and printed layers

Table 2 presents the adhesion parameters between the surfaces in the contact, i.e., papers and prints, as well as between the flexographic and screen prints. There was no difference in the contact angles (and therefore surface free energy) on the printed ink layers obtained using different flexographic and screen printing plates, since the thickness of all ink layers was high enough to uniformly cover all substrates.

Table 2: Adhesion parameters between the surfaces in contact (paper substrates and prints)

Surfaces in contact	Adhesion parameters (mJ/m^2)		
	γ_{12}	W_{12}	S_{12}
Paper A - Black	2.44	60.26	-6.74
Paper A - Fluorescent	1.58	64.24	-9.00
Paper B - Black	2.12	61.14	-5.86
Paper B - Fluorescent	1.31	65.07	-8.17
Paper C - Black	2.54	53.34	-13.66
Paper C - Fluorescent	2.35	56.65	-16.59
Black - Fluorescent	0.31	69.81	-3.43

By observing Table 2, it can be concluded that the differences in the surface properties of the papers and inks were enough to have an impact on the adhesion parameters. Specifically, while the interfacial tension (γ_{12}) between all papers and printed ink layers was low, values closer to zero were obtained between the papers and fluorescent inks, while γ_{12} for paper-flexographic ink interface was a bit higher. Lowest and therefore closest to optimal γ_{12} for the paper-ink interface was calculated between paper B and fluorescent ink (1.31 mJ/m^2). Work of adhesion (W_{12}) was higher between papers and fluorescent screen-printed ink than between the papers and flexographic ink. Furthermore, papers A and B displayed higher W_{12} with both inks than paper C, which pointed to the poorest adhesion between paper C and both types of inks. The values of the wetting coefficient (S_{12}) were negative for all interfaces, with paper C again displaying the poorest result in terms of the optimal adhesion with the ink layers. Finally, most favourable adhesion parameters were obtained between the flexographic black and fluorescent screen ink: γ_{12} was the lowest among all tested interfaces, W_{12} was the highest, and S_{12} did not express significantly negative value. This points to the conclusion of the optimal interactions between these two types of printed ink layers and their compatibility.

4. CONCLUSION

This research aimed to determine the effect of using different types of recycled printing substrates and printing plates with varying properties on the characteristics of fluorescent screen prints when combining flexography and screen printing. To carry out the research, black UV-curable ink was pre-printed on three different types of recycled papers using flexography, and then screen-printed using fluorescent printing ink. Referent samples of fluorescent prints were also printed, without the pre-printed black ink. The results showed differences in the characteristics of fluorescent prints on unprinted and pre-printed paper substrates. Specifically, the fluorescent ink layer was thicker on unprinted paper A than on paper with pre-printed black flexographic UV-curable ink. The lowest thickness of the fluorescent ink layer was obtained on paper A after preprinting with flexographic ink, which can be attributed to its smoothness. Thickness of the prints on papers B and C, however, deviated significantly. Nevertheless, the mesh count still had a decisive influence on defining the thickness of the fluorescent ink on the print. Furthermore, similar flexographic ink layer thickness was obtained when printing with a patterned solvent-washable flexographic plate and a water-washable one, which was noteworthy, since a water-washable flexographic printing plate has an advantage in the ecological aspect of the production. Although the spectral reflectance of fluorescent print can typically exceed 100% at specific wavelengths, it was significantly reduced on paper

C due to its optical properties. The black pre-printed ink layer and mesh count also influenced the results, with a higher mesh count of the screen resulting in a thinner layer of the ink on the paper substrate and therefore lower spectral reflectance. Furthermore, microscopy showed that the mesh count significantly affected the quality of the fluorescent print in terms of the reproduction of details, as expected. However, this influence did not significantly depend on the pre-printed black layer. Microscopic images of print details revealed that the prints obtained with a mesh of 100 l/cm had clearer edges and a higher width. Most favorable adhesion parameters were obtained between the flexographic black and fluorescent screen ink: interfacial tension was the lowest among all tested interfaces, work of adhesion was the highest, and the wetting coefficient did not express a highly negative value; which pointed to the optimal interactions between these two types of inks on the print and their compatibility, i.e., adequate applicability in the real system. In conclusion, the research provided information on the compatibility and features of layers printed with a combination of flexo and screen printing techniques on different recycled paper substrates. It was shown that it is possible to achieve adequate reproduction of fluorescent motifs on recycled and pre-printed paper substrates by carefully selecting the printing substrate, printing inks, and printing plate for screen printing, ensuring adequate mechanical resistance of such prints on a pre-printed flexographic ink layer.

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THE INFLUENCE OF THE FLEXO PLATE MOUNTING FOAM BACKING ON THE QUALITY OF MAGENTA COLOUR REPRODUCTION

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Abstract: *Flexographic printing technology is relevant for producing flexible packaging. The quality of reproduction in flexographic printing is influenced by various factors such as the screen frequency, the volume of the anilox roller cells, and the hardness of the plate mounting foam backing. This study aims to investigate the impact of different plate mounting foam backings with varying hardness (Tesa Softprint Soft, Tesa Softprint Medium, and Tesa Softprint Hard) when used with the standard NX raster produced by Kodak (STD_NX). Additionally, different volumes of anilox roller cups ranging from 3,8 cm^3/m^2 to 11,6 cm^3/m^2 were considered. NX plates were produced on a Kodak Flexcel large CtP device and printed using a WGH VISTAFLEX CL8 machine with a printing speed of 300 m/min. The printing was done on a 60 µm low-density polyethylene substrate using process magenta solvent ink. The printed samples were analysed using a densitometer and a spectrophotometer (TECHKON SpectroDens) to obtain and compare the reproduction curves with the ISO printing standard 12647-6 (FOGRA 39 reference data). Furthermore, a detailed visual analysis of the printed samples was conducted using a Dino-Lite Edge digital microscope. The results of this research will provide guidance on the selection of the appropriate plate mounting foam backing in combination with the standard Kodak Flexcel NX screen and the suitable anilox cell counts in the roller. It was observed that the finest anilox (400L/cm = 3.8 cm^3/m^2) yields the highest quality magenta prints and the smallest tone value increase. Additionally, the soft Tesa plate mounting foam backing offers the most accurate initial reproduction curve, staying closest to the allowed tolerance area.*

Key words: flexography, plate mounting foam backing, print quality, reproduction curve, anilox rollers, Kodak Flexcel NX screening

1. INTRODUCTION

Flexo printing has been a key contributor to the growth of the packaging, label, and commercial printing markets over the last five years. With a satisfactory stability, these areas have seen significant growth: packaging printing market (+2.1%), label printing market (+2.9%) and commercial printing market (1.8%). While other areas of application of flexo printing are slightly stagnating, the overall picture is one of robust growth and promising potential. In total revenues (in billion US dollars) related to output by print process, we see an increase in revenues of 2.1%, or 0.4% in print equipment sales (Smyth, 2017).
Flexo printing is a direct rotary printing technique, similar to letterpress, that uses resilient relief image plates primarily used for packaging production. The relief printing form is made of rubber or polymer, on which the printing elements have a spatial frequency from 20 to 60 lines/cm. The thickness of polymer plates can be different. Plates with a thickness of 1,14 mm are used for high-quality reproductions, while thicknesses from 2,52 to 6,35 mm are used for packaging printing. The flexographic printing units use the rotary principle (cylinder-cylinder) and consist of a plate cylinder, an impression cylinder, and an inking device (Figure 1). The ink is placed in the ink fountain. The surface of the ink fountain roller is partially immersed in the ink fountain with the ink, and by rotation, it transfers the ink to the surface of the distributor roller and further to the printing form (FFTA Flexography, 1999; Petrović, 2020).
Modern flexographic machines are equipped with special anilox rollers made of ceramic or chrome, which ensure precise ink application. The surface of these rollers is screened in spatial frequency from 75 to 400 L/cm, and depending on the spatial frequency used, the amount and thickness of the ink applied to the printing surface are defined. In flexographic printing, the application of ink on the substrates is between 0,8 and 1 µm, demonstrating the precision and quality of the technique. When printing packaging, three types of flexographic inks are used: alcohol-based inks, water-based inks, and UV cured inks.
Solvent-based flexographic inks contain 40-60% aqueous or alcoholic solvent, 15-25% binder, 10-25% pigments, and 5-10% additives. Viscosity, which ranges between 0,05-0,5 Pa·s, is regulated by the amount of solvent in the ink (Rogers, 2011).

ORCID numbers are provided at the end of the paper.

Inks based on alcohol solvents are applied to non-absorbent aluminum and polymer foils. Such inks are dried by vaporization and evaporation of the solvent, which is accelerated by exposing freshly printed imprints to high temperatures. Water-solvent inks are applied to more absorbent printing substrates with a rougher surface (paper and cardboard). Prints obtained with such inks require a slightly longer drying time (FFTA Flexography, 1999).

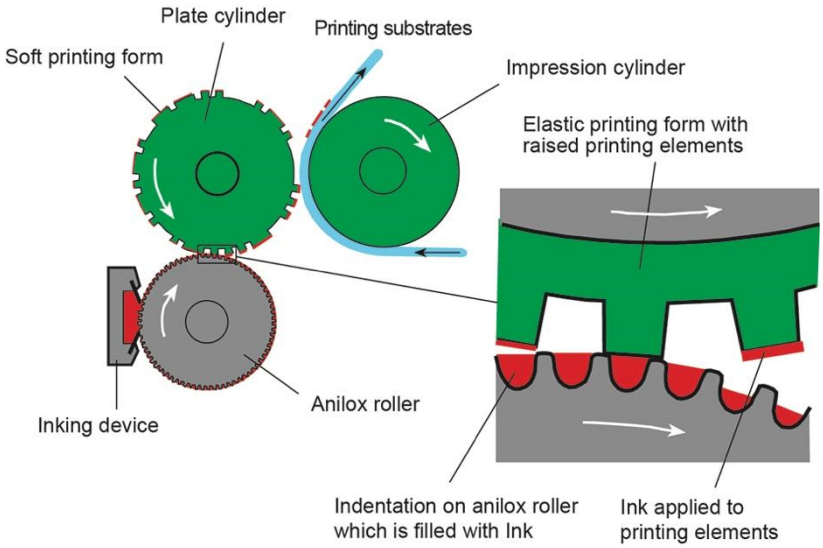


Figure 1: Flexographic Printing Unit

UV-cured inks do not contain solvents and are composed of 55-80% binders, 10-20% pigments, 5-15% photoinitiators, and 5-10% additives. When the printed material is exposed to UV radiation, immediate drying occurs. The photoinitiators in the ink start the polymerization process upon illumination, resulting in solidification. These inks produce high-quality prints with good mechanical and chemical properties, making them suitable for printing on substrates such as paper, PVC, aluminium foils, and laminates. The tone values of the print depend on the pressure force between the plate and the impression cylinder. Compared to other letterpress printing techniques, a lower pressure is required to achieve a visible print, with a maximum pressure of 1,5 MPa achievable with harder polymer forms (White, 1998).

Double-sided plate mounting tapes were introduced in 1975 for mounting photopolymer and polymer printing forms on the plate cylinder. Some companies producing mounting tapes also introduced plate mounting foam backing to the market. The addition of compressible foam improved the compressibility of the mounted printing forms and enhanced uniform pressures in the NIP zone, reducing tonal value increases during printing (FFTA Flexography, 1999). The foam compound provides consistent pressure compensation and maintains a constant return force even after significant changes in thickness. When using rigid forms, there is a continuous increase in the intensity of the return force from the initial contact (Bin, 2009).

The composition of the plate mounting foam backing may differ structurally to achieve these results (Figure 2). Both flexible and classic plate mounting foam backing share the same three top layers (liner, plate-side adhesive, PE reinforcement film) and an underlying adhesive layer for binding with the sleeve cylinder (TESA, 2024). In the case of the softer, flexible construction, there is a thin unique PE reinforcement film beneath the PE foam, while the hard strip utilizes a central lamination adhesive layer (above the PE foam layer). The central layer of PE foam (with a thickness of 0,3 and 1 mm) acts as a shock-absorbing component, reducing pressure on specific parts of the printing form, and exhibits 1800 compressions and recoveries per minute (Lee, 1998).

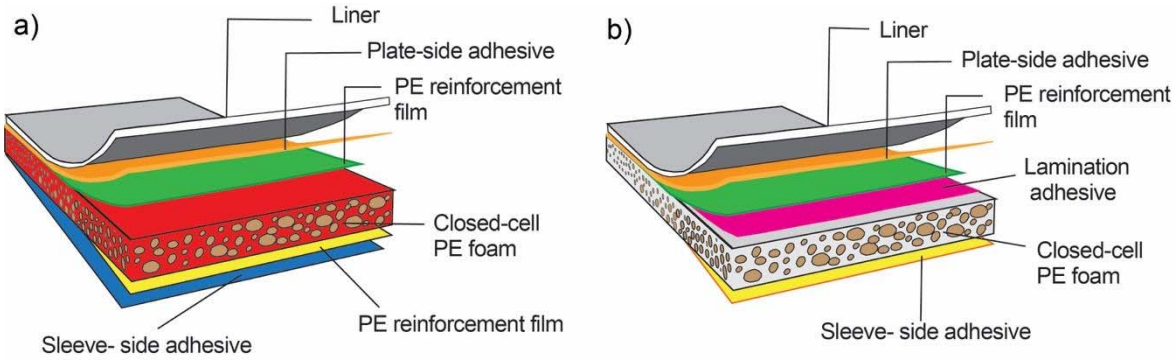


Figure 2: Structure of plate mounting foam backing: a) flex foam; b) Classic foam

The influence of plate mounting foam backing on the reproduction quality in flexographic printing is not just a crucial area of investigation, but a key aspect that significantly impacts the printing industry. Research by various authors has shown that the hardness of the printing forms plays a pivotal role in determining the printing quality. The choice of plate mounting foam backing can lead to different printing results. Softer printing forms adapt better to the printing surface. In contrast, harder ones deform less, reducing the increase in tonal values and contributing to a longer lifespan of printing forms (Anderson & Vreeland, 2019). For instance, five different double-sided plate mounting foam backings have been shown to change the optical density of solid tone surfaces from 1,34 to 1,66 (Lee, 1998). This underscores the importance of plate mounting foam backing in achieving optimal flexographic printing results.

According to the author's paper (Joyce et al., 2014), the increase in the width of screen elements (line) is one of the main disadvantages of the flexographic printing process. It is caused by the compression of the printing form that occurs when the colour is transferred to the substrate, and it can be controlled by the correct selection of plate mounting foam backing, as well as fine adjustment of the pressure-softer plate mounting foam backing results in a more significant increase in print element thickness. If the tape is too hard, it may bounce during printing (FlexoTech, 2019). The density and compressibility of PE foam can also vary, but generally, softer plate mounting foam backing is used when reproducing tonal values, and harder ones for full-tone printing. Therefore, when combining motifs, the choice of strip is a critical parameter.

For good results of flexo printing, the assembly of the plate mounting foam backing for the sleeve cylinder is also essential. In the case of insufficient adhesion, the formation of bubbles and lifting of the ends of the printing forms can occur, which decreases the stability and quality of the printing process. Lifting the ends of the printing forms is a major technical problem that often arises due to the ink penetration between the plate mounting foam backing and the printing form. Also, the degradation of the adhesive by the action of cleaning agents has the same effect. Ultimately, this leads to errors in the registry and a decreased quality of the printed product (Mark Andy, 2018). Some versions of the plate mounting foam backing are designed to have micro-channels that allow air to flow through the adhesive, which helps eliminate bubbles between the plate mounting foam backing and the printing form.

2. METHODS

Currently, the densitometric method is most commonly used to control and determine the quality of flexible packaging. In this paper, the authors discuss the exciting possibility of printing on the WGH Vistaflex CL8 printing machine at a printing speed of 300 m/min. For the experiment, five anilox rollers with precisely defined cubic capacities were varied on the machine, of which anilox 3,8 cm^3/m^2 was used, which corresponds to a spatial frequency of 400 L/cm, anilox 5,5 cm^3/m^2, which corresponds to a spatial frequency of 340 L/cm, anilox 7,7 cm^3/m^2 which corresponds to a spatial frequency of 280 L/cm, anilox 10 cm^3/m^2 which corresponds to a spatial frequency of 200 L/cm and anilox 11.6 cm^3/m^2 which corresponds to a spatial frequency of 160 L/cm.

The purpose of the experiment was to investigate the influence of plate mounting foam backing on the reproduction quality in flexographic printing. For the experiment, a printing form was first made that contained two types of elements: elements for monitoring the optical density (Density) and elements for monitoring the tone value (printing wedge from 3% to 100% of the patch in steps of 10% of the screen tone value). For printing purposes, a Kodak Flexcel NX 74° Sh A printing form was used, which was made on a Kodak Flexcel Format Large 5080 CTP device. Standard_NX raster was selected.

The produced plates were fixed in different ways, using three plate mounting foam backings of varying hardness: Tesa Softprint hard plate mounting foam backing, Tesa Softprint medium plate mounting foam backing, and Tesa Softprint soft plate mounting foam backing. In the experiment, only one separation was used: a magenta solvent ink produced by Gecko and a 60 µm LDPE film produced by Di. Ri. Plast was used as a printing substrate.
During the experiment, 15 possible combinations were meticulously made, where changes were made to five different anilox rollers along with changes to three plate mounting foam backing. All combinations were measured with a TECHKON SpectroDens spectrophotometer and densitometer, based on which we obtained the results of the relative tonal value of the print and the optical density of the magenta tones. The obtained results are displayed in the Origin application. A microscopic image magnified 176 times obtained with a DinoLite microscope was used for detailed analysis. The microscopic image was used to evaluate the results obtained visually. Figure 3 shows a schematic representation of the performed experiment.

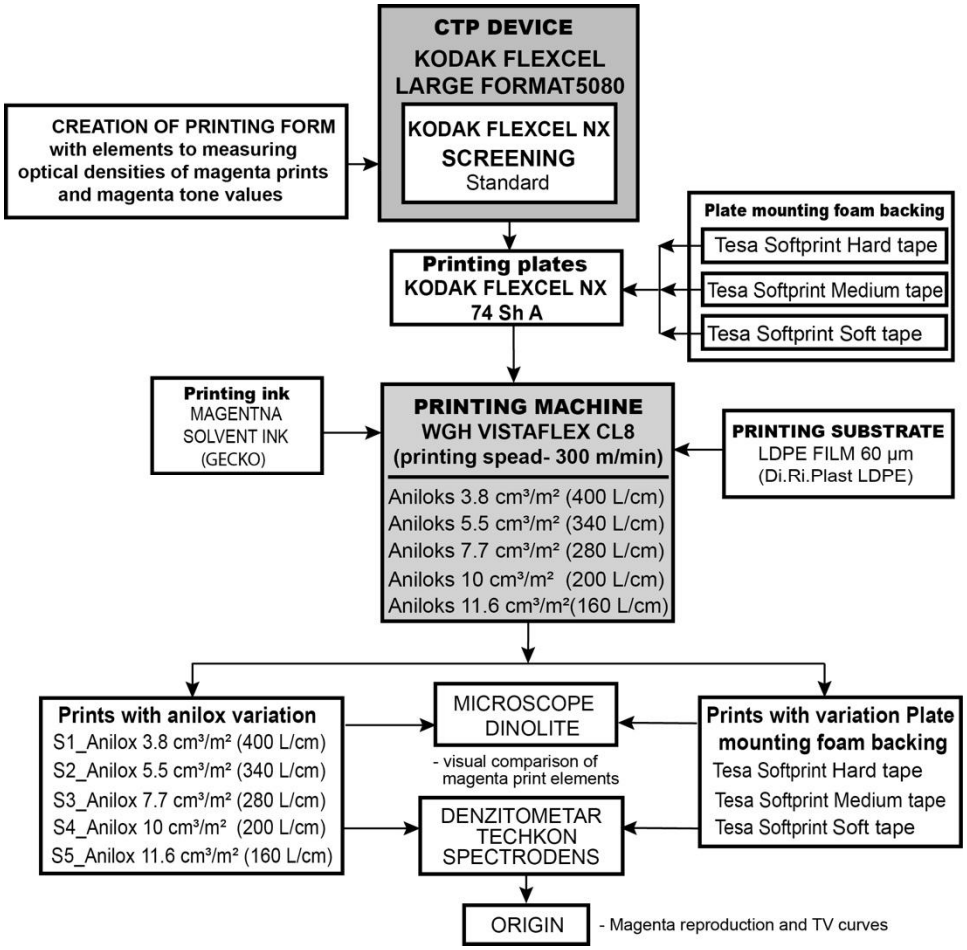


Figure 3: Schematic representation of the performed experiment

3. RESULTS AND DISCUSSION

The appropriate combination of plate mounting foam backing is applied to achieve the desired (controlled) deformation of the NX flexo plate. Figure 4 shows reproduction curves and magnified segments of light tonal areas of magenta prints created with five anilox rollers (160, 200, 280, 340, and 400 L/cm) along with the show of the permissible limit of colour deviation according to the FOGRA 39 standard.

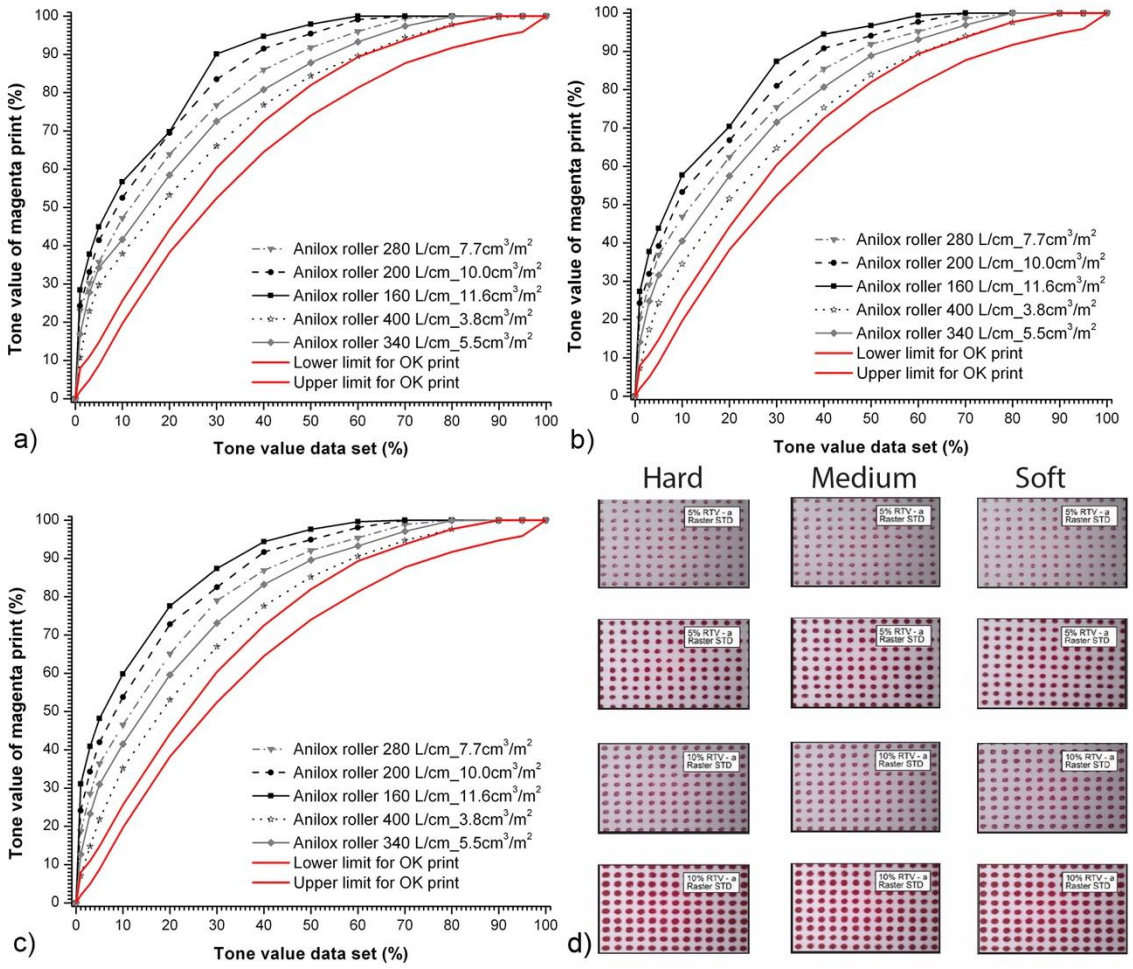


Figure 4: Influence of anilox rollers on the magenta reproduction curve when using the NX standard plate fixed with plate mounting foam backing: a) Tesa Softprint Hard; b) Tesa Softprint Medium; c) Tesa Softprint Soft; d) enlarged view of wedge segment with anilox 400 L/cm and anilox 160 L/cm

By applying a hard plate mounting foam backing in combination with a standard NX flexo plate (made with the screen option STD_NX) and printing with all experimental anilox rollers, reproduction curves were achieved that do not correspond to the values of the target ISO 12647-6 2013. At the same time, the anilox of the largest cubic capacity will give the worst, and the anilox of the shallowest cubic capacity will get the best results. The measured patches with the most negligible surface coverage (the lightest magenta tones) achieve a significant colour tone change, the tone value increase of which is ($TVI_{5\%TV}$=15,1%). After that, the magenta curves maintain a uniform increase, which is most pronounced in the tone area of 30% ($TVI_{30\%TV}$=24%). Minimal oscillations occurred in the range of higher tonal values ($TVI_{80\%TV}$=2,3%), after which their matching occurs.

By applying a medium hard plate, mounting foam backing in combination with an NX flexo plate made with the screen option STD_NX, and printing with five experimental anilox rollers, reproduction curves corresponding to the tone values (area) of the FOGRA 39 standard are also achieved. Thus, anilox 160 L/cm will give the worst results, and anilox 400L/cm will provide the best results. The measured patch with the most negligible surface coverage (the lightest magenta tones) achieves a significant magenta colour change, the increase of which is ($TVI_{5\%TV}$=19,4%). After that, the magenta curves maintain a uniform increase, most pronounced in the tone value area of 30% ($TVI_{30\%TV}$=22,6%). Minimal oscillations occurred in the range of higher tonal values ($TVI_{80\%TV}$=2,3%), after which their matching occurs.

Applying soft plate mounting foam backing and NX flexo plate made with the STD_NX screen option and printing with five experimental anilox rollers do not achieve the desired reproduction curves and do not correspond to the tone values (area) of the FOGRA 39 standard. Thus, anilox 160L/cm will give the worst results, and anilox 400L/cm will provide the best results.

The measured patches with the most negligible surface coverage (the lightest magenta tones) achieve a significant colour change, the increase of which is ($TVI_{5\%TV}$=26,3%). After that, the magenta curves maintain

a uniform increase, most pronounced in the tone value area of 20% ($TVI_{20\%TV}$=24,5%). Minimal oscillations occurred in the area of higher tonal values ($TVI_{80\%TV}$=2,3%), after which they became uniform.
The experimental application of five anilox rollers and three hardness plate mounting foam backing showed that the combination of anilox with the most minor spatial frequency and the most significant cup volume (160 L/cm = 11,6 cm^3/m^2) will be the worst, while the combination of anilox with the most significant spatial frequency and the smallest cup volume (400 L/cm = 3,8 cm^3/m^2) to be the best.
By applying all three plates mounting foam backing and anilox roller 3,8 cm^3/m^2 tone value in the range of 3 to 5% TV, the effect of print elements with visible central white will be maintained. In doing so, a shift of the white to the upper right edge can be observed, thereby reducing the ideal magenta tone. Anilox 11,6 cm^3/m^2 retains solid print dots, simultaneously achieving a higher optical density of magenta tone. Only the fields of 10% TV created with anilox 3,8 cm^3/m^2 are optically well realized and do not have whiteness within the print dots (barely noticeable). By using anilox with three times higher cubic capacity, a more contrasted magenta print will be realized with rapidly larger print dots reproduced. The most significant changes in the reproduction curve will be realized with the application of the largest and smallest cubic capacity of the anilox roller. Figure 5 shows the curves of mutual differences created using anilox of 3,8 cm^3/m^2 and 11,6 cm^3/m^2.

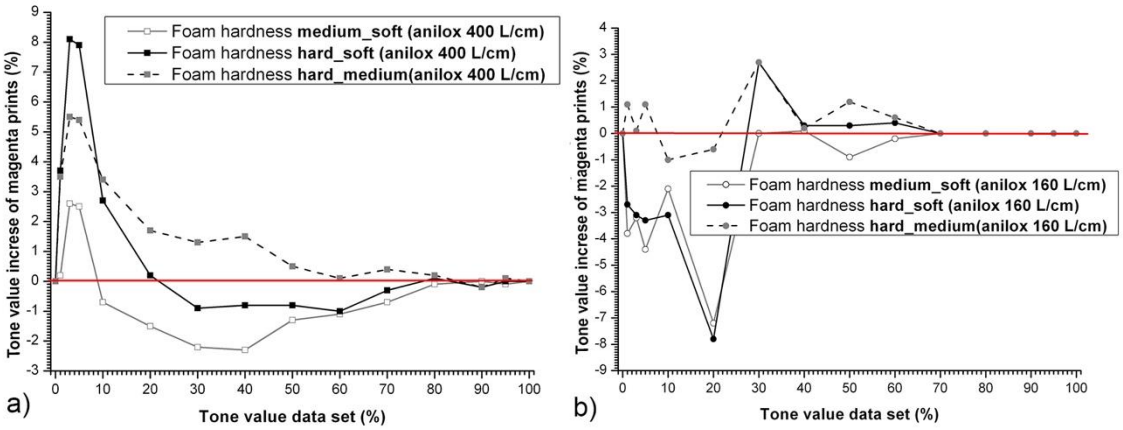


Figure 5: Comparison of changes in the reproduction curves resulting from direct variation of the hardness of plate mounting foam backing: a) with anilox 400 L/cm b) with anilox 160 L/cm

When using different plate mounting foam backings with the shallowest anilox, we observed large deviations. The most significant positive increases were achieved only up to the 5% tone value area. Changing from soft to medium plate mounting foam backing will result in the smallest increase ($\Delta TVI_{5\%TV}$=2,5%), while changing from hard to soft will provide the most significant growth ($\Delta TVI_{5\%TV}$=7,8%). Changing from medium to hard will also cause positive deformation of the printing elements (ΔTVI_{aver}=1,05%). All other combinations of plate mounting foam backing result in negative changes, with the most significant decrease occurring when changing from a medium-hard to a soft plate mounting foam backing (ΔTVI_{aver}=-1,07%). Using a 400 L/cm anilox roller with varying plate mounting foam backing hardness will result in minor oscillations within standard limits (+/- 2% TV). Adjusting the LUT curve in the CTP device's prepress will easily achieve optimal halftone printing. The least favourable combination with the least impact on the print is the variation from hard to soft plate mounting foam backing, which results in the printing elements closing after 80% TV.
When using the 160 L/cm anilox and different plate mounting foam backing hardness, no significant changes are observed in the reproduction curves. Positive changes occur when changing from hard to hard plate mounting foam backing, but there is visible instability in the print in the 10 to 20% tone value range ($\Delta TVI_{10\text{-}20\%TV}$=-1%). Other plate mounting foam backing combinations also show instability in the achieved changes, resulting in negative tone in the reproduction curves. The maximum decrease in the 20% TV patch area is $TVI_{20\%TV}$=-8. However, all other measured patches (covering more considerable surface) will not result in visible changes in increments ($\Delta TVI_{30\text{-}90\%TV}$= 0,2%).

4. CONCLUSIONS

The use of Tesa plate mounting foam backing with a Kodak NX flexo plate and various anilox rollers did not produce reproduction curves that align with the FOGRA 39 standard tone values. As a result, it will be necessary to create plate compensation curves for the analysed anilox rollers.
Densitometric measurements indicated that the finest anilox (400 L/cm = 3,8 cm^3/m^2) produced the highest-quality magenta prints with the smallest increase in tone value. On average, all combinations of plate mounting foam backing and halftoned surfaces resulted in a 67,7% tone value increase.
Conversely, the anilox 160 L/cm (11,6 cm^3/m^2) led to the poorest magenta prints and the highest dot gain increments, with an average tone value increase of 79,55%. The average difference between the best and worst reproduction curves was 11,85%.
The use of soft Tesa plate mounting foam backing resulted in the most accurate initial reproduction curve, closest to the allowed tolerance area. Transitioning from the soft plate mounting foam backing to the medium plate mounting foam backing while using the shallowest anilox led to a slight negative dot gain increase and improved reproduction of the brightest areas of the image. However, using the 160 L/cm anilox resulted in unsatisfactory dot gain increments, with minimal impact from the variation in plate mounting foam backing. Nonetheless, changing the hardness of the plate mounting foam backing from medium to soft still achieved an increased curve within the ISO standard tolerance 12647-6. The use of Tesa plate mounting foam backing with a Kodak NX flexo plate and various anilox rollers did not produce reproduction curves that align with the FOGRA 39 standard tone values. As a result, it will be necessary to create plate compensation curves for the analysed anilox rollers.

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TO ANALYSE THE FACTORS AFFECTING INK MIGRATION IN THE OFFSET LITHOGRAPHIC PRINTING PROCESS

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Abstract: *Packaging for food is available in different forms based on product and technical requirements in the supply chain and the branding required for the product and package. Paper and board are versatile materials used to package foods. Manufacturers in the food packaging segment focus on the highest levels of manufacturing controls to protect the user and consumer. Migration from paper occurred very fast compared to migration from plastics. Printers must focus on the printing quality of that package. The offset press room manages colourful images with aesthetic outputs by ink flow. The offset process will do printing on paperboards with four process colours. Ink transferred on paperboard at the time of printing with an offset machine may affect the migration of foodstuff; therefore, using the experiment design, it is possible to evaluate migration due to paperboard and press parameters. Overall, ink migration on food simulant was measured. The simulants were selected as per regulations of U.S. FDA 176.170. The ink migration equation was used to calculate migration in mg/in^2. Also, an optical microscope measured the ink penetration of each process colour to know its relation with ink migration. Thus, an analysis of the migration of contaminants into food simulants was carried out to evaluate the suitability of paperboards and inks.*

Key words: food packaging, ink migration, Total Area Coverage (TAC), Paper board, simulant

1. INTRODUCTION

Paperboard is cheap and readily available, which is why food packaging has been using it for hundreds of years. To improve its functionality, certain additives are added during processing; however, if these additives are used more than safe limits, they may be harmful to human health and result in conditions like cancer or organ inflammation. Migrants are substances that can enter packaged food via a printed layer and contaminate it because of their molecular size and chemical makeup. During the printing of paper or paperboard, ink solvent migration may take place, which could contaminate food items through direct or indirect contact. There are multiple ways in which this can happen: penetration, set-off, vapor phase, and condensation. Food safety must be guaranteed by addressing essential aspects of the printing process to remedy this problem. The issue arises when raw materials used in packaging, such as paperboard and ink, are manufactured. As a result, it needs to be taken care of during raw material production and packaging manufacturing. Safeguarding end users' safety is of primary importance in this matter. The main goal of Richter, Gude and Simat's (2009) study was to calculate the amount of ink contamination that migrated into the food that was packaged using offset ink. The low-migrating patented ink was utilized. Typically, mineral and vegetable oils make offset inks; however, the new fatty acid ester (FAE) eliminates these ingredients. The migration test was conducted on food goods that came in packaging, including meat, chocolate, and sweets. These foods had contamination levels ranging from 5 to 80 µg fatty acid ester/kg. The work was reviewed after ITX levels as high as 250 ug/l were discovered in baby formula and with an emphasis on the set-off phenomenon-the migration of materials from the printed outside layer of packaging to the inner layers - Clemente et al. (2016) investigated the ink and varnish migration from packaging materials. Two different kinds of studies were designed and carried out to investigate this. Set-off effects can cause printing inks to migrate even though they are applied to the packaging's outer layer. In migration testing, 149 volatile chemicals in total were found. Usually composed of many polymeric layers or paper linked with adhesives, food packaging materials have outside coatings like varnish or inks. The study aimed to discover volatile substances that migrate because of set-off occurrences and investigate mitigation or prevention techniques. SHI et al. (2015) conducted several experiments to determine the pace at which photoinitiators transfer within paperboards. The investigation used six distinct photoinitiators and two types of paper and board. The partition coefficients (K_paper/air) between paper and air for each of the six photoinitiators were found for kraft paper and white carton board. The lowest and highest K values were found for 2-ethylhexyl-4-dimethylaminobenzoate (EHDAB) and

ORCID number is provided at the end of the paper.

4-methylbenzophenone (MBP). Yang et al. (2012) emphasized the significance of using gas chromatography along with mass spectrometry (GC-MS) to identify pollutants in food packaging materials. Because GC-MS may identify pollutants by ionization, it is necessary to identify dangerous chemicals found in food packaging, as the study demonstrated. For food packaging materials, this technique is essential for quality monitoring. Plasticizers, solvents, and antioxidants with low molecular weight are added during the manufacturing and processing of paper-plastic food packaging materials. Food packaging uses more recycled paperboard. However, as Triantafyllou, Akrida-Demertzi and Demertzis (2006) pointed out, there are drawbacks. The study compared two paper samples with varying thicknesses, grammage, and percentages of recycled pulp. Depending on where they came from, recovered paper and board may include printing inks, adhesives, waxes, fluorescent whitening agents, dyes, sizing agents, organochlorine compounds, plasticizers, volatile organic compounds, aromatic hydrocarbons, curing agents, grease-proofing agents, amines, biocides, and surfactants. Ten model substances were chosen to symbolize various molecular weights, polarities, volatilities, and functions in paper production. Extraction techniques and GC-FID quantification were used in the analysis. Temperature, the properties of the paper sample (grammage, thickness, and pulp content), and the surrogate characteristics (molecular size, chemical structure, and volatility) all affected the migration kinetics. Meal's fat content, the chemical makeup of the migrants, their volatility, and the type of paper samples all significantly impacted the percentage of chemicals that migrated into meals. The substrates with the highest fat content showed the highest organic pollutant migration. It was discovered that Tenax worked well as a food simulant for dry goods with low to moderate fat content. Jung, Simat and Altkofer (2010) examined the literature showing that food can come into contact with packaging-related ink. Specifically, he emphasized that UV printing inks can enter packed foods through the set-off effect in multilayered materials such as beverage cartons. Due to its detectability, the study used the well-known migratory ITX model. Paperboard was tested to be waterproof and resistant to moisture migration by Wu et al. (2013). Diffusion of water vapor in empty spaces and condensed form via fibre cell walls are the two ways that moisture migrates. They found that corrugated paperboard's compressive strength drops by 25% as ambient humidity rises from 60% to 80%. By using sizing agents to change the paperboard surface's wettability or applying a hydrophobic coating, a waterproof or moisture-proof barrier can be produced. Tenax and food were used by Aurela, Ohra-Aho and Soderhjelm (2001) to investigate the migration of alkylbenzenes from packaging. Ten of the fifteen samples, comprising three different types of board, had alkylbenzenes in them. Migration tests at 70°C for 30 minutes revealed the migration of alkylbenzenes, a solvent used in offset printing inks, from printed hamburger collars into rolls. It was proposed that alkylbenzene migration at 40°C over 10 days might be worth investigating. A different test that used Tenax as a simulant examined the impact of a varnish coating on the food contact surface by subjecting samples to single-side contact with Tenax. A 70% reduction in migration was seen when the varnish layer was applied. Compared to experiments using rolls as a food simulant, testing using Tenax produced increased migration. The mechanisms of alkylbenzene transfer were unclear. The relationship between ink penetration and binder migration in paper coatings was examined by Li and Gu (2015). According to the study, the behavior of ink penetration is determined by the coating's surface structure as well as the characteristics of the binders and pigments. By using scanning electron microscopy (SEM) and fluorescent inks, the study demonstrated that higher drying temperatures caused a greater amount of binder migration toward the paper surface. The binder surface coverage was found to be lowest at 100°C and highest at 220°C when drying temperatures were measured using Atomic Force Microscopy (AFM). Higher temperatures led to less ink penetrating the paper layer, according to an inverse relationship between drying temperature and ink penetration depth. Our study aimed to study the impact of using a low migration facility on the migration of the components using various methods, such as penetration with Total Area Coverage.

2. METHODS

The experiments used different paperboards, inks, and press room chemicals. Table 1 lists the types of paperboards used in the press trials and their properties. Table 2 lists the process colour inks of a specific category for a low migration printing facility from Huber Group. Table 3 lists the various low-migration press room chemicals used before, during printing, and after the press trials, such as fountain solutions, cleaning solvents, etc.

Table 1: Specifications of paperboards used for press trials

Paperboard	GSM	Coating Thickness	Coating	Porosity	Cobb in GSM
SCD	280	10 gsm	30% clay + 70% $CaCO_3$	60 ml/min	35
CYD	285	20 gsm	15% clay + 85% $CaCO_3$	10 ml/min	35
MGTH	180	-	-	200 ml/min	25-30

Table 2: Specifications of inks used for press trials

Material Group	Material Description
MGA Process Colours	MGA NATURA YELLOW
MGA Process Colours	MGA NATURA MAGENTA
MGA Process Colours	MGA NATURA CYAN
MGA Process Colours	MGA NATURA BLACK

Table 3: Pressroom chemicals used during printing

Material Group	Material Description	Material Code
Additives 2	MGA LIQUID DEGLAZER	HGI-20342/1F7
NGA Roller Wash	MGA WASH	HGI-20096
Fountain System Cleaner	MGA SYSTEM CLEANER	HGI-20340/1F7
MGA Fountain Solution	MGA COMBIFIX	MGA-806009/10A1
MGA Fountain Solution	MICRONOL MGA	HGI-20097/10A1
Washes/Cleaners	MGA PLATE CLEANER	HGI-20341/1F7
Spray Powder	MGA Anti Setoff Powder	HPC-0591
MGA Acrylac	ACRYLAC MGA GLOSS S	GA 1200/25D2

We designed a test chart for printing on three different paperboards. It contains standard test chart images, a control strip, halftone patches, solid Cyan, Magenta, Yellow and Black patches, and a Total Area Coverage (TAC) chart. The test chart also contains a patch of varying Process colours (C 75%, M 68%, Y 67%, K 90%) used for migration testing. The test chart is seen in Figure 1. The test chart was printed using a Lithrone SIX29 offset press, details mentioned in Table 4.

Table 4: Lithrone Komori 629

LITHRONE SIX29 (29-inch offset printing press) specification		
MODEL		LSX-629
Number of colours		6
Max. printing speed	sheets per hour	16000
Max. sheet size	mm	610 X 750
Min. Sheet size	mm	297 X 420

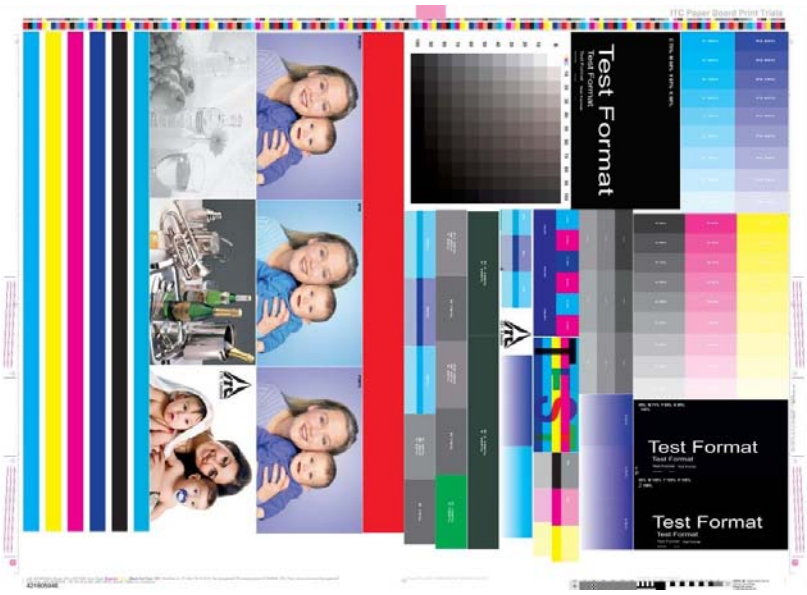


Figure 1: Test chart comprising of various elements

Printing was done on a six-colour offset machine, as given in Table 3, at a speed of 9600 sheets/hour. All food safety precautions were taken into consideration, and the machine was cleaned according to safety requirements. The same low migration process inks were used for each of the three paperboards. The ink densities on the press were varied so that three total area coverage values were achieved. The print sequence was black, cyan, magenta, and yellow.

Low migration products covered under the brand MGA (By Huber) were used along with offset MGA inks. While using MGA products to manufacture food-safe packaging, the pressroom followed guidelines to print without contaminating unwanted chemicals.

The SOP was followed in our presence during the run of our MGA system.

1. All the inking rollers were cleaned thoroughly by applying MGA LIQUID DEGLAZER HGI-20342 and running for 15 minutes.
2. Rollers were then cleaned with MGA WASH HG-20096
3. MGA process inks MGA 5250 (and MGA spot colours, if applicable) were applied to the rollers of respective units and run for 15 minutes.
4. The rollers were cleaned with MGA WASH HG-20096
5. Repeat steps 3&4
6. The ink ducts were filled with MGA inks, and the rollers were cleaned with MGA WASH HG-20096 after all colours were registered before commencing the production run.
7. The impression cylinders were cleaned with MGA WASH HG-20096
8. The dampening solution tank was drained completely, and the freshwater was run for 15 minutes. After draining it out, fresh water with MICRONOL MGA HG-20097 was run for 15 minutes. After draining it out, fresh water was run for 15 minutes. The dampening form rollers were cleaned with MICRONOL MGA HG-20097
9. The new dampening solution was prepared in a tank by adding 4% of MGA COMBIFIX HGI-806009 fount concentrate and 8% of MICRONOL MGA HG-20097 with fresh water.
10. The aqueous coating unit was cleaned with water and MICRONOL MGA HG-20097. The warm water was then circulated for 30 minutes. ACRYLAC MGA HIGH GLOSS 58 MGA 1200 aqueous coating was pumped directly from the can.
11. The plates, after mounting on the cylinders, were cleaned with MGA PLATE CLEANER HGI-20341

Measurement of Ink Penetration: Ink penetration of paperboards in the Z-direction was measured on a 4x optical microscope. IDS photo-capturing software was used to get pixel data. With the help of ImageJ software, Pixel data were converted into micrometres to know the penetration depth (Real Distance: Scaled pixels = 100 µm: 116). Ink penetration was measured for solid patches of process colour, as mentioned in the test chart in Figure 1. An image of the solid patches is given in Figure 2.



Figure 2: Total Area Coverage patches

Ink Migration: Ink migration test for the patch of varying % of Process colours (C 75%, M 68%, Y 67%, K 90%) was measured by Sec. 176.170 components of paper and paperboard in contact with aqueous and fatty foods. Overall migration testing was done for the samples. Ink migration was measured for the total area coverage (TAC) patches mentioned in the test chart in Figure 1. The patches are given in Figure 3.



Figure 3: Solid Patches of Cyan, Yellow, Magenta and Black

Migration testing procedure and Simulants used:

1. Distilled water,
2. n-heptane,
3. 50% ethanol,
4. Vegetable oil,
5. 3% acetic acid.

The selection of extractability conditions was done as per the 176.170 section. First, the type of food product being packed commercially in the paper or paperboard and the standard conditions of thermal treatment used in packaging the kind of food involved were ascertained. As per the 176.170 section, the food-simulating solvent or solvents and the time-temperature exaggerations of the paper or paperboard use conditions were selected. The applicable extraction procedure was followed, and the appropriate food-simulating solvent or solvents were chosen, as well as the time-temperature exaggeration over normal use. The following Reagents were used:

1. Water: All water used in extraction procedures should be freshly demineralized (deionized) distilled water.
2. n-Heptane: Reagent grade, freshly redistilled before use, using only material boiling at 208 deg. F.
3. Alcohol: 8 or 50 percent (by volume) was prepared from undenatured 95 percent ethyl alcohol diluted with demineralized (deionized) distilled water.
4. Chloroform: Reagent grade, freshly redistilled before use, or a grade having an established consistently low blank.

After selecting the Reagents, the test method was selected: Paper or paperboard ready for use in packaging was tested using the extraction cell described in the "Official Methods of Analysis of the Association of Official Analytical Chemists."

3. RESULTS

Ink migration is essential for food safety in the food packaging industry. It can occur due to many input parameters. In this analysis, inks and paperboards are considered influential parameters of the material manufacturing industry in ink migration. Total area coverage (TAC) is regarded as an influential parameter of the pressroom in ink migration. The results of migration using 3% Acetic acid solution migration values in ($Mg/inch^2$) are given in Table 5.

Table 5: Ink migration reports

Grade	TAC Value	Marking during measurement	3% Acetic Acid Solution Migration Value ($Mg/Inch^2$)
CYD	370	D	0.18
CYD	350	H	0.26
CYD	330	G	0.27
SCD	390	E	0.23
SCD	370	F	0.17
SCD	350	A	0.33
MGTH	390	B	0.22
MGTH	370	I	0.18
MGTH	350	C	0.16

Ink penetration of solid patches (Process inks) was measured in pixels, and then the measurements were converted into Z-directional depth. Three samples of each paper and TAC were taken for measurements, and random measurements on solid patches were taken from every sample. Penetration data for 330 TAC are given in Table 6.

Table 6: Penetration results at 330 TAC

Paper type	Penetration in Cyan ink (microns)	Penetration in Magenta ink (microns)	Penetration in Yellow ink (microns)	Penetration in Black ink (microns)
SCD	141.09	150.96	176.55	118.78
CYD	149.71	137.17	155.55	129.49
MGTH	109.58	132.57	156.32	91.09

4. DISCUSSION

Distilled water, N-heptane, 50% ethanol, Vegetable oil and 3% acetic acid were used for migration testing. These four simulants, Distilled water, N-heptane, 50% ethanol, and Vegetable oil, did not show any migration of residues. Distilled water and N-heptane are used as a simulant for nonacid, aqueous, dairy, and bakery products; 50% ethanol is used as a simulant for beverages containing more than 8% alcohol; Vegetable oil (95% ethanol & iso-octane) is used as a simulant for fatty foodstuffs while 3% acetic acid is used as a simulant for acidic foodstuffs (watery foodstuffs pH<4.5). Ink migration by simulants distilled water, N-heptane, 50% ethanol and vegetable oil did not show migration on paperboards. At the same time, simulant 3% acetic acid detected a migration level below the compliance limit of 0.5 mg/in^2.

5. CONCLUSIONS

The main purpose of the paper coating process is to cover the paper fibres by filling a thin film layer of pigment, binder, and some additives onto the base paper or cardboard to fill in the gaps between them

and to obtain a smoother surface. Fillers/Coatings can influence optical properties and sheet structure, such as formation, bulk, pore structure, and surface topography (texture). $CaCO_3$ and clay are used as a coating content for the paperboards. $CaCo_3$ is more in content, as compared to clay in those paperboards. Calcium carbonate is an alkaline material that reacts strongly to acidic conditions. Calcium carbonate may also contain trace amounts of magnesium carbonate, silicon dioxide, aluminium oxide, iron oxide, and water. The presence of calcium carbonate in papers creates difficulty in offset lithography, as the alkalinity of the paper filler or coating tends to react with the acidic dampening solution used on the press. As, the 3% acetic acid was used as a simulant for migration testing, there can be a chance of detection of $CaCO_3$ as a migrant in migration test. Solvents or inks used in printing which contain organic compounds can have a high affinity towards acetic acids, and may be detected as migrants. Ink penetration of ink pigment particles was measured by a reflection microscope. Colourless particles or solvents cannot be measured from optical microscope. So, it cannot be clearly said whether ink penetration has any relation with ink migration or not. Colourless particles from the coating can be penetrated, which may cause migration.
Yellow and black process inks were transferred to the gloves when handling a printed sheet while cutting the samples for ink migration and penetration test. This will cause ink migration due to set-off.
TAC is proved to be the most considerable factor for ink penetration and migration in this analysis. In the pressroom, Printers print their jobs at standard densities as per their machine calibration. Though, sometimes ink deposition (TAC) affects printability as well as effects on ink migration and penetration on paperboards. TAC can be a highly effective parameter for the food packaging industry, especially as safety is the main concern for end users/ consumers.
Ink migration by simulants distilled water, N-heptane, 50% ethanol and vegetable oil did not show migration on paperboards. While simulant 3% acetic acid detected a migration level below the compliance limit of 0.5 mg/in². All the mentioned paperboards taken for analysis can be used in the food packaging industry as they have migration levels below the compliance limit.

6. ACKNOWLEDGMENTS

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EVALUATION OF PRINT MOTTLE IN TEXTILE PRINTING: IMPACT OF PRINTING METHODS ON MACRO NON-UNIFORMITIES

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Abstract: *Besides the quality of colour reproduction itself, there are other secondary print quality attributes. Secondary print quality evaluation is very important and is influenced primarily by the print method and type of substrate. For textile printers, there is an additional challenge related to macro non-uniformities due to the nature of the substrate. One of these secondary quality attributes is print mottle, which is influenced by macro non-uniformities that remain at the top layer of the print after the ink is fixed on the substrate.*
Print mottle values primarily consist of an analysis of macro non-uniformities and can be analysed using the Gray Level Co-occurrence Matrix (GLCM) method, among others. In this study, the GLCM method was used as well as the macro non-uniformity index or NU value verification method performed by ImageJ software. Four different textile printing methods and one cotton fabric substrate are used. The objective is to examine print mottle and the impact of printing method on macro non-uniformities. The printing methods include DTF, DTG, screen printing, and screen transfer printing. The aim is to compare the results of different printing methods and to determine their relation to perceived non-uniformity as assessed visually.

Key words: print mottle, textile printing, macro non-uniformities, printing methods, substrate

1. INTRODUCTION

Colour plays a crucial role in creating a strong visual impression, influencing decisions in nearly every aspect of life. For textile products, colour is often the initial factor that captures the consumer's attention and significantly impacts their purchasing decision (JiHyun, 2007). Clothing must now go beyond fulfilling basic functions like protection and utility; it must also satisfy aesthetic and fashion criteria to effectively express an individual's personal character and lifestyle (Grujić, 2010). Textile printing is both an art and a science, involving the decoration of fabric with vibrant patterns or designs. While screen printing is the most common method used for textile materials, other techniques such as digital printing and thermal transfer are also employed. Today, there are numerous methods for embellishing clothes, each employing different technologies and materials (Prybeha et al., 2021).
According to Prybeha et al. (2021), a popular technique for enhancing textiles in the fashion industry is printing directly on garments. Despite the extensive history of fabric printing, manufacturers still encounter challenges in applying high-quality images to textiles. Specifically, there is a lack of guidance on selecting the appropriate image application method, as well as on determining the optimal parameters of the technological process-such as temperature, time, and pressure-based on the material's chemical composition. Currently, modern manufacturers utilize various methods for printing images on textiles. The choice of printing technology is influenced by several factors, including the quantity of products, the size of the image, the number of colours in the image, the fabric's raw material composition, and the fabric's colour. Each method has its own set of advantages and drawbacks that must be evaluated before application. It is important to recognize that no single technology is superior in all cases, as each type of product necessitates a specific method.
A numerical evaluation of colour reproduction alone isn't sufficient to determine the overall quality of a print. It has been shown that print quality doesn't simply correlate in a straightforward manner with hue, saturation, and value (Fedorovskaya et al., 1997; Pedersen et al., 2009). Quality attributes such as contrast, sharpness, and macro-uniformity are not related to colour reproduction, but they do impact print quality. These attributes are directly associated with line and dot quality, which are essential components of any image (Dhopade, 2010).
According to Lindberg (2004), while using all quality attributes is ideal for assessing print quality, a selection of specific attributes is often more practical in industrial settings. Lindberg found that print mottle and colour gamut significantly influence image quality perception. Additionally, colour shift and sharpness also play a crucial role in perceived quality (Petterson, 2005). Based on Lindberg's findings, it is possible to narrow down the number of quality attributes to these four, aligning with Engeldrum's observation that observers generally perceive no more than five quality attributes simultaneously (Rilovski et al., 2012).

ORCID numbers are provided at the end of the paper.

Pedersen (2011) further refined the quality attributes from existing literature to six key categories: sharpness, colour, lightness, artifacts, contrast, and physical attributes.
Petterson also emphasized the significance of print mottle in print quality, alongside colour gamut, colour shift, and sharpness (Petterson, 2005). Print mottle, defined as the visual irregularities in print density affecting overall print quality, is considered one of the major issues in printing (Fahlcrantz, 2005; Kawasaki & Ishisaki, 2009). It refers to the optical inconsistency and unevenness in optical density and print gloss, which can manifest in solid tones or smooth image areas (Rilovski et al., 2012). Fahlcrantz defines mottle as perceived variations in lightness across the printed surface under uniform illumination (Fahlcrantz, 2005). Evaluating the overall product quality relies on the uniformity of homogeneous image regions (Lindberg, 2004).
Print mottle arises from uneven toner transfer and adhesion, influenced by substrate and toner properties, as well as printing press conditions, such as toner fixation (Rilovski et al., 2012). Consequently, print density and mottle issues occur when toner adhesion and colorant fixation are inconsistent across the paper surface (Petterson, 2005). The paper, toner, and printing process are identified as the three primary factors affecting toner adhesion and fixation (Rilovski et al., 2012).
Print quality in any printing process depends on the process, ink, and substrate. Imperfect interactions among these factors can lead to unwanted effects like print mottle. Print mottle appears as unevenness in solid areas and impacts the print's density and gloss, varying with the ink, substrate, and printing method used. Print mottle is a common printing defect, making it crucial to reduce or eliminate it as much as possible. Given the many factors that influence print mottle, controlling these variables is essential for minimizing its occurrence or selecting a printing process that produces the least amount of mottle.
This research concentrates on examining macro-level non-uniformities such as print mottle. The key print mottle parameters under investigation include contrast, correlation, entropy, energy, and homogeneity. The findings indicate that a uniform grey level distribution, which corresponds to low print mottle, is characterized by low contrast, low correlation, low entropy, high energy, and high homogeneity (Chen, 1998; Hladnik & Lazar, 2011; Ružičić et al., 2014).

2. METHODS AND MATERIALS

This study involves four different textile printing techniques.
Considering the printing techniques for clothing in small and medium runs, the following will be explained:

- The DTF method involves aqueous inkjet technology and transferring an image from a specialized film to the fabric using heat and pressure. The image is first printed onto a special film, which is then applied to the fabric. The image is transferred onto the fabric through the application of high temperature (Prybeha et al., 2021).
- DTG refers to the process of printing digitally on apparel or other assembled products, using an aqueous ink jet technology (Chandavarkar, 2013).
- Screen printing (also known as silkscreen printing) involves pushing ink through the open areas of a flexible mesh stencil onto the printing surface using a special tool called a squeegee. This technique can be used to print on a variety of materials, including paper, metal, glass, fabric, polyethylene, plastic, leather, and other sheet or roll materials and their products (Prybeha et al., 2021).
- Screen transfer printing is a process where an image is moved from a special film to fabric using heat and pressure. Initially, the image is printed onto a unique film via screen printing, and then this image is placed onto the fabric. The image is transferred to the fabric through the application of high temperatures.

The printing substrate used for all printing techniques in this study is identical. It is a cotton fabric from the same manufacturer and batch 155 gsm. The fabrics were cut to dimensions of 21 x 30 cm, and a patch was printed on each piece. Once dry, the samples were scanned using an Epson Perfection V600 Photo flatbed scanner. During scanning, all automatic image adjustment options are disabled. The scanning settings are identical for each sample.

The DTF printing technique was carried out using the Storm Jet printer, which employs inkjet printing technology. This printer uses the Epson I3200-A1 printhead CMYK+W. The DTG printing technique was performed on the Epson SureColor F2000 DTG printer, which also uses inkjet printing technology. This printer uses the Epson PrecisionCore printhead CMYK+W. Screen printing is conducted using a mesh with a count of 100 threads/cm for both direct printing and transfer printing within the research. The process uses Argon Texiplast inks.

To obtain results, the study utilized solid tone patches of 16 x 16 cm (refer to Figure 1). The test image for the study was created using Adobe Illustrator 2023. Previous research employed solid tone patches, specifically 2.54 x 2.54 cm, to evaluate print mottle (Stančić et al., 2013a; Stančić et al., 2013b; Ružičić et al., 2014; Jurič et al., 2015). Another study (Milošević et al., 2013) used 1 x 1 cm patches for similar assessments. Due to the variability in patch sizes in earlier studies, this research opted for the 16 x 16 cm patches, as suggested by Jurič (2018).



Figure 1: Solid patch

The print mottle parameters under investigation are conducted by GLCM image processing. The GLCM image processing technique was utilized on the scanned printed samples using MATLAB software and a plugin developed by Uppuluri (Uppuluri, 2008). This plugin offers data on 22 parameters, with the most pertinent ones used in both existing literature and this research being contrast, correlation, entropy, energy, and homogeneity. The macro non-uniformity of the surface is quantified also by the macro non-uniformity index, or NU value conducted by ImageJ software.
Table 1 outlines all the parameters used in the experiment and explains the significance of each one.

Table 1: GLCM parameters for evaluation of print mottle

CONTRAST	Measures the intensity contrast between a pixel and its neighbour over the whole image.
CORRELATION	Correlation is a measure of how correlated a pixel is to its neighbour over the whole image.
ENTROPY	Entropy in any system represents disorder, where in the case of texture analysis entropy is a measure of spatial disorder in an image.
ENERGY	Energy is a measure of local homogeneity. Basically, this feature will tell us how uniform the texture is.
HOMOGENEITY	Measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal.

In Table 2, the samples are listed in order along with their abbreviated names and a description of the printing technique used.

Table 2: Sample overview

Sample number	Sample label	Printing techniques
1	SD-WB	Direct screen printing. Black over White. Curing with hot air.
2	SD-B	Direct screen printing. Black only. Curing with hot air.
3	DTF-WB	Digital inkjet printing on film. Black over White. Transfer and drying with a heated press.
4	DTF-B	Digital inkjet printing on film. Black only. Transfer and drying with a heated press.
5	ST-WB	Screen printing on film. Black over white. Transfer and drying with a heated press.
6	ST-B	Screen printing on film. Black only. Transfer and drying with a heated press.
7	DTG-B	Direct digital inkjet printing. Black only. Drying with a heated press.

3. RESULTS

The results from GLCM image processing are obtained in charts in Figure 2.

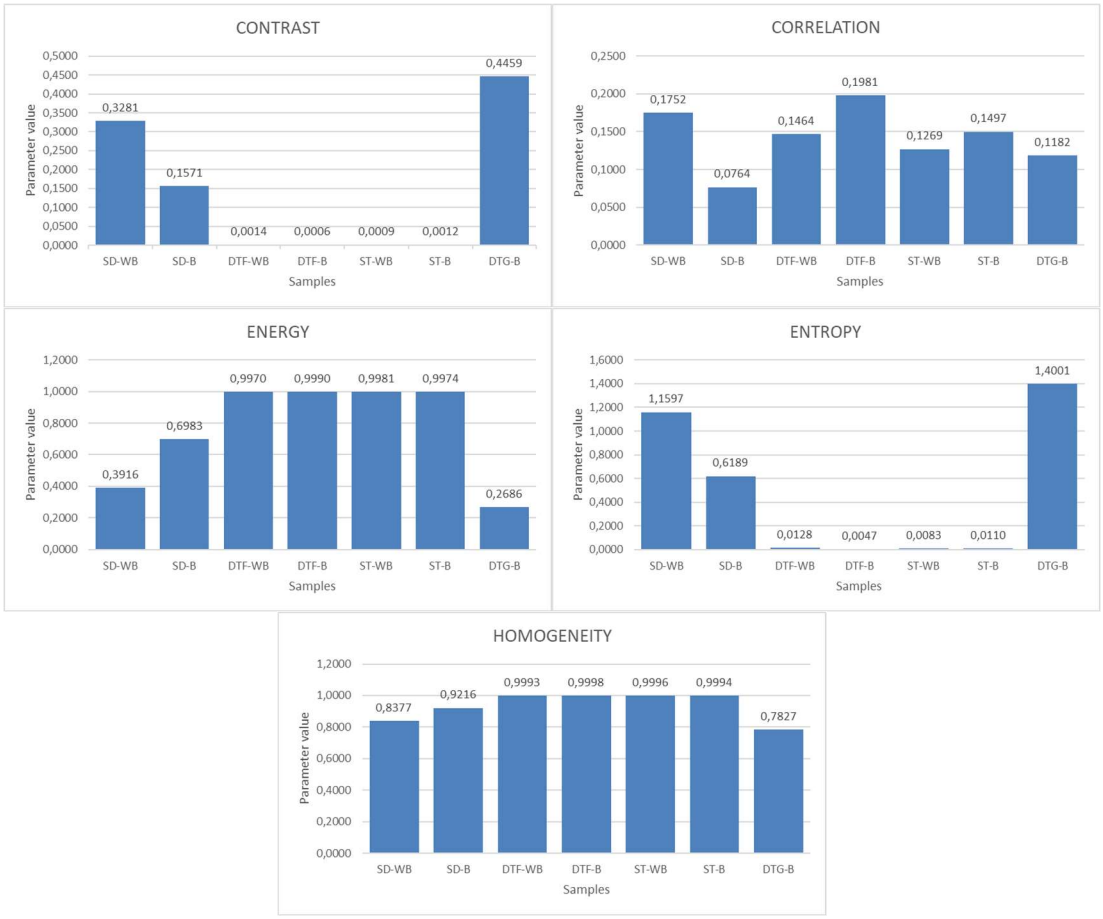


Figure 2: Macro non-uniformity parameters

The macro non-uniformity of the surface is quantified by the macro non-uniformity index, or NU value. Table 3 shows the macro non-uniformity results for the samples, as determined through image analysis with ImageJ software. The optimal macro non-uniformity value is zero; thus, results nearer to zero indicate less macro non-uniformity.

Table 3: Macro non-uniformity results conducted with ImageJ software.

Sample number	Sample label	NU mottle
1	SD-WB	15,6446
2	SD-B	8,5041
3	DTF-WB	1,8236
4	DTF-B	1,8941
5	ST-WB	1,2544
6	ST-B	1,3524
7	DTG-B	16,4383

Figure 3 shows scanned samples prepared for GLCM analysis using MATLAB and ImageJ software.

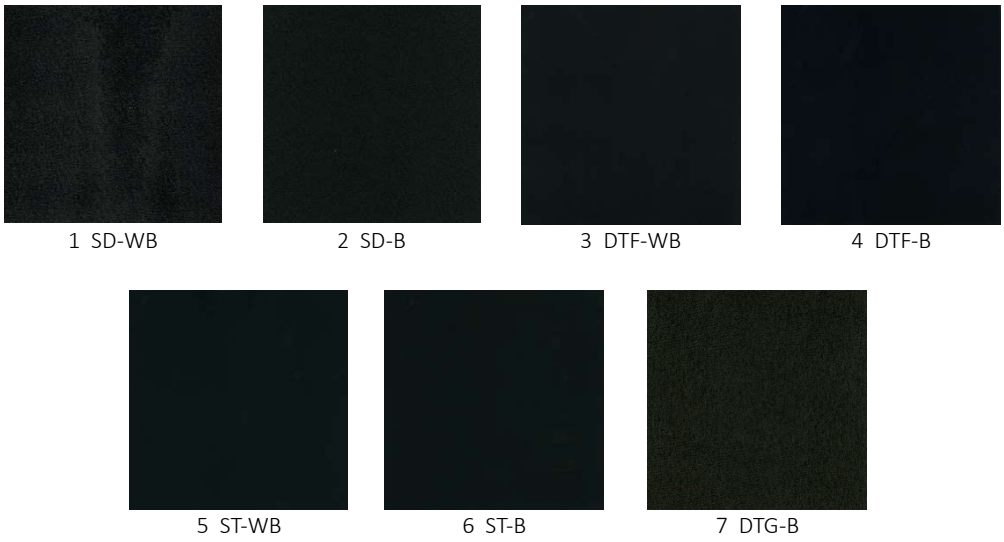


Figure 3: Scaned samples 500 x 500 px

4. DISCUSSION

Reviewing the results of GLCM analysis for different samples reveals clear differences in texture, which can help identify macro-uniformity. Sample 1 SD-WB (0.3281) and Sample 7 DTG-B (0.4459) have the highest contrast values, suggesting sharp transitions between dark and light areas. These samples may be uneven. Samples 3-6 have very low contrast values, indicating an almost uniform surface. All samples exhibit different, but relatively low correlation values. It is expected that there will be variations in correlation values between samples, with the greatest difference occurring between Sample 2 SD-B (0,00764) and Sample 4 DTF-B (0,1981), indicating greater variations in surface uniformity.

Energy is inversely proportional to entropy. Samples 3-6 have very high energy (close to 1), indicating that these samples are highly uniform. Sample 7 DTG-B (0.2686) and Sample 1 SD-WB (0.3916) have lower energy, suggesting fewer uniform textures. Sample 7 DTG-B (1.4001) and Sample 1 SD-WB (1.1597) have high entropy values, indicating a more complex and unpredictable texture. This is a classic sign of uneven surfaces. Samples 3-6 have very low entropy values, suggesting a very simple, uniform surface.

Samples 3-6 have nearly perfect homogeneity (close to 1), confirming that these surfaces are consistent. Sample 7 DTG-B (0.7827) and Sample 1 SD-WB (0.8377) have lower uniformity values, indicating some variation in texture.

Considering the NU values from Table 3, it is evident that Samples 1 SD-WB, 2 SD-B, and 7 DTG-B have very high surface non-uniformity values, which characterise them as having significant surface unevenness and texture complexity. In contrast, Samples 3 DTF-WB, 4 DTF-B, 5 ST-WB, and 6 ST-B have relatively low and uniform values, indicating that they are quite consistent and even.

5. CONCLUSION

Samples 1 SD-WB and 7 DTG-B show high values for both contrast and entropy, indicating unevenness and macro-nonuniformity. Samples 3-6 are very uniform, with low contrast, high energy, and low entropy, suggesting that their surfaces are quite consistent. Samples 3-6 have very low values for contrast and entropy, along with high values for energy and homogeneity, which indicates high macro-uniformity and simple textures. Sample 7 DTG-B has the highest entropy, the lowest homogeneity, and the highest contrast, indicating the greatest surface unevenness and texture complexity.

Summarising all of the above, the following conclusion can be drawn: Printing techniques that use transfer foil (such as screen transfer and DTF) in samples 3-6 yield consistent results in terms of macro non-uniformity parameters. It can be concluded that the method of transferring images and fixing the ink through temperature and pressure, which is common to both screen transfer and DTF techniques, plays a significant role in achieving favourable results regarding macro non-uniformity. In contrast, direct printing

techniques that use hot air drying or fix the ink through temperature and pressure tend to leave surface irregularities caused by the weaving of the cotton fabric. Consequently, the direct printing method exhibits poor macro non-uniformity results and leads to a pronounced print mottle effect, which can negatively impact colour reproduction quality.

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INVESTIGATION OF THE IMPACT OF CHEMICAL AGENTS AND SUBSTRATES ON THE STABILITY OF THERMOCHROMIC PRINTING INKS

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Abstract: *This research aims to analyse the chemical stability of thermochromic (TC) prints to determine which substances affect the TC effect and which parameters contribute to their better stability. Two different types of paper were chosen: synthetic and bulky, each distinguished by its unique chemical composition and absorbency characteristics. This study employed two TC inks based on leuco dyes-a 45°C activation temperature offset TC ink and a 31°C activation temperature TC screen printing ink. The offset TC printing ink dries through oxidative polymerisation, whereas the screen printing TC ink dries using UV radiation. Following printing, the samples underwent a chemical stability test in accordance with the ISO 2836 standard by employing water, ethanol, oil, and alkali. From the obtained results, we can conclude that the printing substrate significantly affects the stability of the TC ink. Samples printed on bulky paper were found to be less stable compared to those printed on synthetic paper. The paper's structure enables bulky paper to absorb more ink and chemicals, thereby accelerating the degradation of the TC ink. The greatest impact on the TC ink was shown by samples exposed to alkali printed with offset TC ink, while a slightly lesser impact was observed on samples printed with screen printing TC ink and exposed to oil and ethanol. UV TC inks require special drying conditions and drying units, while TC inks that dry by oxidative polymerization require an adequate air source and fewer conditions, making them cheaper. All these parameters ultimately define the cost of the product itself and the profitability of the entire printing process. The results of this study show that it is necessary to consider the type and purpose of the product itself and accordingly choose the appropriate TC ink and substrate for printing.*

Key words: thermochromic printing inks, chemical stability, bulky paper, synthetic paper

1. INTRODUCTION

Thermochromic inks have two primary applications: functional and promotional. In the functional application, thermochromic inks display the current temperature, while in the promotional application, a specific hidden message becomes visible or shelf presence is enhanced at the activation temperature (Bamfield, 2010; Homola, 2008; Thamrin et al., 2022).

As with all other inks, the application of thermochromic inks depends on the type of substrate used. Additionally, the method and type of printing used to apply the ink to the product must be considered (Kulčar et al., 2022; Rožić et al., 2016).

For a wide range of substrates such as cardboard, flexible or rigid plastics, other plastic products, and coated papers, flexographic and screen printing are used to apply UV thermochromic inks or solvent-based thermochromic inks, which exhibit good resistance to abrasion (WRAP, 2020).

Water-based thermochromic inks are used on absorbent printing surfaces and can be applied by flexographic, gravure, or screen printing methods. Thermochromic inks based on leuco dyes are very easy to apply, and the printing process is almost indistinguishable from other packaging inks.

Printed thermochromic inks can last for years while undergoing colour changes; however, excessive exposure to UV radiation will negatively impact the longevity of the printed ink. UV sensitivity is one of the main reasons why thermochromic inks are not used in advertising posters or the automotive industry. Additionally, as with other inks, aggressive solvents and extremely high temperatures of 120°C or more negatively affect the durability of thermochromic inks. Thermochromic inks are as durable as other inks if they are not exposed to high temperatures and prolonged UV radiation (Vukoje, Huzjak & Kulčar, 2022; Friškovec, Kulčar & Gunde, 2013).

As previously mentioned, the printing substrate can significantly impact the thermochromic print's stability. This can be particularly noticeable due to certain external factors that may negatively affect the print and thus impair the thermochromic colour-changing effect. Therefore, for this study, the stability of the thermochromic ink was tested on two different printing substrates, synthetic and bulky paper.

Synthetic papers consist of fibers similar to paper fibers but made from synthetic resin, serving as a substitute for conventional papers made from interwoven cellulose fibers. In many cases, the synthetic

ORCID numbers are provided at the end of the paper.

resin used to make synthetic paper is treated to impart paper-like characteristics. The porous structure gives synthetic paper properties very similar to those of paper made from cellulose pulp but significantly reduces its mechanical properties. Bulky papers are more environmentally friendly, provide satisfactory quality, are cheaper, contain no fluorescent whitening agents, and have a high proportion of mechanical pulp. Due to their low grammage, they reduce the overall weight of the finished product and lower transportation costs.
A chemically stable print is one in which no significant change in the print occurs when exposed to certain chemical substances. Chemical changes can manifest as changes in colour, fading, reduction in the mechanical properties of the ink and substrate, and other factors.
The international standard ISO 2836:2021 in graphic technology specifies methods for evaluating the resistance of printed materials to liquids, solids, solvents, varnishes, and acids (ISO, 2021).
This research aims to analyze the chemical stability of prints with thermochromic inks to determine which substances affect the thermochromic effect, which is a crucial factor when such inks are used as indicators on packaging. The goal is to identify which type of paper is preferable and, considering the different chemical compositions of dyes, to determine which are more chemically stable. It is expected that some substances used for chemical stability will have a lesser impact, while others will have a greater effect on the thermochromic effect. Additionally, it is hypothesized that UV inks might be more chemically stable.

2. METHODS

2.1 Materials

This study selected two printing surfaces: synthetic and bulky paper. Synthetic Yupo paper, weighing 73 g/m², is extruded from polypropylene pellets, while bulky Munken Print White paper, weighing 80 g/m², contains more than 10% mechanical pulp. The selected papers differ in their chemical structure and absorbency.
The prints were made with two commercially available thermochromic inks, one intended for offset printing and the other for screen printing technique. An offset thermochromic printing ink based on leuco dyes with an activation temperature of 45°C (CTI45) was used. This ink changes colour from green to yellow above the activation temperature. The other ink used was a thermochromic screen printing ink based on leuco dyes with an activation temperature of 31°C (CTI31). This ink changes colour from purple to pink above the activation temperature.

2.2 Printing

The thermochromic offset printing ink was printed on a Prüfbau MZ II multipurpose printing machine, while the thermochromic screen printing ink was printed on a semi-automatic screen printing machine Siebdruckgeräte von Holzschuher K.G., Wuppertal, through a polyester mesh 60/64Y. Both inks were printed in full tone.
The thermochromic offset printing ink dries by oxypolymerization, while the thermochromic screen printing ink dries using UV radiation, and its drying was carried out in a UV dryer Akrilprint L (Technigraf, Germany).

2.3 Conducting the Chemical Stability Test

The international standard ISO 2836 for graphic technology specifies methods for evaluating the resistance of printed materials to liquid and solid agents, solvents, varnishes, and acids. The ISO 2836 standard can be applied to all printing surfaces produced using conventional printing techniques, as well as digital methods such as inkjet, electrophotography, and others, utilizing materials suitable for the respective printing technique.
The samples were exposed to four substances – water, alcohol, oil, and alkali. Each sample was exposed to these substances according to the procedure specified in the international ISO 2836 standard in graphic technology. These substances were chosen for testing chemical stability due to their frequent contact with packaging products in everyday life (ISO, 2021).
For the chemical stability test with water, distilled water was used. The printed paper sample was placed between four layers of filter paper previously soaked in water, two on top and two on the bottom. Then the sample with the soaked filter papers was placed between two glass plates, dimensions 2.5 cm x 7 cm x 0.2 cm and weighed 1 kg. The samples were left in this state for 24 hours at room temperature.

The chemical stability tests with oil, using aromatic olive oil, and alkali, a 1% solution of sodium hydroxide (NaOH) dissolved in distilled water, were conducted in the same manner as the water stability test. The sample exposed to olive oil was left at room temperature for 24 hours under 1kg of pressure, while the sample exposed to alkali was left under 1 kg of pressure at room temperature for 10 minutes. The sample exposed to alkali was rinsed in distilled water until a neutral pH was achieved before drying.
For the ethanol resistance test, the printed samples of 6 cm^2 area were placed in the test tube filled with the solvent to half of its height, for 5 minutes at 23 ± 2°C.
After conducting the chemical stability tests, all samples were dried in a drying chamber at a temperature of 40°C. Samples exposed to water, oil, and alkali were dried for 30 minutes, while samples exposed to alcohol were dried for 10 minutes in the drying chamber.

2.4 Colorimetric Measurements

Colorimetric properties were measured using a previously calibrated Ocean Optics USB 2000+ spectrophotometer and the Ocean View software. The device uses an integrating sphere ISP-50-8-R-GT. Measurements were taken from 400 nm to 730 nm at 1 nm intervals by the (8°:di) measurement geometry. Colorimetric values were measured at temperatures of 15°C, at the activation temperature depending on the sample, and at 55°C. The measured values included CIE *L*, a*, b*,* and *C*,* from which the CIEDE2000 value was also calculated.
The samples were heated on a copper plate coated with a layer of nickel to ensure durability and even heat distribution, allowing for more precise measurements. This setup also enabled the maintenance of a constant temperature and gradual heating to the next set temperature on the device. The heater warms the liquid to the set temperature, which circulates through the system to heat the copper plate and, consequently, the sample on it. Measuring colorimetric values at different temperatures allows for the assessment of specific characteristics of thermochromic inks.

3. RESULTS AND DISCUSSION

Spectral reflectance curves were measured at three different temperatures: 15°C, the activation temperature depending on the sample (31° or 45°C), and 55°C. Reflectance was measured on two printing substrates, synthetic and bulky paper, and on samples exposed to alkali, ethanol, water, and oil, compared to unexposed original samples. Samples marked as CTI31 on the graph transition from purple to pink at an activation temperature of 31°C, while samples marked as CTI45 on the graph transition from green to yellow at an activation temperature of 45°C. Based on the results, the spectral curves were obtained and are shown in Figures 1 to 4.

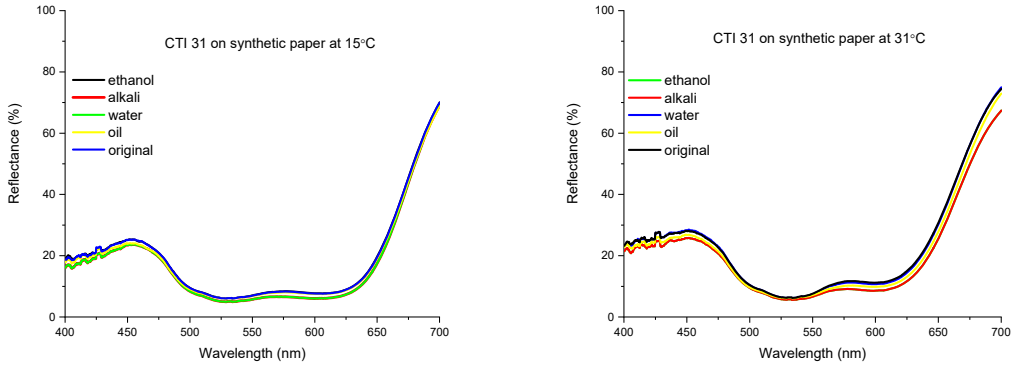


Figure 1 (part 1): Spectral reflectance curves of CTI31 measured at three different temperatures on synthetic paper

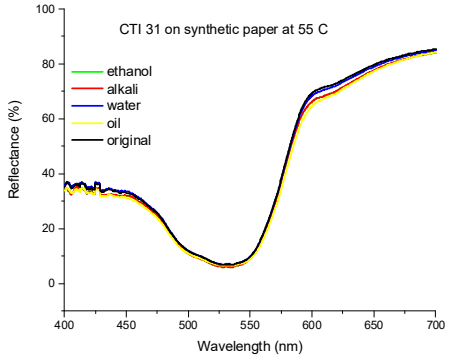


Figure 1 (part 2): Spectral reflectance curves of CTI31 measured at three different temperatures on synthetic paper

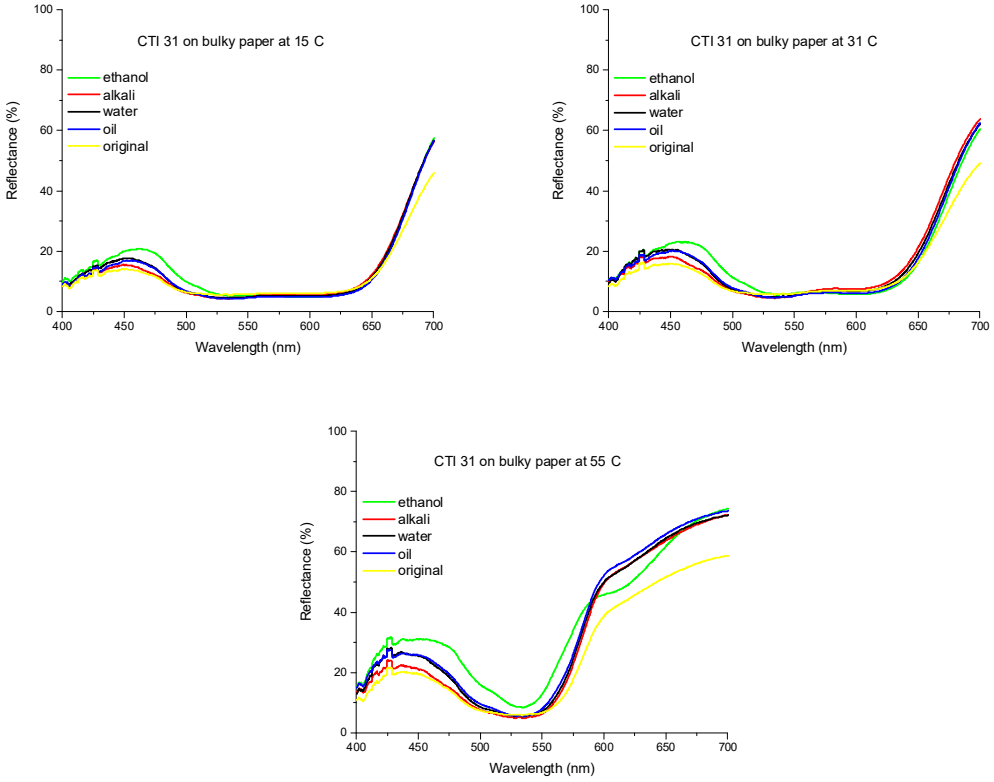


Figure 2: Spectral reflectance curves of CTI31 measured at three different temperatures on bulky paper

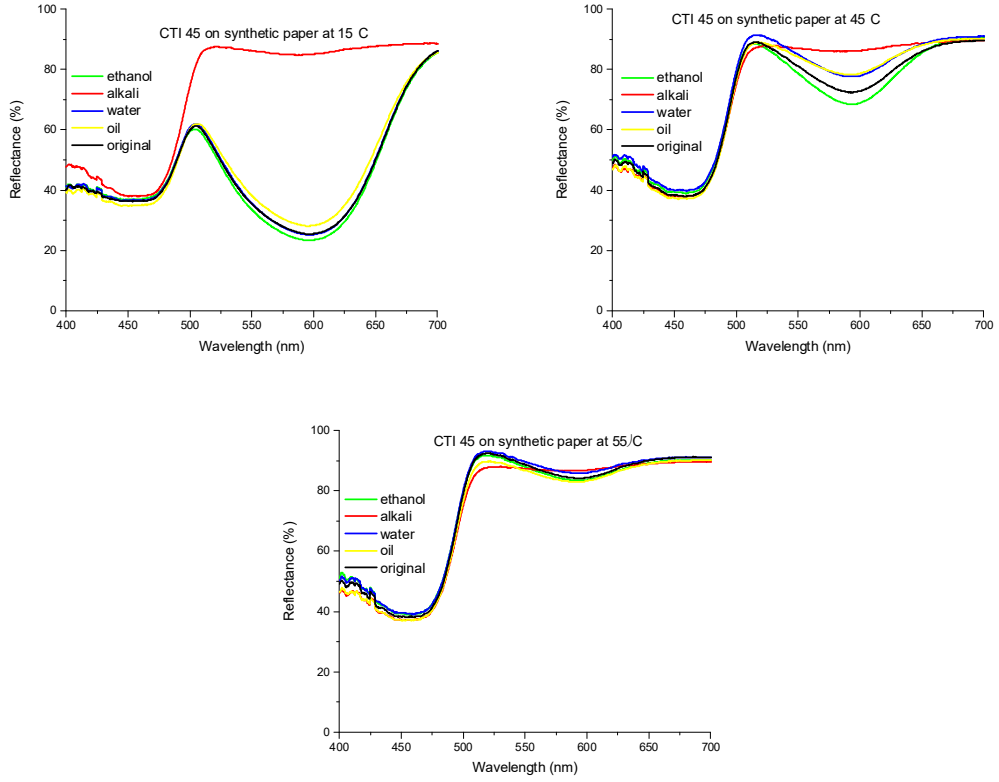


Figure 3: Spectral reflectance curves of CTI45 measured at three different temperatures on synthetic paper

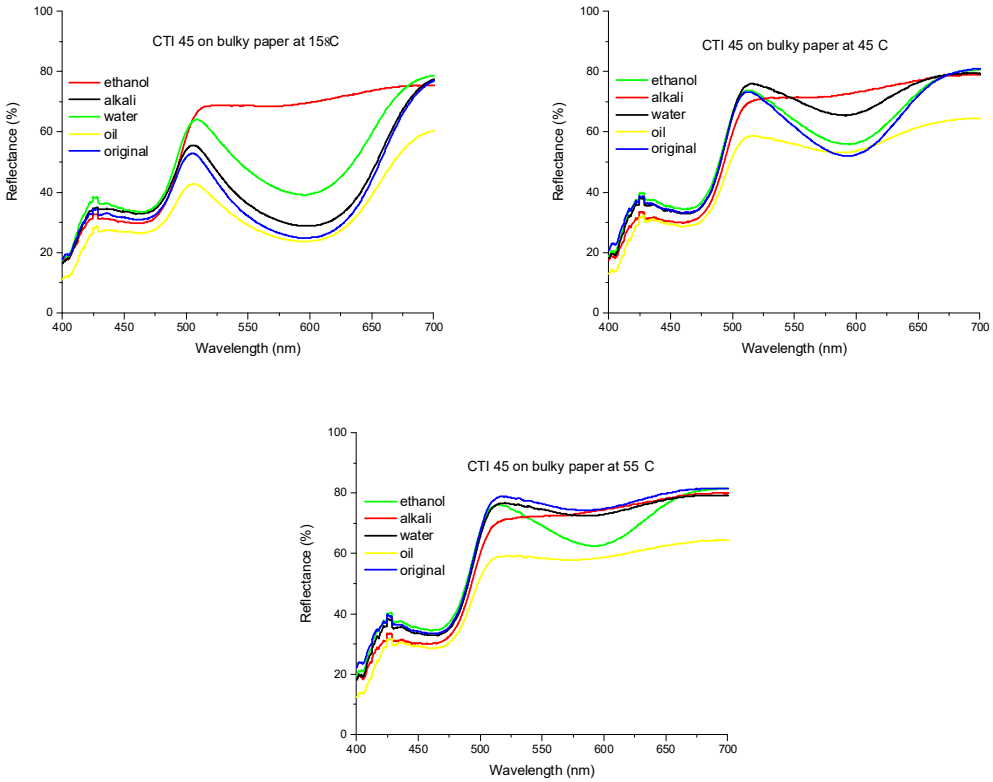


Figure 4: Spectral reflectance curves of CTI 45 measured at three different temperatures on bulky paper

Samples printed with screen printing thermochromic ink at an activation temperature of 31°C transition from purple to pink (Figures 1 and 2), and at 55°C they completely exhibit a pink coloration.
Samples printed with screen printing thermochromic ink on bulky paper show greater deviations in samples exposed to oil (Figure 2, yellow), whereas samples printed on synthetic paper show no significant deviations compared to the original samples (Figure 1). Greater deviations are also observed in samples exposed to ethanol and printed with screen printing thermochromic ink on bulky paper (Figure 2, green) compared to those printed on synthetic paper (Figure 1, green).
Samples printed with offset thermochromic ink at an activation temperature of 45°C transition from green to yellow (Figures 3 and 4). The greatest deviations were observed in samples exposed to alkali (Figures 3,4, red) and at the activation temperature (Figure 3,4, red), suggesting that the alkali may have degraded the thermochromic ink properties. Deviations are also noticeable in samples exposed to oil on bulky paper at the activation temperature (Figure 4, yellow) and above the activation temperature (Figure 4, yellow).
It can be observed that the spectral reflectance curves differ between synthetic and bulky paper. Samples printed with screen printing thermochromic ink on bulky paper (Figure 2) exhibit lower reflectance than samples printed on synthetic paper (Figure 1). This observation is also noted for samples printed with offset thermochromic ink (Figures 3 and 4).
The results suggest that the printing substrate affects the stability of the thermochromic ink. Samples printed with screen printing thermochromic ink show greater stability after exposure to certain chemicals than samples printed on bulky paper.

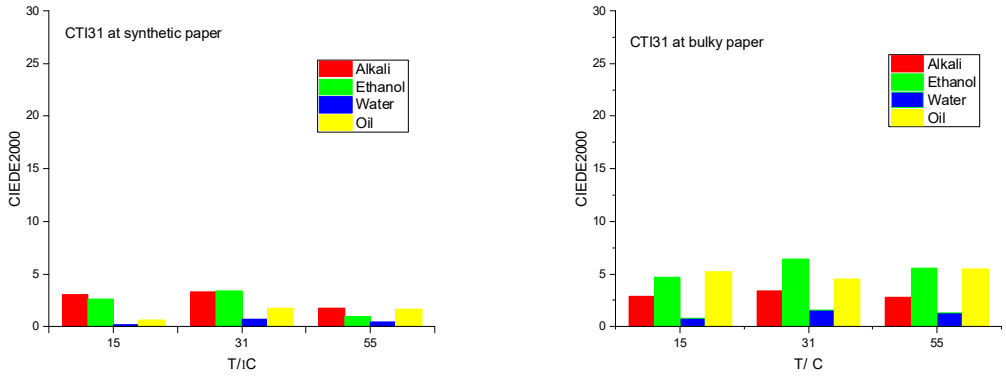


Figure 5: CIEDE2000 colour difference observed on CTI31 samples when exposed to different chemicals

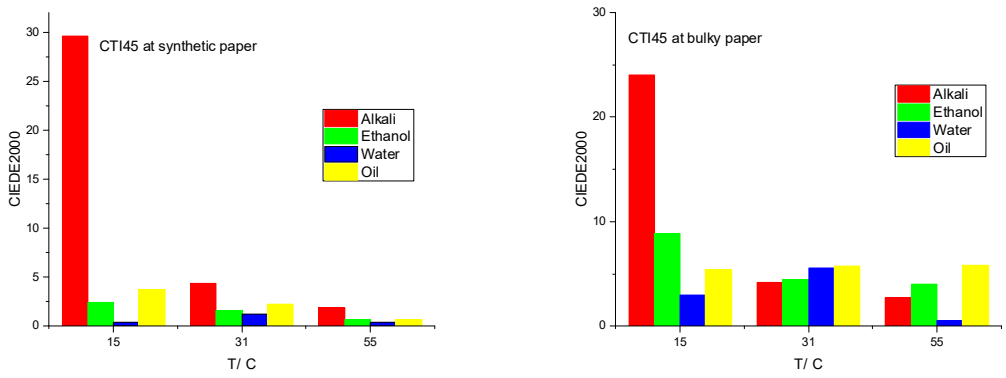


Figure 6: CIEDE2000 colour difference observed on CTI45 samples when exposed to different chemicals

For samples printed with purple thermochromic ink (CTI31), the greatest colour difference was observed in samples exposed to ethanol and alkali, while the smallest colour change was noted in samples exposed to water (Figure 5). For green thermochromic ink (CTI45), the most significant change was observed in samples exposed to alkali, whereas smaller changes were noted in samples exposed to oil (Figure 6).

Greater colour differences were observed in samples printed with green thermochromic ink compared to purple, and in samples printed on bulky paper compared to synthetic paper.
Based on the results, it can be concluded that the printing substrate significantly impacts the stability of thermochromic inks. Samples printed on bulky paper were found to be less stable compared to those printed on synthetic paper. This instability is attributed to the paper's structure, which allows the bulky paper to absorb more of the ink and the chemicals to which it is exposed, leading to faster and easier degradation of the thermochromic ink.

4. CONCLUSION

The objective of this study was to determine which type of paper is preferable and to assess which types of dyes are chemically more stable given their different chemical compositions.
The samples were exposed to four substances: water, oil, ethanol, and alkali. The greatest impact on the thermochromic ink was observed in samples exposed to alkali and printed with offset thermochromic ink, while a slightly smaller impact was noted in samples printed with screen printing thermochromic ink and exposed to oil and ethanol. This is likely due to the drying method of the thermochromic ink. UV-cured inks showed better stability against the exposed substances compared to inks dried by oxy polymerization, as the microcapsules are protected by a polymeric binder.
UV thermochromic inks require specific drying conditions and units, while thermochromic inks that dry by oxy polymerization demand less air supply and fewer conditions, making them more cost-effective. All these parameters ultimately define the cost of the product and the efficiency of the printing process. The results of this investigation suggest that the type and purpose of the product must be considered when selecting the appropriate thermochromic ink and substrate for printing.

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EVALUATION OF TEXTILE PRINTS PRINTED WITH INKJET PRINTER

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Abstract: *In the rapidly evolving textile printing industry, it is critical to understand the impact of substrate properties on print quality. This study objectively compares the print quality and geometric deformations of typographic elements on paper and textile substrates using a large format inkjet printer. We evaluated print non-uniformity and geometric deviations by analysing prints on Microporous Satin Photo Paper and Blackout VI DirectTex textile fabric. Our analysis, conducted using ImageJ software, revealed that the textile substrate had significantly higher NU values and greater variations in both the area and perimeter of the typographic elements compared to the paper substrate. These deviations are attributed to the textured, uneven surface of the textile, the higher thread density and the greater bleeding of the ink, while the smoother paper substrate showed more consistent results. This study highlights the importance of substrate properties in assessing print quality and suggests that future research could focus on optimising materials and printing technologies to improve accuracy on different substrates.*

Key words: inkjet printing, printing on textiles, textile structure properties, quality of prints

1. INTRODUCTION

In modern society, where aesthetics are just as important as the materials used, textile printing has become increasingly popular. It is often used for clothing, home décor, signage and technical textiles. With the rapid growth of the textile printing industry, we now face many challenges. Unlike printing on paper, there are many different variables when printing on textiles, such as the type of fabric, weave or knit structure, thickness and surface finish, all of which have a significant impact on the final print quality.
Advances in digital printing, print head technologies and ink and dye formulations have made digital printing the dominant technique for textile printing. Several manufacturers are introducing new models of inkjet printers that offer higher productivity and faster single-pass printing (Digital Textile Printer, 2024).
Print quality is influenced by numerous factors, such as printheads, inks or dyes, coatings, print settings (speed, resolution, colour management), and the most important factor - the printing materials used. Although the final prints are often compared visually, this method is subjective and is influenced by lighting, room conditions and personal perception. Relying solely on visual judgement can lead to inaccurate conclusions. For this reason, it is important to analyse the print quality objectively. This takes into account various data such as speed, resolution, ink consumption and colour accuracy, which are essential for an accurate comparison. Objective analysis ensures more accurate assessments and helps to determine the best printing device and settings for specific requirements. It is advisable to use standardised test forms or user-created custom forms to systematically evaluate and measure specific attributes or performance criteria (Schilling, 2023).

2. EXPERIMENTAL

In our study, we compared the final prints on paper and textile printing materials to objectively evaluate the differences between the materials and to determine how the basic properties of the textile printing material affect the final prints compared to those on paper.
The paper printing material used was Microporous Satin Photo Paper. This is a one-side coated, semi-gloss paper with a grammage of 195 g/m² (Figure 1) (Papergraphics, 2024).
Blackout VI DirectTex (Pongs, Germany) was chosen as the textile printing material. This is a PVC-free fabric made of 100% polyester (PES) with a grammage of 330g/m². The fabric has a bright white front side and a dark grey back side, which prevents light from shining through (Figure 1) (Pongs technical textiles, 2011).
We analysed the textile substrate in detail and found that it uses multifilament yarns in a woven construction with two weft yarns in a 1:1 sequence, consisting of a reinforced satin with 7 ends on the front and a weft satin with 14 ends on the back. The front side has a thread density of 597 threads per 10 cm in

ORCID numbers are provided at the end of the paper.

the warp and 275 threads per 10 cm in the weft, with the warp threads having an average diameter of 170 µm and the weft threads 340 µm.
The higher thread density reduces the open areas and increases the surface density. The floating threads of the satin weave can affect ink bleeding and wicking, which can lead to smudged or blurred prints. The front side has an inkjet coating to smooth the surface and improve print quality (Mendizza, 2024).



Figure 1: Selected printing materials; paper substrate on the left, textile substrate on the right

The imagePROGRAF PRO-4000S is a large-format inkjet printer designed for the poster and signage industry. Both selected printing materials are compatible with this printer. The Fiery XF RIP (raster image processor) was used to calibrate and manage the colours of the printer and the selected printing materials. In order to objectively compare the final prints, we created our own test form with different elements. It included a 100 × 100 mm square with 100% black coverage, lines of different widths and various typographic characters.

3. RESULTS WITH DISCUSSION

3.1 Non-uniformity of prints

Using image analysis, we performed a print non-uniformity (NU) analysis for a 100% coverage black area in the form of a 100 × 100 mm patch. The images were captured with an optical scanner and analysed with ImageJ software. We used a plugin described and developed in the study by Muck and colleagues (Muck, Hladnik, & Stanić, 2009). A higher NU value indicates greater print non-uniformity. The NU value is calculated from the difference between the average pixel intensity above the median (Ux) and the average pixel intensity below the median (Lx). As part of the image analysis, we also created the histograms of the captured images, which show the print non-uniformities of the width of the area in the graph.
Table 1 shows the NU values for the selected materials. The NU value for the digitally designed colour patch is 0, while it is quite high for the textile material (24.2119) and significantly lower for the paper (3.7912). We expected the NU values to be higher for the textile material due to its much rougher surface compared to the glossy coated paper. Figures 2 show the printed patches captured with an optical scanner together with the corresponding histograms. The higher NU value is visible in the scanned images and is also illustrated by the histograms, with the histogram for the textile image covering a larger area than that for the paper.

Table 1: NU values for selected materials

Material	NU value
Digitally designed colour patch	0.0000
Paper	3.7912
Textile	24.2119

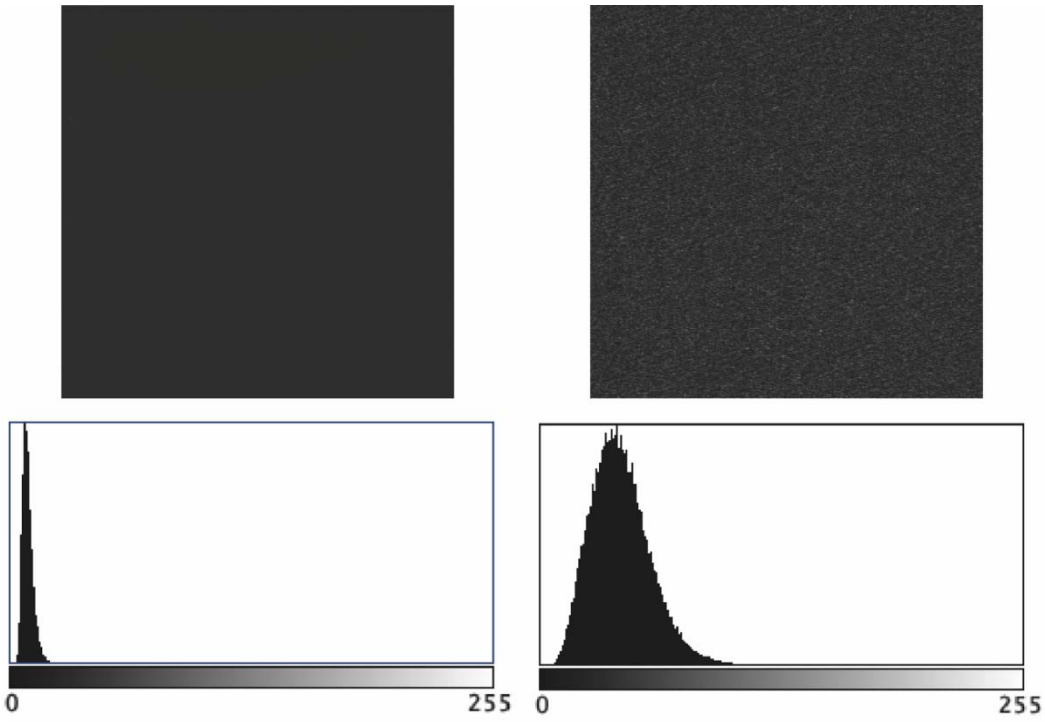


Figure 2: NU for paper substrate on the left and textile substrate on the right, with associated histograms

3.2 Geometric deformations of typographic elements

Using a digital magnification device with the same settings, we photographed the same typographic elements on both substrates in order to analyse the image. The typographic elements were the lowercase letter n in Helvetica font, size 20 pt, and the number 7 in Helvetica font, size 17 pt, both in horizontal and vertical layout and in positive and negative print (Table 2). Using image analysis, we measured the area and circumference of these elements, compared them with the digitally designed ones, and calculated the corresponding deviations (Tables 3–4).

The analysis of the results in Tables 3 and 4 showed significant deviations for both positive and negative print types on the textile substrate. The deviations on the paper substrate were smaller, as expected due to the smoother surface. The areas of the negative prints on both substrates were smaller than those of the digitally designed. The horizontal prints were larger than the vertical prints on both substrates, which we attribute to the warp direction of the fabric and the higher thread density in the textile substrate, as well as the orientation of the fibres in the paper substrate.

The deviation of the in circumference for both typographic elements was higher on the textile substrate, with larger values for the vertical position observed for in both positive and negative print types. The image analysis distinguishes precisely between dark prints and light backgrounds and detects even the smallest changes in the outlines of the elements. The difference was less pronounced on the paper substrate. In the textile substrate, there was a stronger ink spread in the direction of the warp, where the thread density is higher. This was evident when analysing both the lowercase letter n and the number 7.

Table 2: Images of horizontally and vertically printed positive and negative lowercase letters n in Helvetica font, size 20 pt, and number 7 in Helvetica font, size 17 pt, on paper and textile

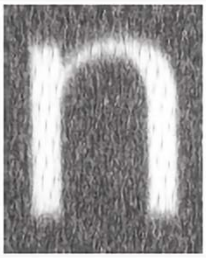
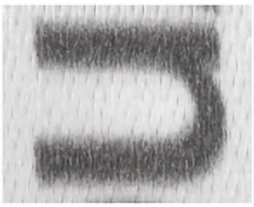
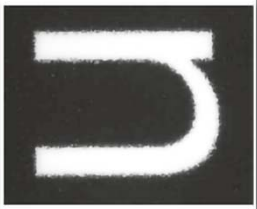
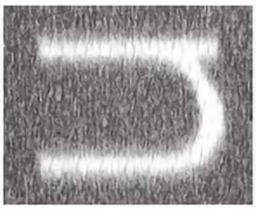
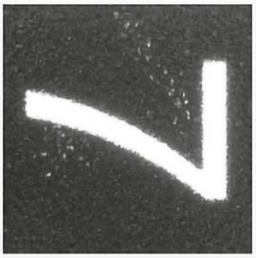
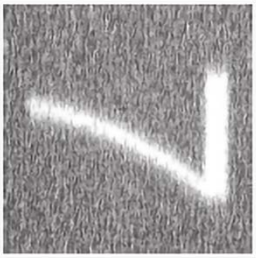
	Printing materials			
	Paper	Textile	Paper	Textile
Digitally defined typographic element				
Horizontal direction				
				
Vertical direction				
				

Table 3: Digital and measured values of area (A) and circumference (C) of lowercase letter n in Helvetica font, size 20 pt, with corresponding deviations (Δ)

	Layout and type of print	A [mm^2]	ΔA [mm^2]	C [mm]	ΔC [mm]
Digitally designed typographic element	/	5.47	/	19.70	/
Paper	horizontal, positive	5.73	0.26	23.13	3.43
	horizontal, negativ	4.86	–0.61	25.36	5.66
	vertical, positive	5.80	0.33	26.76	7.06
	vertical, negativ	4.56	–0.91	23.88	4.18
Textile	horizontal, positive	6.44	0.97	33.29	13.59
	horizontal, negativ	4.48	–0.99	37.26	17.56
	vertical, positive	7.74	2.27	52.84	33.14
	vertical, negativ	3.45	–2.02	58.78	39.08

Table 4: Digital and measured values of the area (A) and circumference (C) of the number 7 in Helvetica font, size 17pt, with corresponding deviations (Δ)

	Layout and type of print	A [mm^2]	ΔA [mm^2]	C [mm]	ΔC [mm]
Digitally designed typographic element	/	3.53	/	15.47	/
Paper	horizontal, positive	3.78	0.25	21.07	5.60
	horizontal, negativ	3.23	–0.30	18.92	3.45
	vertical, positive	3.60	0.07	17.77	2.30
	vertical, negativ	3.19	–0.34	18.06	2.59
Textile	horizontal, positive	4.46	0.93	29.65	14.18
	horizontal, negativ	2.96	–0.57	42.01	26.54
	vertical, positive	3.98	0.45	26.27	10.80
	vertical, negativ	2.54	–0.99	35.64	20.17

4. CONCLUSION

In this study, the print quality and geometric deformations of typographic elements on paper and textile substrates were analysed using a large-format inkjet printer. The aim of the analysis was to objectively evaluate the differences between these materials and to understand how their basic properties influence the final print quality.

Our results show significant differences in print non-uniformity (NU) and geometric deformations between the substrates. The textile substrate had a much higher NU value compared to the paper substrate, reflecting the more uneven surface and greater variability in print quality. This was to be expected due to the textured surface of the textile and the effect of the multifilament yarns, which lead to greater ink bleeding and wicking.

As far as the geometric deformations are concerned, both the area and circumference of the typographic elements were significantly influenced by the type of the substrate. The deviations from the digitally designed typographic elements were more pronounced on the textile substrate, with the horizontal prints showing greater deviations than the vertical ones. This phenomenon is attributed to the higher thread density and warp direction of the textile, which influence ink bleeding and print accuracy. On the other hand, the paper substrate showed more consistent results with less deviation due to its smoother and more even surface.

Overall, the study emphasises the importance of considering the characteristics of the substrate when assessing print quality. While digital magnification devices and objective analysis methods provide valuable insights, the inherent properties of the printing material—such as surface texture and thread density—play a crucial role in determining the final print quality.

Future work could further investigate how different types of materials, coatings and printing technologies could mitigate these issues and improve print accuracy on different substrates.

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ENVIRONMENTALLY FRIENDLY WATER-BASED INKJET INK PRODUCTION AND DETERMINING PRINTABILITY

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Abstract: *Inkjet printing system, one of the digital printing systems, has a more widespread market day by day due to its low operating costs and allowing variable data printing. Bio-based inks, in which natural polymers are used and whose solvent is water, are attracting more and more attention both in the food industry and other industries, in order to reduce the decrease in oil resources and possible harm to environmental and human health. Polymers that can be used in naturally sourced inks include cellulose, starch, polylactic acid, polyvinyl alcohol, and cellulose derivatives. In this study, water-based ink was prepared with magenta pigment as a colorant and hydroxyethyl cellulose, a natural polymer as a binder, and printed with thermal inkjet, and its printability properties were examined. For this purpose, the study started with the preparation of ink. In ink production, first, a binder was prepared with hydroxyethyl cellulose and water. 6.5% magenta pigment was added into the prepared binder. The viscosity of the ink was adjusted to 9 cP using pure water. Since the colorant used is water-soluble, there is no need for a surfactant. Surface tension was adjusted to 31 mN/m with 3 drops of BYK 348. Test prints were made with the obtained ink using the BENTSAI BT-HH6105B1 Portable Handheld Mobile inkjet printing machine. The most stable prints were obtained at 1 m/s speed, 300 dpi resolution and 11 volt printing parameters. The color measurements of the obtained prints were measured with an X-Rite spectrophotometer and their gloss was measured BYK Gardner gloss meter. As a result, it was determined that stable ink with good printability parameters was produced in thermal inkjet.*

Key words: inkjet ink, printability, natural ink, water-based ink, thermal inkjet

1. INTRODUCTION

Inkjet printing is a printing method that creates an image by rapidly directing small droplets or particles onto a substrate surface. There are two distinct methods of creating and transferring droplets; continuous inkjet and drop on demand inkjet. Continuous inkjet is a continuous jet of ink that is forced out of a small nozzle under pressure. Under these conditions, a jet of liquid tends to break up into a stream of droplets of a size and frequency determined primarily by the surface tension of the liquid (Leach, 2012). Since inkjet is a versatile technology and the range of inks is so wide, almost any surface can be printed on; however, paper is more commonly used as the most widely used substrate in the graphics and printing industry. Most inkjet inks are highly surface-active and penetrating. The quality of the print depends on both the ink properties (surface tension and viscosity) and, to a large extent, the absorption properties of the substrate (surface tension, roughness, and porosity) (Svanholm, 2007). It is used for industrial applications where it is ideal for printing information such as batch numbers and date marks on products with rough or uneven surfaces, especially in mass production. Continuous inkjet is increasingly popular for on-line naming and addressing printing on high-speed presses. It is called by this name because the droplets are continuously produced regardless of the printed or unprinted area and the droplets in the areas that should not be printed are returned to the ink tank. The production of droplets is based on the principle of stimulating the spray liquid by destabilization (mixing) in a controlled manner. In continuous ink jet systems, as mentioned above, the jetting is made unstable, and the ink moves in controlled droplets with the vibration movement. The structure, physical and chemical properties of the ink are very important for the droplets to be consistent as desired and then for the required charging process. In DOD inkjet systems, ink droplets are produced only for the areas that need to be printed, and again these droplets move with a pressure ejection mechanism. This mechanism is the characteristic feature of DOD systems. It has a very wide area of use regardless of outdoor or indoor and has the ability to work with different printing materials. The most prominent drop on demand technologies are thermal inkjet and piezo inkjet printing. In piezo inkjet, the ink drop is created by mechanically deforming the jet chamber and is ejected from the nozzle; this action is caused by an electronic signal and the piezoelectric properties of the ink chamber (Cao et al., 2024).

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Thermal inkjet printers are one of the most widely used technologies in desktop printers and are widespread in the industry. In this technology, droplets are formed by rapidly heating and localized evaporation of a resistive element in a small area containing the ink (Figure 1). The temperature of the resistive element rises to 350-400°C, causing a thin film of ink on the heater to evaporate. This evaporation rapidly forms a bubble and causes a pressure pulse that forces a drop of ink through the nozzle. The ejection of the drop then leaves a void in the chamber, which is then filled with reserve fluid in preparation for the formation of the next drop.

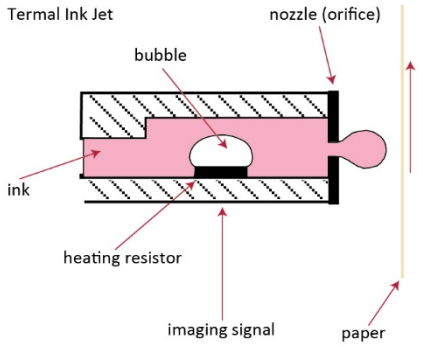


Figure 1: Drop on demand - Thermal ink jet ink system schematic view (Kipphan, 2001)

Thermal inkjet has the potential advantage of producing high nozzle density and very small drop sizes. In this way, more compact devices can be produced and print head costs are more affordable. This advantage is also reflected in unit product costs. On the other hand, the liquids that can be used in ink production are limited compared to other systems. Because the liquid to be used in this system must be more resistant to environmental conditions and temperatures. If the ink is not well designed, environmental factors and unwanted temperatures can cause unwanted situations in the ink tank. This leads to changes in properties such as conductivity and surface energy, efficiency decreases, and the print head can be short-lived. For example, if the functionality of the liquid is damaged due to high temperatures (as in some sensitive liquids and polymers), high temperatures can also cause problems.

Thermal ink jet has different shooters depending on the configuration, one of them is called a roof shooter which has a hole on the top of the heater and is placed behind the heater nozzle, the other is known as a side shooter which has a hole on the side near the heater and is placed together with the heater nozzle. In another configuration, the heater is suspended in the ink chamber (Le, 1998). Most industries manufacture and use roof shooter thermal ink jet (Simske, 2017). The biggest problem with thermal ink jet printhead is its short life due to electromigration of the heater, damage due to bubble cavitation and cracks due to thermal stress (Lim et al., 2005). The life can be increased by increasing the thickness and shape of the heater (Bar-Levav, Witman, & Einat, 2020). Another problem is cogging, a phenomenon in which ink particles accumulate on the heater surface during thermal ink jet operation, affecting the formation of bubbles and droplets. Adding anions to the ink can prevent this phenomenon (Shah et al., 2021).

In inkjet systems, the ink colorant must be immobilized quickly on the substrate surface and separated from the ink carrier. If the ink is absorbed too quickly by the substrate, it can cause a decrease in optical density and therefore a decrease in color intensity in the print. On the other hand, if the ink is not absorbed quickly enough, it can cause color bleeding, edge irregularities and distortions in lines. Therefore, the transfer and placement of the ink on the substrate must be at an optimum level (Svanholm, 2007).

The use of water-based ink in inkjet printing systems is not new. However, solvent-based systems have been widely used for a long time. Today, water-based systems are again coming to the fore with environmental factors, health and legislation. Low toxicity value and the absence of volatile organic compounds are the most important preference criteria. However, compared to solvent systems, drying occurs more slowly in rough-surfaced printing materials, and light fastness values are also low. With these features, it is recommended to be used in indoor printing or lamination can be preferred for protective purposes after printing. However, this also increases the printing cost.

Water-based inks are called by this name because they use water as a carrier, and in some cases, different solvents (that do not produce ozone) can be used. The water ratio in the ink formulation varies between 75-90%. These inks, which have water or a similar carrier, stand out with their lower cost and environmental friendliness compared to their counterparts. In addition to these advantages, they settle more slowly on some substrates, some surfaces may have adhesion problems and drying problems may

occur. In industrial applications where these types of inks are used and durability is at the forefront, lamination is needed to strengthen and reinforce the surface, which can increase the cost.
Water-based inks are also used in flexographic printing systems for printing paper and board materials. Due to the absorbent nature of paper fibers, printing with water on these substrates has been easily achieved. Inks and solvents (including water) are partially absorbed into the substrate and partially evaporate into the surrounding air. However, placing a water-based solution on a film or foil is like putting water on a freshly waxed car: The water beads up and slides around the surface. The surface tension differences between the ink and the substrate - particularly emphasizing the difference between solvent and water-based inks - require the substrate surface tension to be modified to facilitate transfer and adhesion of water-based inks. In addition, components added to the film to give it certain properties can also migrate to the surface and prevent the inks from adhering. Inks need to be resistant to all external influences. Overcoming these obstacles is one of the biggest challenges facing packaging printers who choose to use water-based inks and coatings.
The average water-based inkjet printing ink components are as follows; pigment or dye as a colorant is 2-5%, surfactants or additives are also at the same rate of 2-5%, ethylene glycol or diethanolamine as a moisturizing agent is around 30% and the remaining 65% consists of water. Viscosity is in the range of 2-5 cp and surface tension is 30-40 dyne/cm (Svanholm, 2007). While colorants are more prominent in other printing systems, colorants in inkjet ink can be both pigment and dye. We can explain this situation by the ability to print on very different substrates with these systems. The difference between these two colorants is that the dye is completely dissolved in the carrier, while the pigment is found as very small particles homogeneously distributed in the carrier (Figure 2). Both colorants are widely used in industrial applications (Marie et al, 2013).

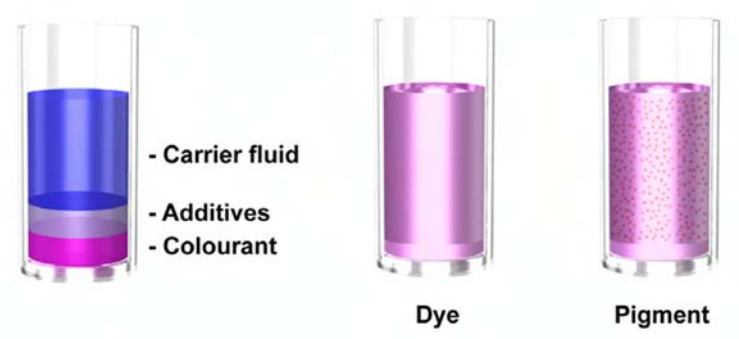


Figure 2: Inkjet ink colourants

For an ink formulation, the required rheological properties must first be provided. The ideal rheological properties required for an inkjet system are a (static) Newtonian ink viscosity between $\eta = 3$ and 40 mPa s (ideally 10 – 20 mPa s) and a surface tension in the range of $\sigma = 25 – 40$ mN/m (Reis, Ainsley, & Derby, 2005; Liu & Derby, 2019). Apart from these ink properties, the compatibility of the ink to be produced with the substrate is also important. The adhesion of the ink to the material, drying properties and color properties, conductivity, working stability, and fastness properties are also important for a good ink (Castrejón-Pita et al., 2021). In addition, spray performance depends on the nozzle, purity to prevent clogging, particle size, pH, and defoaming properties are also important (Tyler, 2005).
In the study, water-based inkjet digital printing ink formulations were prepared and produced for use in thermal inkjet printing. After obtaining the optimum ink, printing was carried out under optimum conditions on a hand-held inkjet printing machine and the suitability of the new ink for inkjet digital printing systems was determined.

2. METHODS

For the production of water-based inkjet ink, distilled water, surfactant to control viscosity, dye as colorant, buffer as pH regulator and defoamer if needed were used. Surfactant tergitol, dye Reactive Red 195, and buffer were purchased from Sigma-Aldrich (Germany). The viscosity of the produced water-based ink was measured with a viscometer and the surface tension was measured with a surface tension meter and the necessary additions were made and adjusted. The basic formulation of the produced ink is given in

Table 1. In addition, it was monitored with a dilatometer whether there was expansion in the dimensions of the produced ink depending on temperature and time.
In the first stage for ink production, dye was mixed with water, then surfactant was added. Homogenization was achieved by mixing at 600 rpm for 10 minutes. The pH of the resulting mixture was measured, and buffer was added to bring it to a weak basic condition suitable for printing. BYK 024 anti-foaming agent 1 drop was added to the formulation to eliminate the foam formed in the prepared ink. The long-term stabilization of the obtained ink was visually examined for 72 hours. The images of the dye used in the study and the prepared inks are given in Figure 3.

Table 1: Water-based ink formulation

Contents	Ratio (%)
Water	90
Surfactant	3
Dyes	6.5
Buffer	0.5
Total	100



Figure 3: Dye and prepared inks used in the study

Prints were made on 80 g/m^2 office papers using water-based inks. Bentsai bt-hh6105b2 thermal inkjet digital printer (Figure 4) was used as the printing machine. Technical specifications of the paper used in the study are given in the Table 2. Then, the spectrophotometric properties of the papers were determined using CIEL*a*b* color values by using an X-Rite eXact spectrophotometer according to the ISO 13655:2017 standard. The difference between the colors of the different prints was calculated according to the CIE ΔE 2000 color-difference formula ISO 11664-6:2014. Calculations were performed by calculating the average of five measurements.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}} \quad (1)$$



Figure 4: Bentsai bt handheld thermal inkjet digital printing machine

Table 2: Technical properties of the paper used in the study

Properties	Standard	Office paper
Grammage (g/m^2)	ISO 536	80
Thickness (µm)	TAPPI T411	188
Whiteness (D65/10) (%)	ASTM E313	95
Gloss (75°)	ISO 8254-1 Part-1	5.8
Yellowness	ASTM E313	0.06

3. RESULTS AND DISCUSSION

As a result of printing experiments with inks having different viscosity values, it was determined that the ideal ink viscosity was 9-11 cps 25°C. The ideal surface tension in this viscosity range was measured as 30-31 dyn/cm. Surface tension was adjusted to 31 mN/m with 3 drops of BYK 348. In addition, expansion depending on temperature and time was monitored with a dilatometer and no expansion occurred in the ink.

The water-based inks produced were used with Bentsai bt-hh6105b2 thermal inkjet digital printer prints. The prints were made with 11 volts, dual nozzle, 256 dots, 300 dpi resolution, 1m/s speed and 35° angle. The printed text sample is shown in Figure 5. The average values of CIEL*a*b* color measurements performed with the spectrophotometer are L*52, a*54, b*7. The difference between the color obtained according to the CIE ΔE 2000 color-difference formula and the standard color is around ΔE_{00} 2.5.



Figure 5: Printing sample with prepared ink

The long-term stabilization of the obtained ink was visually examined for 72 hours, and no changes were observed in the inks (Figure 6).

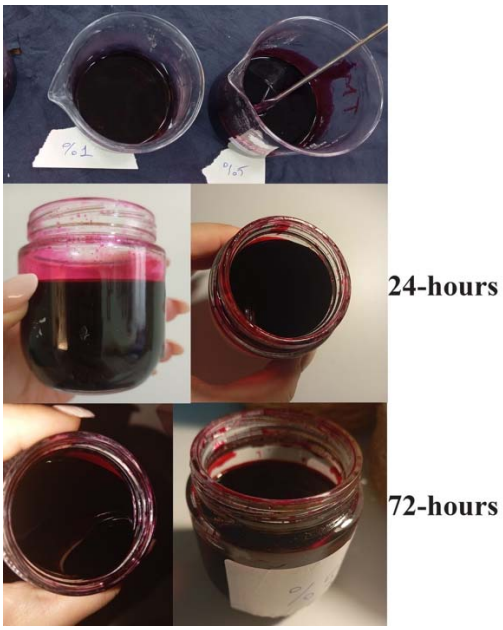


Figure 6: Visual control of the stabilization of prepared inks for up to 72 hours

4. CONCLUSIONS

In the study, after various tests, magenta color thermal inkjet printing ink with a viscosity range of 10-14 cps 25°C and a surface tension of 30-35 dyn/cm was produced. There was no expansion in the produced ink depending on temperature and time. Its stabilization was monitored for a long time, and it was seen that there was no problem. The ink was currently examined by printing on only one type of paper. Tests will be made on other process colors and different substrates.

5. ACKNOWLEDGMENTS

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INVESTIGATION OF BIO-BASED PAPER COATINGS CONTAINING NATURAL PIGMENT AND THEIR HEAT RESISTANCE PROPERTIES

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Abstract: *Cellulosic paper which is created from cellulose-rich wood fibers has a highly flammable property and can easily catch fire. Some studies are being conducted to improve and increase the flame-retardant properties of paper, but there are currently very few studies that apply flame retardant coatings on sheet paper. By coating the paper surface using some bio-based coating materials containing natural pigments, oxygen can be prevented from reaching cellulose and the rapid ignition of the paper can be delayed. In this study, paper coating materials were prepared using three different types of pigments (PCC, zeolite and bentonite) and coated on 80 g/m^2 base paper. Thermogravimetric analysis (TGA) measurements were performed on the coatings. Prints were made on the coatings with an Epson Stylus Photo R3000 digital printing machine, and printing color measurements were made using an X-Rite eXact spectrophotometer. The surface morphology of the coatings was examined, and the limited oxygen index (LOI) was determined. As a result of the investigations, it has been determined that the coatings created increase their flame retardancy and have a good hydrophilia. At the same time, when the printing parameters were examined, it was determined that the measured values were in accordance with ISO 12647-2 standards.*

Key words: paper coating, inkjet printing, printability, heat resistance

1. INTRODUCTION

Paper is widely used for magazines, journals, valuable documents, and packaging due to its biodegradability, easy recyclability, high sustainability, and low cost (Zhang et al., 2021; Zeng, Gu & Cao, 2020). Despite these positive features, papers have poor barrier properties against water, oil, and oxygen (Nechita & Roman, 2020). In order to improve the weak barrier properties, attempts are made to improve this weak barrier property by using polymers, aluminum foils and different waxes. However, these coatings used consist of fossil-based synthetic materials that are difficult to biodegrade, especially in recycling (Kabir et al., 2020).

Sustainable biopolymers have become a good alternative to petroleum-based plastics in recent years. Among the biopolymers, proteins, polysaccharides, lipids, and polyesters can also be used to produce films and coatings (Lisitsyn et al., 2021).

It is common to treat the paper surface to obtain better substrate performance. Surface treatments improve optical and mechanical properties. With these treatments, certain pigments and binders are applied to the surface according to specific formulations. Starch derivatives and polyvinyl alcohol are common binders, and calcium carbonate and clay are also the most used pigments (Gadhave, Gadhave & Dhawale, 2022).

However, paper, which consists of cellulose fibers, is an extremely flammable and combustible material. For this reason, many valuable works have been destroyed in fires. These losses have caused the loss of important information for human history. For example, the great fire in the Notre Dame Cathedral in Paris in 2019 caused many works to be destroyed by fire. Applications that are applied to papers during or after production and that give them fireproof properties have become quite widespread. These applications increase the resistance of papers to burning and improve their flame retardancy. This is extremely important for the safe and long-term preservation of valuable works of art (Fang et al., 2022).

In the printing industry, many products with high heat resistance are required to be produced (Ozcan et al., 2020). In recent years, many methods have been used to impart fire retardant properties to papers. These can be listed as dipping, coating, spraying and layer-by-layer (LBL) bonding. The most effective method is the coating method. However, halogen and phosphorus-containing components frequently used here are extremely dangerous for the environment (Fang et al., 2022). Halogen-based flame retardants have been reported to cause cancers and poor neurocognitive functioning in children (Chen et al., 2020).

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For this reason, the use of natural, environmentally compatible, and environmentally friendly pigments as fire retardants is increasing. There are many pigments used as natural coatings. Zeolite is a natural pigment with unique crystal structures and is also used in the paper industry. Thermal stability and catalytic activity are just two of its distinctive features. It is mostly synthesized from sodium, aluminum and silicon sources and made ready for use (Soares et al., 2023). Easy availability, low cost, penetrability, low refractive index, and compatibility with other materials have made calcium carbonate ($CaCO_3$) one of the most widely used pigments in the paper industry (Ma et al., 2022). Bentonite clay is one of the materials that human beings have used in their daily lives for centuries (Borah, Nath, & Saikia, 2022). This natural pigment has many properties and is widely used in agriculture and paper industry (Wang et al., 2023). It is also used as a filler in paper production or later as a coating material (Umar et al., 2022).
The aim of the research is to produce flame-retardant paper to be used in the paper industry by using different paper coating pigments. In addition, it was investigated how much the produced paper coating affects the print quality.

2. MATERIALS AND METHODS

2.1 Materials and Methods

In the study, 80 g/m^2 high grade base paper was used. The papers were conditioned at 22°C and 55% humidity for 24 hours before the coating process. PCC, Zeolite and Bentonite were used as coating pigments. $CaCO_3$ (PCC) was supplied by Omya, Zeolite was supplied by ZO mineral partners and Bentonite was supplied by Imerys. The coatings were carried out automatically with a stick coater (model K303 Multi-coater, RK Print Coat Instruments Ltd, United Kingdom) on the base paper at a speed of 2 m/min. The coatings were allowed to dry for 24 hours at 20°C and 65% relative humidity (RH).
Test prints (Figure 1) on coatings were made with an inkjet Epson Stylus Photo R3000 digital printing machine and an X-Rite i1iO, X-Rite i1Pro Spectrophotometer and X-Rite eXact Portable Spectrophotometer were used for spectrophotometric and densitometric measurements to measure CIE *L*a*b** values, color gamut volumes and dot-gain values on the printed paper. The measurement conditions of the spectrophotometer were a D50 light source in the range of 400-700nm and a polarizing filter with a geometry of 0/45° with a 2° observer angle. The difference between the colors of different prints was calculated according to the CIE ΔE_{00} color difference formula ISO 11664-6:2014. Chromix ColorThink Pro 3.0 was used to calculate the color gamut volumes.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}} \quad (1)$$

where ΔL: is the lightness difference, ΔC: is the saturation difference, ΔH: is the hue difference, with correction using weighing coefficients (SL, SC, and SH) and constants called parametric coefficients (kL, kC, and kH) (El-Rashidy, Abdelraouf & Habib, 2022).
Thermogravimetric analyses (TGA) of coatings were performed using a Perkin–Elmer Thermogravimetric analyzer Pyris 1 TGA model. For color space measurements, a 400-piece i1Profiler Test Chart page (Figure 1) was used.
The flammability characteristics of composites were determined by Limited oxygen index (LOI). The LOI values of the coatings were measured by using an FTT (Fire Testing Technology) type instrument.
The crystalline phases of zeolite doped starch hybrid film, bentonite doped starch hybrid film and $CaCO_3$ (PCC) doped starch hybrid film were identified by X-Ray diffraction analysis (XRD, Rigaku Geigerflex D/Mac, C Series, Cu Kα radiation, Japan). Copper Kα radiation (λ = 1.5406 nm) produced at 30 kV and 25 mA scanned the range of diffraction angles (2θ) between 5° and 50° with a 2θ-step of 0.02°/s.

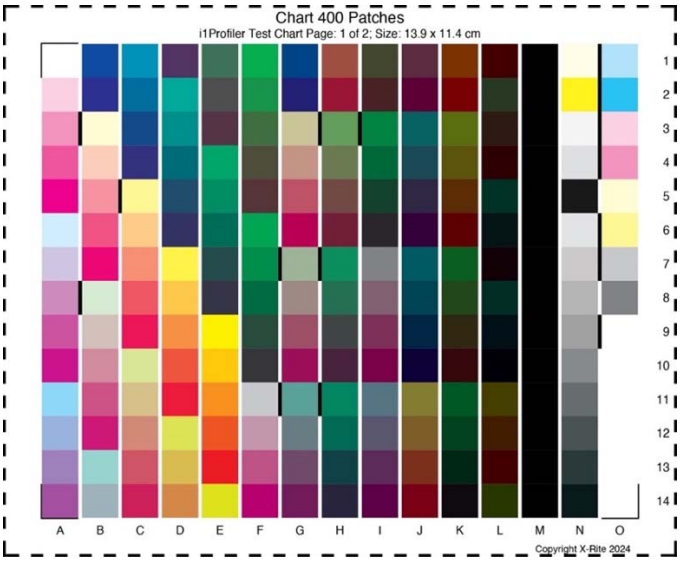


Figure 1: i1Profiler test chart page

3. RESULTS AND DISCUSSION

Paper formulations containing different pigments (PCC-starch, bentonite-starch and zeolite-starch) were successfully prepared and then coated on the base paper. Then, prepared test chart prints (Figure 1) on coatings were made with an inkjet Epson Stylus Photo R3000 digital printing machine.
The CIE *L*a*b** color values and dot gain values of the printed papers were measured with the X-Rite eXact Portable Spectrophotometer and the difference between the colors in the prints was calculated according to the CIE ΔE_{00} color difference formula ISO 11664-6:2014. The measurement results are given in the Table 1 and dot gain curves are given in the Figure 2. Chromix ColorThink Pro 3.0 was also used to calculate the color gamut volumes and the measurement results are given in the Table 2 and the 2D gamut volume curves are given in the Figure 3.

Table 1: Spectrophotometric color and color difference values of the papers used in the study

	ISO Lab Ref.			Base paper			ΔE_{00}
	*L**	*a**	*b**	*L**	*a**	*b**	
Cyan	55	-37	-50	61.6	-27.2	-39.8	7.27
Magenta	48	74	-3	54.1	65.3	-5.6	6.54
Yellow	91	-5	93	80.5	-9	78.9	7.91
Black	16	0	0	23.9	-3.6	-3.8	7.93
				PCC-Starch			
				57.8	-39.8	-48.1	2.94
				51.2	72.1	-3.8	3.25
				87.2	-6.2	89.8	2.58
				17.8	-2.1	-1.1	3.33
				Bentonite clay -Starch			
				57.8	-40.2	-49.6	3.16
				51.2	73.7	-5	3.3
				87.3	-6.9	87.4	2.84
				18.1	1.8	-2.1	3.47
				Zeolite -Starch			
				58.1	-39.1	-47.9	3.11
				50.6	72.2	-4.2	2.68
				86.9	-7.1	89.7	2.93
				18.2	-1.2	-0.8	2.4

Dot gain in printing is a feature that occurs in almost all printing and shows different variations in each. Dot gain is a measurable value that occurs between the printed dot value and the original dot value. As the dot

sizes deviate from the standards, darker or lighter images are obtained in the print compared to the original, and this is not a desired result in printing.

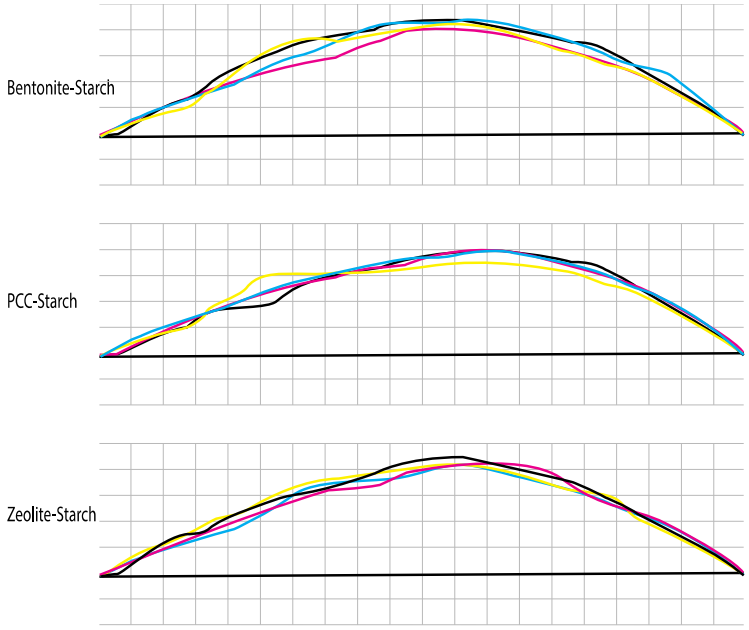


Figure 2: PCC-starch, bentonite-starch and zeolite-starch coatings dot gain curves

When the dot gain values for the bentonite-starch coating are examined, it is seen that the dot-gain value is at standard values for four colors in medium and dark tones, but there is a deviation in magenta color in light tones. For the PCC-starch coating, it is determined that the dot-gain is higher in yellow in light tones and lower in medium tones, and there is an irregularity in other colors. However, this irregularity is not seen in dark tones. For the zeolite-starch coating, it is determined that the dot gain value creates a more homogeneous, smooth dot-gain curve in all tones. The biggest reason for this is the difficulty of obtaining high quality prints using the heads of inkjet printers. These irregularities are also reflected in the irregularity of the dots obtained in the print (Shin, Fleming & Lee, 2021).

The CIE*L*a*b** color space is a three-dimensional, spherical model in which L* represents the brightness, *a** represents the red/green value, and *b** represents the yellow/blue value. *ΔE*ab* is defined as the difference between two colors in an *L*a*b** color space, where L represents the difference between each of the a and b readings compared to the initial readings.

When the uncoated base paper CIE*L*a*b** values were evaluated, it was determined that the color values measured in printing were significantly different from the reference values. According to the calculated ΔE_{00} values, it was seen that all ΔE_{00} values except magenta were outside of the acceptable values. PCC-starch coated papers show that CIEΔE_{00} color differences are below 3 in cyan and yellow values, indicating that color differences cannot be distinguished by eye. Magenta and black values are within acceptable values. The bentonite clay -starch coating values are examined; the yellow value is below 3 while the other 3 color values are within acceptable values. The zeolite-starch coating values were examined, it was determined that all color values except cyan were at values that could not be distinguished by the eye, but the cyan color value was very close to 3 and was within acceptable values.

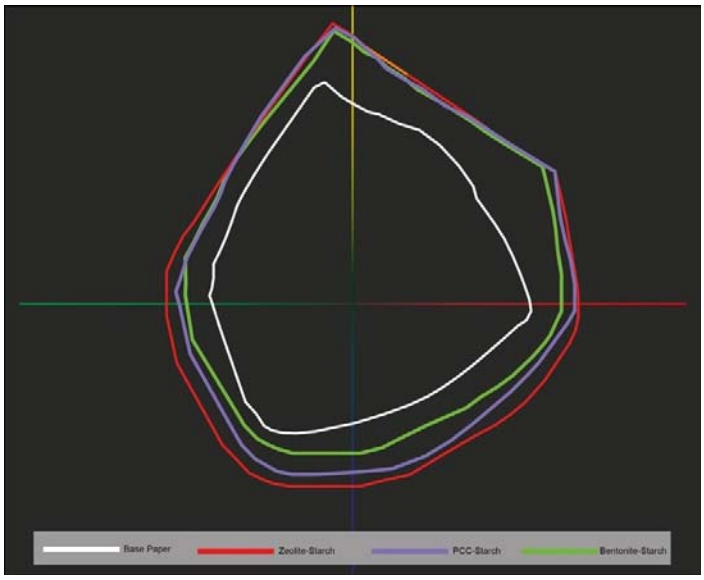


Figure 3: Base paper PCC-starch, bentonite-starch, and zeolite-starch coatings color gamut values

When all coatings and base paper 2D color gamut values are compared, it is seen that the base paper color gamut value creates a narrower area in all colors. The color gamut of matte paper is lower because uncoated papers give a lower density (D) because of their greater ink absorption and more microporous surface (Gigac, Stankovská & Pažitný, 2016), this resulting a loss of saturation, that is, the worst color gamut (Perales et al., 2009). When the coatings are compared with each other, it is seen that all coatings have the same area in yellow tones in the +b direction. Zeolite-starch has the widest green tones in the -a direction. PCC-starch coating and bentonite-starch coating values are very close to each other. In the +a direction, PCC-starch and zeolite-starch coatings are closer to each other in red tones and have a wide area. In the -b direction, the coating with the widest blue tones is zeolite-starch coating, followed by PCC-starch and bentonite-starch coatings. This can be explained by the fact that calcium carbonate pigments form coating layers with higher permeability and a more open pore structure, which allows rapid dye fixation. The use of starch, a cationic polymer, in the formulation is, as might be expected, beneficial to the cyan color (Hladnik, Cernic & Bukosek, 2008). Zeolites obtained from kaolin's efficiently adsorb methylene blue, safranin, and malachite green from aqueous solutions (Pereira et al., 2018). This explains why zeolite-starch coating creates a wider color gamut in both green and blue tones.

Table 2: Color gamut volume values

Coating Type	Volume
Base paper	211.779
PCC-starch	328.184
Bentonite-starch	298.517
Zeolite-starch	372.412

When the color volume gamut values obtained with Chromix ColorThink Pro 3.0 were compared, it was determined that the zeolite-starch coating had the widest color volume value (372.412). The narrowest color universe volume value (211.779) belonged to the uncoated base paper. The PCC-starch coating value (328.184) is quite wide compared to the bentonite-starch coating value (298.517).
Thermal behaviors of coated papers with different contents were investigated with TGA (Figure 4). When TGAs were examined, the decomposition curve of the base paper started at 320°C. It was determined that the thermal decomposition temperatures of the TGA curves increased slightly with the addition of fillers. This shows that the added fillers increased thermal stability. When the ash amounts of all coatings were examined, it was seen that they had more ash than the base paper, which can be attributed to the inorganic substances remaining without decomposition at 750°C. When the fillers were compared with each other, the fact that calcium carbonate and clay had very close curves and zeolite had a lower decomposition temperature is due to the decomposition of natural zeolite at 750°C and calcium carbonate and clay at

800°C. Addition of all relevant fillers to the medium changed the melt rheology in the coating and delayed the burning rate. The results are consistent with the literature (Md Nasir et al., 2019).
When the figure is examined, it is determined that the addition of zeolite, PCC and bentonite ignites the coating at a higher rate of oxygen, that is, delays combustion. It is also seen from the figure that zeolite provides more flame retardancy than clay and PCC. The reason for this is PCC and clay are hardly considered as an inorganic flame retardant. Still the decomposition of this inorganic materials is releasing some carbon dioxide. This is an endothermic process. Zeolite, which is an intumescent fire retardant, can form a protective barrier on polymer matrix surface and therefore increases charring. this is same line with TGA.

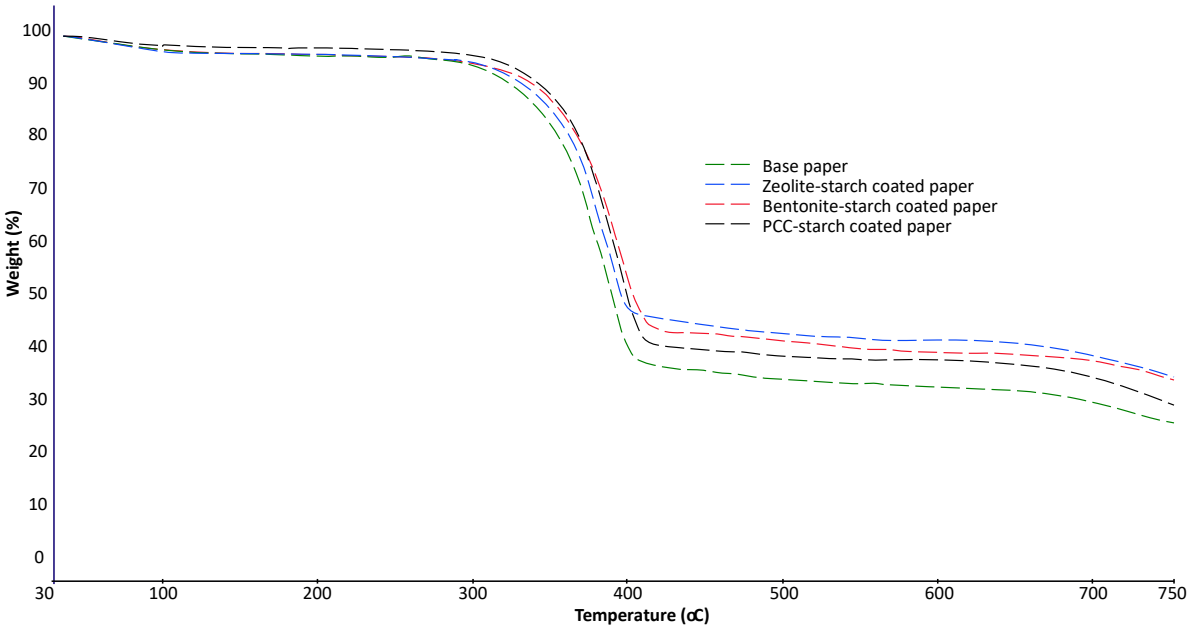


Figure 4: TGA thermograms of base paper PCC-starch, bentonite-starch, and zeolite-starch coatings

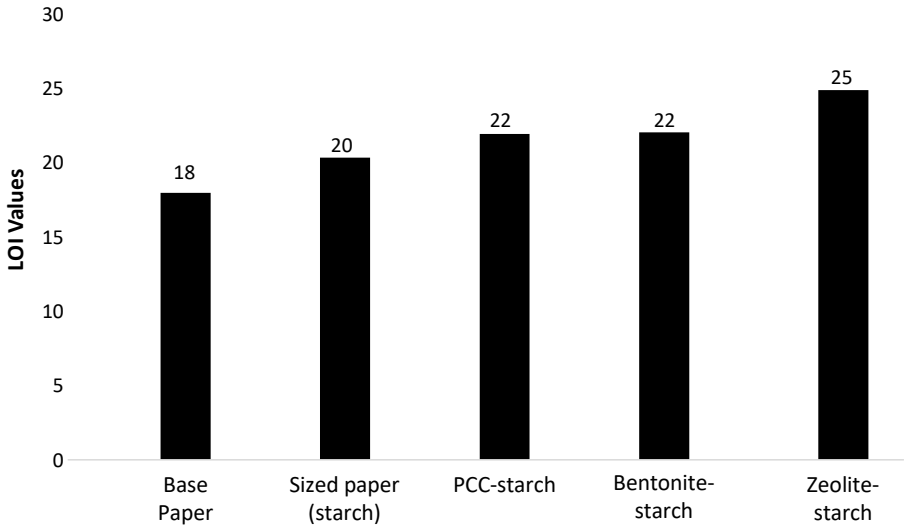


Figure 5: LOI values of base paper PCC-starch, bentonite-starch, and zeolite-starch coatings

Flame retardancy properties of paper coatings obtained with the limiting oxygen index technique (one of the most widely used techniques for determining flame retardancy) were examined. The measurement results are given in Figure 5. As can be understood from the figure, the LOI value of all coatings, especially zeolite, increased.

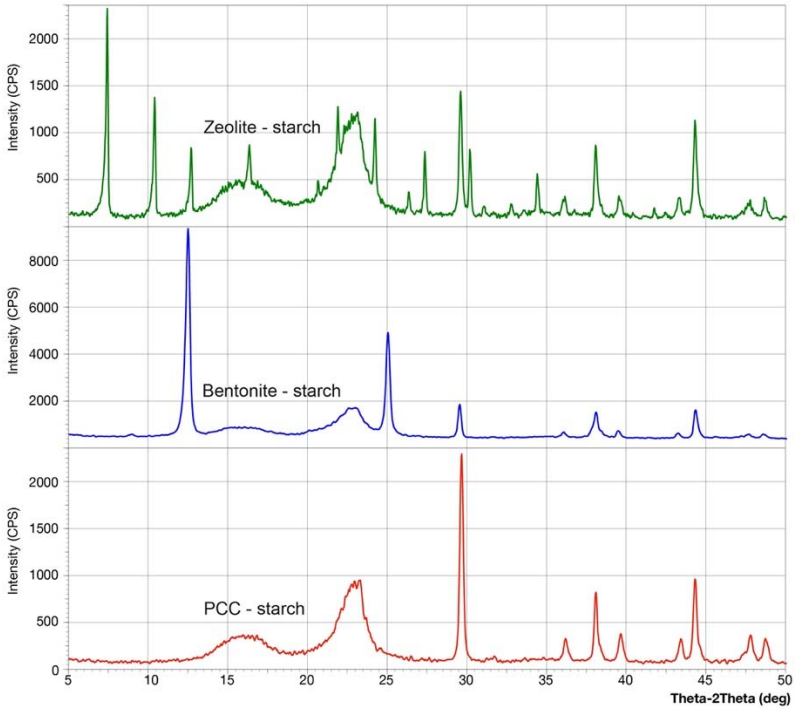


Figure 6: X-Ray diffractograms (XRD) of zeolite doped starch hybrid film (green), bentonite doped starch hybrid film (blue), $CaCO_3$ (PCC) doped starch hybrid film (red)

The X-ray diffraction patterns of zeolite doped starch hybrid film, bentonite starch doped hybrid film and PCC doped starch hybrid films are shown in Figure 6. When zeolite added starch film is examined, two peaks between 2θ = 20° and 2θ = 15° clearly show the semicrystalline structure of starch. In addition; the peaks occurring at 2θ = 7.37; 10,13; 30; 45° are the crystallinity peaks of the zeolite consistent with the literature (Belibi et al., 2013). When XRD bentonite doped starch spectrum is examined, three strongest peaks are observed which are 2θ = 12,46°, 25,01°, 29,49°. 2θ which may be assigned to aluminosilicate plates, corresponding to the basal spacing of kaolinite Si2Al2O5(OH)4 (d=7.09 Å) and shoulder (d=3.55 Å), respectively. These results are in line with the literature (Romo-Uribe et al., 2023). When the PCC doped starch film is examined, three peaks between 2θ = 24,11°, 36,14 ° and 39,58° are proves the crystalline structure of calcium carbonate and are supported by literature (Syafri, 2017). The simultaneous release of starch peaks clearly demonstrates the formation of the hybrid film.

4. CONCLUSIONS

In this study, PCC-starch, bentonite-starch, and zeolite-starch coatings were prepared and applied on high grade base paper. After the coating process, the coated papers showed much better properties than the base paper. Improvements in printing were detected in the base papers, which had a smoother surface after coating.

When the coatings were compared with each other, the zeolite-starch coating dot-gain values could be obtained homogeneously in all tones. This result is also clear when the color universe volumes are compared. When the 2-dimensional color universes are compared, the zeolite-starch coating has the widest color universe in the +a red area, -a green area and -b blue areas. It has a very high color gamut, especially in blue tones.

When the TGA curves of the coatings were examined, it was determined that all three different fillers triggered thermal decomposition at higher temperatures, that is, delayed the decomposition of the coating. The LOI results showed that all the coatings provided delayed ignition, and the best result was the coating containing zeolite. When these two results were examined, it showed that inorganic fillers were quite effective in cases where delayed ignition and non-flammability were sought.

XRD results show that all inorganic materials are crystalline without any chemical bonding and are fully compatible with the film. As a result, it has been seen that zeolite, PCC and bentonite are good additives in cases where late flame retardancy or non-flammability is sought.

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DIFFERENT METHODS FOR PRODUCING COLOR REPRODUCTIONS ON 3D PRINTED OBJECTS

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Abstract: *This article presents two methods of colour printing on programmable 3D structures and their use for practical applications in everyday life. The colour printing was done by direct printing with a flatbed UV inkjet printer and indirect printing by thermally transferring the electrophotographic toner to the 3D printed object produced with the most widely used and affordable material extrusion 3D printing technology. The print quality of the colour reproductions was determined by basic densitometric and spectrophotometric measurements, ink adhesion analysis and image analysis of the printed graphic elements. The research was also extended to the field of 4D printing, where 3D printed objects with flat geometry can be subsequently transformed when exposed to a suitable activation medium. In this case, the direct printing process was used for colour printing, as it allows printing on both sides of the programmable 3D structures compared to the indirect printing process. The advantage of colour printing on a programmed 3D structure is that the flat geometry can be easily printed with colour graphics on the entire surface and later transformed into a new 3D object shape, whereas conventional 3D objects cannot be printed in very inaccessible places due to their geometry. These methods, which use direct or indirect printing techniques to create coloured reproductions on 3D-printed objects, enable the personalisation and aesthetic enhancement of products and can also provide additional interactivity if, for example, QR codes or RFID tags are included. The research focuses on the production of colour-printed smart objects for consumer products.*

Key words: 4D printing, 3D printing, UV inkjet, electrophotography, colour reproduction

1. INTRODUCTION

3D printing technologies have undergone tremendous development over the past decade, making it possible to create complex three-dimensional structures with high precision. 3D printing is now used in many industries, from medicine to the automotive industry, where it enables flexible and affordable solutions for the production of prototypes and finished products (Jandyal et al., 2022; Ngo et al., 2018). Despite these advances, challenges remain, especially in colour reproduction on three-dimensional objects, where the accuracy and uniformity of printing depends on several factors, such as the printing technology, the materials used and the surface properties (Jiangping et al., 2021; Ngo et al., 2018; Tan et al., 2020).
The development of 3D colour printers, which enable both full-colour and multi-colour printing, is being driven forward intensively worldwide. Full-colour printing enables the accurate reproduction of a wide range of colours, but 3D printers that enable this are much more expensive than monochrome or multicolour printers. The most affordable 3D printing technologies are based on the extrusion of thermoplastic materials (FDM), with these technologies already enabling both full-colour and multicolour printing (Formlabs, 2024; Silapasuphakornwong et al., 2021). UV inkjet printing has proven to be one of the most effective methods for printing on complex 3D surfaces, as it enables instant drying of inks, high quality and flexibility when printing on three-dimensional objects (Clark et al., 2017).
Research in the field of colour printing on 3D printed objects has so far mainly focused on inkjet techniques, with UV printing enabling the reproduction of accurate and high-quality colour prints. This technology is often used for the production of personalised products, didactic tools and in the packaging industry (Yang et al., 2012). In recent years, research in the field of 4D printing, which includes active materials, offers new possibilities for interactive and adaptive structures that can change their shape according to various external factors (Pivar, Gregor-Svetec & Muck, 2022; Pivar et al., 2024; Piyush, Kumar & Singh, 2022; Kumar et al., 2024).
In addition to the challenges of color reproduction on 3D objects, research also shows the significant influence of surface properties such as roughness and gloss on print quality. A rough surface enhances color adhesion, providing a better grip for inks to adhere. However, it can also lead to issues such as uneven ink distribution and reduced optical quality of the color, resulting in a less smooth and visually appealing finish.Various surface treatment techniques such as laser, chemical and mechanical treatment can improve

ORCID numbers are provided at the end of the paper.

the surface quality before printing, leading to a better printing result (Taufik & Jain, 2017; Adel et al., 2018; Singh et al., 2017; Garg, Bhattacharya & Batish, 2017; Chohan & Singh, 2017).
In this study, we focused on the comparative analysis of the use of UV inkjet printing and thermal transfer of electrophotographic toner for colour reproduction on three-dimensional objects. We investigated the advantages and disadvantages of both printing processes in terms of print quality and also presented an example of colour printing on a programmed 3D-printed structure that was transformed into a new 3D shape after exposure in the activation medium.

2. METHODS

2.1 3D printing process

3D printing of the 70 × 130 mm and 0.3 mm thick samples was performed using a ZMorph VX 3D printer (ZMorph S.A., Poland) with a heated build plate. The samples were made from white PLA filament purchased from the manufacturer Plastika Trček d.o.o. (Slovenia, Ljubljana). White PLA was chosen to achieve a wider colour gamut in printed colour reproduction. The PLA was printed directly onto temperature resistant Avery Zweckform 3560 polyester film which was purchased from CCL Industries Inc (Canada, Toronto). In one case the polyester film was unprinted, in the other case it was pre-printed with a colour test images. The 3D printing parameters are listed in Table 1. They were adjusted to achieve good adhesion between the PLA material and the polyester film and to achieve a smooth surface of the samples, which is important for good printability. Finally, they play a very important role in the toner transfer from the polyester film to the PLA material.

Table 1: 3D printing parameters

Printing parameter	Value
Nozzle Diameter [mm]	0.4
Printing Temperature [°C]	215
Build Plate Temperature [°C]	30
1st Layer Height [mm]	0.1
2nd Layer Height [mm]	0.2
Infill Pattern [/]	Rectilinear
Infill Angle [°]	0°

2.2 Colour printing process

The colour test images were printed onto the 3D-printed samples in two ways. The first indirect printing process involves the heat transfer of electrophotographic toner from the polyester film during the 3D printing process, while the second printing process involves the direct printing of UV inks onto the flat geometry of the 3D printed samples. In both cases, digital printing techniques and identical test images were used. A Xerox Vesant 280 electrophotographic digital printer (Xerox, U.S.) was used to print the test images for the indirect printing process and an Apex UV6090 UV LED inkjet flatbed printer (Apex, China) with Nazdar 260 UV LED inks was used for the direct printing process. The test images were designed so that all relevant print quality attributes could be assessed using validated methods. They consisted of colour patches for spectrophotometric measurements, colour patches for measuring optical density and tonal values, elements for evaluating geometric print quality and elements for determining ink adhesion. Five samples were printed for each printing process.

2.3 Printing evaluation

The densitometric and spectrophotometric values were measured with an X-rite Exact spectrodensitometer under D50 illumination, 2° standard observer, 45:0 measurement geometry and white backing. The optical density, tonal value and the CIELAB colour values were determined for both printing processes.
The adhesion of the UV ink and the electrophotographic toner to the PLA material was determined by the cross-cut method using a Byko-Cut device (BYK-Gardner GmbH, Germany). The cuts were made at an angle of 45° to the direction of the deposited filaments and visually inspected using a Dino-Lite AM4113ZT digital

microscope (AnMo Electronics Corporation, Taiwan). The quality of the cross-cuts was evaluated based on the ISO 2409 classification.
The geometric irregularities of the printed graphic elements were analysed with the software ImageJ 1.54 (open source). The images of the graphic elements were taken with a Dino-Lite AM4113ZT digital microscope (AnMo Electronics Corporation, Taiwan) at 50x magnification. The edge sharpness and physical gain were determined on 0.3 mm wide printed lines. They were determined by analysing the line area and perimeter and compared with the reference values (ideal) from the digital document. The influence of the printing processes on the deformation of the graphic elements was determined by measuring the roundness of dots with a diameter of 0.4 mm. The values were compared with the reference value of a geometrically perfect dot, defined by the value 1. The roundness of the dots was determined according to Equation (1).

$$\text{Roundness} = 4 \times \text{area}/(\pi \times \text{major_axis}^2) \quad (1)$$

2.4 Practical example of a smart structure

This chapter presents an example of the use of programmable 3D structures for practical applications in everyday life. An example is a smart mobile phone stand that transforms from a flat geometry into a new 3D shape. The example was printed with colour graphics on both sides using a UV inkjet printer. With UV inkjet printing, both sides of the programmable 3D structures can be printed, whereas with thermal transfer printing, only the underside can be printed. After colour printing, the programmable 3D structure was thermally activated in water at 80°C to change its shape.
The programmable 3D structure was made from a combination of active PLA and passive PRO-PLA thermoplastics. An aligned rectilinear pattern with a fill density of 99% was used for the active part and a rectilinear pattern with a fill density of 30% was used for the passive parts. The printing temperature and the temperature of the build plate were 195°C and 30°C respectively. The technical data of the practical example are shown in Table 2 and the schematic representation can be seen in Figure 1.

Table 2. Technical data of practical example

Specification of active element (AE)	Value
Number of AE	1
Number of active layers	20
Height of active layers [mm]	0.1
Length of AE [mm]	24
Width of AE [mm]	15
Bending direction	Downwards
Filament orientation [°]	0

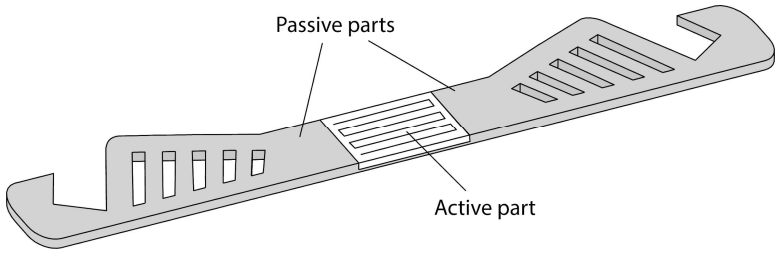


Figure 1: Schematic representation of the flat geometry of a programmable 3D structure.

3. RESULTS

3.1 Densitometric analysis

The measurements of the optical density of the solid tone (100% TV) of process colours are shown in Table 3. Higher optical density values are measured for heat transfer printing. The exception is the optical density of the colour cyan, which is higher for UV inkjet printing. The highest optical density value is

achieved when the colour black is printed using the heat transfer printing process. This indicates that the dynamic range for thermal transfer printing is greater than for UV inkjet printing. The standard deviations of the optical density measurements show that the ink transfer is stable for both printing processes. It can be assumed that the surface properties of the 3D printed samples and the 3D printing parameters did not adversely affect any of the printed inks.

Table 3: Average values and standard deviations of the optical density

Colour	Optical density [/]	
	UV inkjet	Heat transfer
C	2.44 (±0.024)	2.29 (±0.028)
M	1.61 (±0.011)	2.14 (±0.050)
Y	1.71 (±0.015)	2.02 (±0.037)
K	1.71 (±0.004)	2.54 (±0.034)

Figure 2 shows the dependence between the reference value and the measured tone values for or all process colours. The investigation has shown that the dot gain is higher for all colours in the UV inkjet printing process. The smallest dot gain was found for magenta. The dot gain for the colours cyan, yellow and black is between 31.9 and 34.4% at 50% tonal value. For magenta it is 24.3%. With heat transfer printing, all colours have a lower dot gain than with UV inkjet printing, with the exception of magenta. The dot gain for all colours is between 25.2 and 28.1% at 50% tonal value. This means that printing details in light, medium and dark tones achieve a higher quality with heat transfer printing.

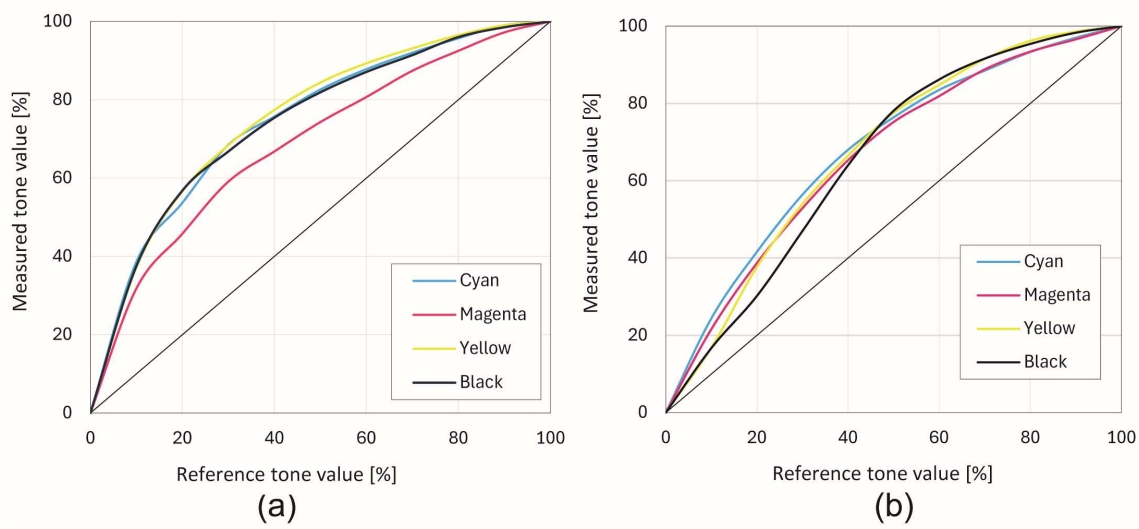


Figure 2: Dependence between the reference value and the measured tonal value for both printing processes. (a) UV inkjet printing and (b) heat transfer printing.

3.2 Spectrophotometric analysis

Based on the measured CIELAB colour values (Table 4) of the primary and secondary solid colours, a colour gamut diagram was created for both printing processes (Figure 3). The larger the colour gamut, the better the colour reproduction. A comparison of the colour gamuts of prints produced with both printing processes shows some differences. The comparative analysis of the colour gamut areas showed that the UV inkjet colour prints have a slightly larger colour gamut than the electrophotographic prints. However, a detailed analysis of the colour gamuts showed that the UV inkjet printing process reproduces richer magenta and blue tones as well as slightly richer green tones, while the indirect electrophotographic printing process mainly reproduces more saturated yellow tones.

Table 4: CIELAB colour values for both printing processes.

Colour	UV inkjet			Heat transfer		
	L*	a*	b*	L*	a*	b*
C	45.53	–35.86	–49.67	46.88	–32.81	–52.71
M	47.33	74.89	–5.95	41.50	74.17	6.01
Y	85.54	–4.91	90.82	87.18	–8.27	100.25
K	17.80	1.80	5.02	13.52	–0.42	–1.36
R	46.69	66.78	52.36	40.29	70.37	44.71
G	39.80	–78.45	18.23	39.28	–73.18	24.46
B	16.90	23.98	-49.15	14.46	17.51	–38.14

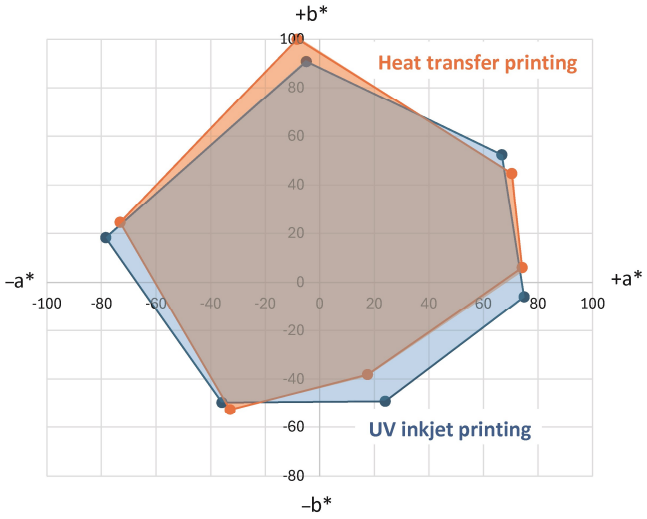


Figure 3: Colour gamut for both printing processes.

3.3 Ink adhesion

The optical images (Figure 4) of the cross-cut pattern show that the adhesion of the UV ink and the electrophotographic toner to the 3D printed samples is very good. The adhesion of the UV ink achieves ISO classification 0 with smooth cut edges and no detached ink. The adhesion of the electrophotographic toner achieved ISO classification 1, with slightly damaged chipped edges and up to 5% detached ink. The analysis of the adhesion showed that both printing processes are suitable for printing on the 3D printed PLA material.

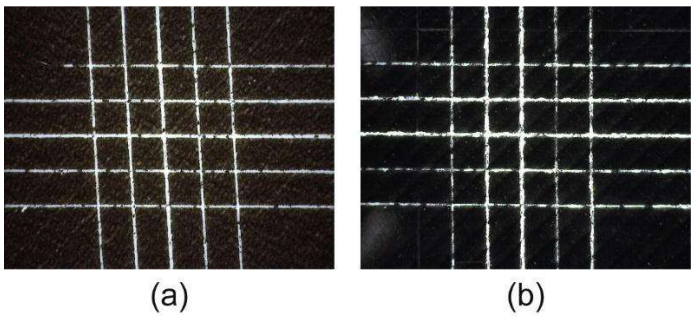


Figure 4: Analysis of ink adhesion on prints with both printing processes. (a) UV inkjet and (b) heat transfer printing.

3.4 Image analysis

The image analysis has shown that geometric irregularities of the printed graphic elements occur in both printing processes, as can be seen from microscopic images (Figures 5 and 6) and from measurements of the roundness of the printed dots (Table 5) and the perimeter and area of the printed lines (Table 6).

The analysis of the roundness of the dots (Table 5) showed that UV inkjet printing leads to a higher deformation of the printed dots. The roundness of the dots printed with a UV inkjet printer reaches a value of 0.821, while the roundness of the dots printed with an indirect printing process is slightly higher at around 0.975 and comes very close to an ideal circular shape with a roundness value of 1. The deformation of the graphic elements during UV printing is due to the distribution of the droplets and the spreading of the UV ink in the channels between the deposited filaments.

Table 5: Average values and standard deviation of dot roundness

Printing process	Dot Roundness
UV inkjet	0.821 (±0.027)
Heat transfer	0.975 (±0.012)

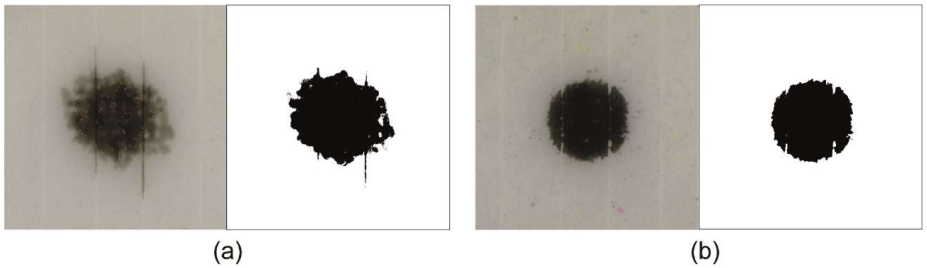


Figure 5: Visual comparison of microscopic images of printed dots with both printing processes: (a) UV inkjet and (b) heat transfer printing.

The comparison of the measurements of the printed line area with the reference value of the ideal line (Table 6) shows that there is a physical increase in the lines with both printing processes. The physical increase is greater with UV inkjet printing. The perimeter of the lines also increases significantly with both printing processes, which indicates a poor sharpness of the edges. In both cases, the deformation of the edges is caused by the channels between the deposited filaments in the 3D printed sample. In UV printing, the liquid UV ink is spread into the channels before the UV light cures it (Figure 6a), while in the indirect process, the electrophotographic toner is not transferred into the channels over the entire surface (Figure 6b), resulting in lower edge sharpness.

Table 6: Average values and standard deviations of the area and perimeter measurements of the printed line with both printing processes.

Printing process	Area [mm²]	Perimeter [mm]
Reference value	2.1	14.6
UV inkjet	2.58 (±0.022)	23.99 (±1.400)
Heat transfer	2.33 (±0.003)	20.96 (±0.428)

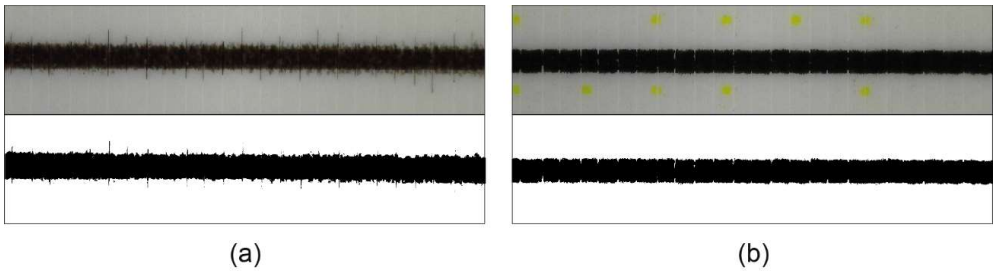


Figure 6: Visual comparison of microscopic images of printed lines with both printing processes: (a) UV inkjet and (b) heat transfer printing.

3.5 Practical example of a smart structure

The practical example, which was printed on both sides with colour graphics using a UV inkjet printer, shows the simplest form of a programmable 3D structure (Figure 7). This example structure demonstrates a unilateral, unidirectional transformation. It contains only one active element, printed with an aligned rectilinear infill pattern, and two symmetrical passive elements that have a specific shape to hold the phone. The printing sequence of the first active layers and the second passive layer causes the phone stand to transform in a convex (downward) direction. The passive elements remain stable during thermal activation and have good mechanical properties to hold the phone. The results of the basic example printed with colour graphics show that the programmable 3D structures are sufficiently stable to produce the intended practical objects and that UV inkjet printing is the appropriate printing process as there are no visible irregularities in the printed UV ink.

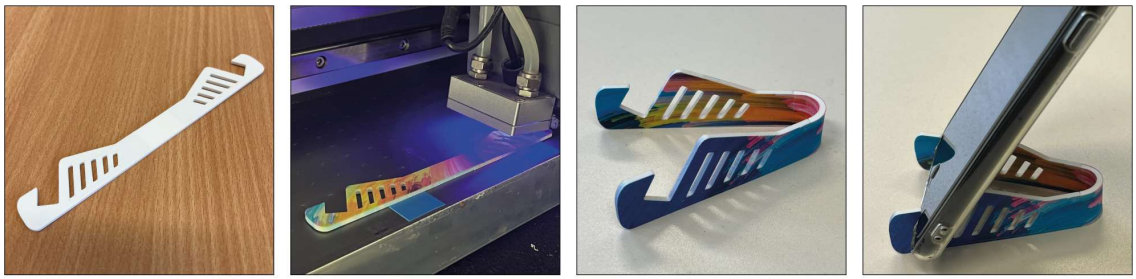


Figure 7: (a) Programmed mobile phone stand in flat geometry. (b) Printing of colour graphics with a digital UV inkjet flatbed printer on a programmed mobile phone stand. (c) Thermally activated mobile phone stand. (c) The final shape of the mobile phone stand in practical use.

The process of thermal activation of the programmed 3D structure is demonstrated in the attached video 1 (supplementary material) or on request (matej.pivar@ntf.uni-lj.si).

4. CONCLUSIONS

The research provides important insights into colour printing techniques on 3D-printed objects and opens up new possibilities in the field of 4D printing. A comparison of direct UV inkjet printing and indirect electrophotographic printing shows differences in the quality of the colour reproductions. The heat transfer of the electrophotographic toner ensures less dot gain and no major deformation of the graphic elements. However, UV inkjet printing allows for a wider colour gamut, especially in blue and green tones, which is an advantage for certain applications. Both printing processes enable good adhesion and are suitable for printing on 3D-printed objects. However, the print quality of both printing processes is affected by the surface of the 3D printed sample, which reduces the sharpness of the edges of the printed elements. It is important to emphasise that for colour printing in 4D printing, UV inkjet printing is more suitable than indirect electrophotography, as it allows colour printing on both sides of the programmable 3D structures. Heat transfer printing only allows printing on the underside of the programmable 3D structures.

The integration of 2D printing into 4D printing represents the next development step, which enables personalisation and aesthetic refinement of the products and can offer additional interactivity. The process presented for the production of practical objects enables 3D printing without support structures and thus avoids plastic waste. The flat geometry of the 3D objects enables volume-efficient storage, shipping and transport of the printed objects.
Research has shown that both printing techniques, direct and indirect printing, can produce an adequateprint quality. However, the requirements of the product must be carefully analysed in order to select the appropriate technique. The expansion of research into 4D printing opens the door to many innovations, particularly in the use of active elements that utilise dynamic morphing. Further research could improve the accuracy and efficiency of these processes while providing new solutions for industrial applications in 3D and 4D printing.

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ANALYSING THE REPRODUCTION QUALITY OF BRAILLE DOTS ON SELF-ADHESIVE LABELS PRODUCED WITH UV INKJET PRINTING

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Abstract: *Although modern digital technologies have successfully replaced many traditional methods of communication, including the use of braille for the blind and visually impaired, braille remains an important element of literacy for this vulnerable group. To accurately recognise the braille dots that make up the standardised characters, it is important that they have the correct dimensions, both in size and height. In this study, the reproduction quality of braille dots on self-adhesive labels was analysed. The elements were printed using the UV inkjet printing technique with a different number of passes (layers) to define and analyse the changes that occur with an increasing number of UV varnish layers. The samples were printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish. The image analysis with the scanning electron microscope (SEM) focussed on the change in the diameter of the dots. The braille dots show deviations from the digitally defined diameter in the graphic prepress (1.60 mm), especially in the horizontal direction, which is due to the spreading of the varnish and the movement of the print head. The first layers of UV varnish behave differently depending on the substrate, while the application of further layers reduces deformation and improves dot formation. Lifting the print head led to a stronger spreading and deformation of the dots in both samples.*

Key words: Braille printing, UV inkjet, UV varnish, image analyses, visual impairment

1. INTRODUCTION

Visual impairment is a major global health problem. It is estimated that at least 2.2 billion people worldwide suffer from some form of visual impairment, including blindness (Pascolini & Mariotti, 2011; Hashemi et al., 2017; WHO, 2019). According to global statistics from 2020, 1.1 billion people live with a visual impairment. This includes 295 million people with moderate to severe impairment, 258 million with mild impairment and 43 million who are blind. In addition, 510 million people have near-vision impairment. Projections suggest that the number of people with severe or moderate visual impairment, including blindness, could rise to 1.7 billion by 2050 compared to 703 million in 2017 (Ackland, Resnikoff & Bourne, 2017; Bourne et al., 2017; IAPB, 2024). These statistics emphasise the urgent need for continued efforts to prevent, treat and integrate visually impaired people into society.
The integration of blind and visually impaired people into society represents a major social, humanitarian and economic challenge. One of the key factors in this process is the use of braille, which facilitates communication and navigation in everyday situations, e.g. when shopping, navigating in the environment, and accessing literature (Havenko et al., 2013). Since 2005, braille has been mandatory on pharmaceutical packaging in accordance with European Directive 2004/27/EC to facilitate access to information for blind and visually impaired people. According to this directive, braille must be uncontacted, with each braille cell representing a single letter, number, or punctuation mark (European Commission, 2005). Braille is only required on the outer, secondary packaging, which is normally made of cardboard. The product name does not have to be printed in braille on the primary packaging, such as blister packs, ampoules or bottles. However, in cases where only the primary packaging is used, such as large-volume bottles (500 ml, 1000 ml, etc.), a braille adhesive label can be applied during production (European Commission, 2005). It is expected that braille labelling will also be mandatory in the food and chemical industries in the future (Havenko et al., 2013). This emphasises the need to explore how braille can be applied to adhesive labels, which are often used for different types of packaging. In view of the specific tactile requirements and durability of the labels, this requires a careful selection of materials and printing technologies (Havenko et al., 2013).

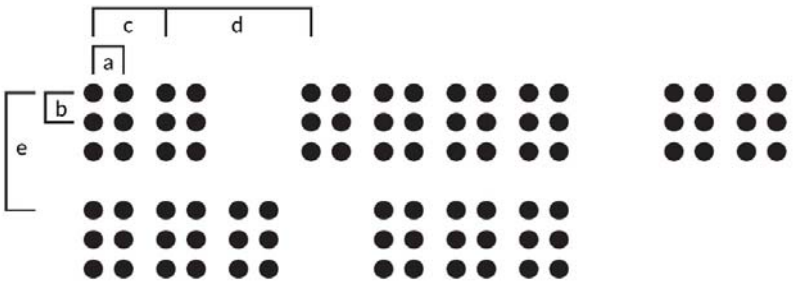
ORCID numbers are provided at the end of the paper.

Braille is not a language, but a universal code that can be adapted to many languages and enables people not only to read and write, but also to master spelling, punctuation, and text structure (American Foundation for the Blind, 2019; Royal Blind, 2019). The raised dots are felt by running a finger over them. They are an important tool for literacy and access to information, significantly improving the independence and social integration of people with visual impairments (European Commission, 2005; Royal Blind, 2019; VisionAware, 2019). This tactile writing system has become an important resource for the blind and visually impaired community worldwide.

Many countries, especially developed ones that produce braille have established their own standards that define the spacing between characters and the minimum height of the dots within each braille cell (Tiresias, 2008). As braille differs from country to country, standardisation has been introduced, including cell size (European Commission, 2005). For accurate recognition and high-quality reproduction of braille characters, the braille system must comply with certain standards and regulations (Rotar, 2021). The standards define the horizontal and vertical spacing between dots within a cell as well as the horizontal spacing between individual cells (i.e., between letters, numbers, or words). They also define the spacing between lines of braille text as well as the diameter and height of the braille dot.

For pharmaceutical purposes, braille must be printed in the Marburg Medium font and the name of the medicine must appear in lower case. This standard was developed specifically for pharmaceutical packaging and labelling and is used throughout the European Union, known as Marburg Medium Braille (Tiresias, 2008; PharmaBraille, 2019). It was recommended by the European Commission (European Commission, 2005; ECMA, 2006) and complies with both European and North American pharmaceutical industry standards.

The Marburg Medium braille standard defines the dot diameter as 1.3 to 1.6 mm and specifies the spacing between braille cells (PharmaBraille, 2019; ECMA, 2006) (Figure 1).



a. Horizontal spacing between dots: 2.5 mm (centre to centre)
b. Vertical spacing between dots: 2.5 mm (centre to centre)
c. Spacing between characters: 6.0 mm (cell to cell)
d. Spacing between words: 12.0 mm (between cells with a single space in between)
e. Spacing between lines: 10.0 mm
Tolerances: ±0.1 mm

Figure 1: Dimensions of braille cell spacing (ECMA, 2008)

Digital printing is becoming increasingly popular, and it is possible to create reliefs, including braille dots, on various substrates such as self-adhesive labels. Digital inkjet printing technology makes it possible to print on a variety range of materials with highly viscous transparent UV varnish. Some studies have shown the possibility of using UV inkjet printing technology to create braille dots on different types of materials (Golob, Rotar & Šulc, 2011; Golob et al., 2013; Klisarić, Novaković & Milić, 2013; Golob et al., 2014; Urbas et al., 2016; Rotar et al., 2020; Miloš, Vujičić & Majnarić, 2021). One study investigated certain technical aspects of reproducing braille dots on adhesive labels using this printing technique (Havenko et al., 2013).

Miloš, Vujčić and Majnarić (2021) investigated the potential of reproducing braille using UV inkjet printing on self-adhesive labels that were previously printed using flexographic printing. The study found that 12 layers of UV varnish produce high-quality, readable braille that represents an optimal balance between quality and cost. The study was conducted with blind and visually impaired people, who gave the 12-layer samples high ratings for legibility and quality. Increasing the number of layers further improves readability, but also increases material consumption and time. The dots had a domed shape and their height reached an optimal level at 12 layers, approaching standards such as the ECMA Euro Braille

standard (0.50 mm). The study concludes that UV inkjet printing is suitable for reproducing braille and suggests further research into the effects of different substrates and the durability of the prints.
In their 2021 review paper, Vujčić et al. provided an overview of the state in the field of UV inkjet printed braille. They concluded that printing braille using digital UV inkjet technology has a promising future. However, they emphasised the need for a series of detailed studies. In their opinion, these studies should focus on different types of substrates, different types of varnishes, resistance to mechanical impact, print durability, working conditions and similar factors.
The reproduction of braille dots using UV inkjet printing on self-adhesive labels is still little researched. The aim was to determine whether it is possible to reproduce braille dots in a suitable shape and diameter and to assess how the appearance and diameter of the dots change with an increasing number of layers of varnish.

2. MATERIALS AND METHODS

In this study, the quality of braille reproduction was analysed in terms of the diameter dimensions of braille dots printed with UV varnish on a Roland VersaUV LEC-540 device using two types of self-adhesive papers/films. These papers are used in various applications, mainly for product labelling.
Two types of self-adhesive papers/films were used: MP CHROM 90V EP KR80 (Muflon, Slovenia) and JAC SERILUX 70100. MP CHROM 90V EP KR80 is suitable for all types of labels that require good print quality. It is a white, uncoated, glossy paper with good mechanical properties. This material achieves good print quality with all conventional printing techniques in label production. It is also suitable for thermal transfer printing (Muflon, n.d.). JAC SERILUX 70100 is a transparent, glossy PVC film used for the production of high-quality labels for indoor and outdoor use. This film is characterised by high tear resistance and good resistance to ageing, water resistance and light fastness, depending on the specific application. JAC SERILUX films are suitable for screen and UV offset printing (JAC, 2021). The properties of the self-adhesive papers/films used are listed in Table 1. The data was taken from the manufacturers' technical data sheets and refers to the top layer (face material) of the respective papers/films.

Table 1: Characteristics of the self-adhesive papers/films used (Muflon, n.d.; JAC, 2021)

	Paper type	Weight (g/m^2) ISO 536	Thickness (µm) ISO 534
Sample 1	MP CHROM 90V EP KR80	90	74
Sample 2	JAC SERILUX 70100	114	90

Braille cells containing all six dots were printed. The braille cell was produced with a dot diameter of 1.6 mm in accordance with the Marburg Medium braille standard. The braille dots were printed with a liquid UV varnish that was applied directly to the substrate and cured with UV light. The varnish droplets are very small, only 6 pl, and cure under LED light. This process enables printing on non-absorbent substrates as curing is immediate and prevents the ink from smearing. The diameter of the droplets formed is less than 20 µm. An ECO-UV varnish with the following composition was used (Roland, 2019): 1,6-hexamethylene diacrylate 20-30%, 2-methoxyethyl acrylate 20-24%, benzyl acrylate 10-25%, N-vinyl caprolactam 10-20%, and diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide 5-10%. The samples were printed with different numbers of varnish layers to assess the changes in the formation of braille dots and the changes in diameter with increasing numbers of varnish layers. Full braille cells were printed with 2, 4, 6, 8, 10 and 12 layers. A maximum of 12 layers of varnish were applied, as previous studies have shown that this number results in high-quality, legible braille (Miloš, Vujčić & Majnarić, 2021). A glossy mode was used for printing (drying with a single UV lamp), with a print resolution of 740 × 1440 dpi. The print direction was set to bidirectional and the dither method was used for screening. Printing was done in high-quality with a larger number of varnish layers, higher resolution and lower printing speed. After applying 7 layers of varnish, the print head was lifted to prevent it from catching on the previously formed braille dots and causing damage.

The image analysis was performed on images taken with a scanning electron microscope (SEM) JSM-6060 LV (Jeol, Japan). The SEM images at different magnifications were used together with ImageJ software for digital image analysis. Before the samples could be analysed, they had to be prepared. The elements to be viewed under the SEM microscope were isolated. The samples were then attached to metal holders adapted to the samples and the SEM microscope using double-sided adhesive tape. The holders with the samples were placed in a fine coater where a thin layer of gold was applied to the sample surface under an electric current (30 mA). The coating process lasted 90 seconds and the applied gold layer thickness was 9.2 nm. The coating was performed using a JFC 1300 Auto Fine Coater (Jeol, Japan). The prepared samples were then placed in the SEM for observation and the desired images were captured. The samples were viewed from above to obtain information about the morphology of the braille dot surfaces, the shape and diameter/size of the printed braille dots (or cells), possible bleeding, etc. The observations were performed at different magnifications to obtain adequate and precise information (Milošević, 2019; Rotar, 2021).
The captured images were analysed using ImageJ software to measure the diameter of the braille dots. First, a calibration had to be carried out in order to obtain precise results. Then the measurements were taken. Due to the observed differences in diameter in the horizontal and vertical directions, the measurements were carried out in both directions. Ten measurements were taken in both the horizontal and vertical directions and the average of the measurements was calculated. It is important to emphasise that the diameter of the dots was measured from the edge where the height of the dot began to increase (Figure 2). This measurement method was chosen to reflect the circumference of the dot that would be tactilely recognised when reading braille by moving the finger over the dots.

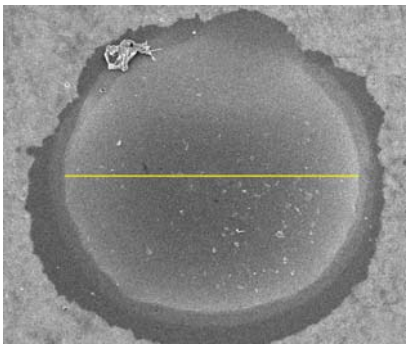


Figure 2: Display of diameter measurements on a braille dot formed by applying 12 layers of UV varnish

3. RESULTS AND DISCUSSION

3.1 Sample 1

Figure 3 shows a diagram depicting the measured values of the diameter of the braille dots in horizontal and vertical direction for a different number of varnish layers: 2, 4, 6, 8, 10 and 12 for sample 1. The diagram emphasises the maximum standard value according to the Marburg Medium standard, namely the diameter of the braille dots as digitally defined in the graphic prepress and set at 1.60 mm.
The examination of the measured diameter of the dot in sample 1 shows deviations from the digitally defined diameter in the graphic prepress (1.60 mm). The horizontal diameter is larger than the vertical diameter, which indicates that the vertical measurement is closer to the standard value. This indicates a larger deformation in the horizontal direction, which is probably due to the movement of the print head and affects the trajectory of the varnish droplets before the UV light initiates drying.
After applying two layers of UV varnish, the vertical dot diameter is slightly larger (1.617 mm) than the standard, while the horizontal diameter increases significantly to 1.767 mm and exceeds the standard by 0.167 mm. This results in an elliptical shape as shown in Figure 4a (*with a yellow circle marking the standard diameter in the SEM images*). The horizontal bleeding of the dot is probably caused by the movement of the print head in the horizontal direction, as previously mentioned. When the varnish droplets are applied in this direction and absorbed by the surface of the paper, this leads to an increase in diameter along this axis.

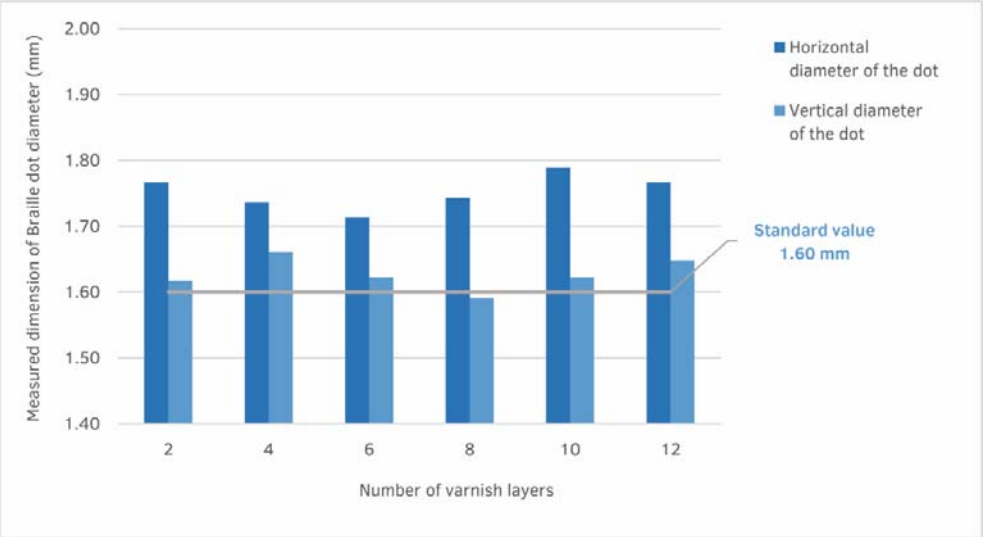


Figure 3: Measured dimensions of the diameter of the braille dots in horizontal and vertical direction printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish on sample 1

Subsequent varnish layers touch the previously printed, polymerised layers and not the substrate directly. They are printed using the same graphic prepress. The first layer penetrates the substrate, fills surface irregularities and creates a more uniform surface, reducing dot deformation and improving precision (Urbas et al., 2016). Bleeding of the varnish is minimised and depends on whether and to what extent, the varnish flows over the edges of the previously polymerised layers. With reduced bleeding, the application of subsequent layers of varnish leads to an increase in the dot height and reduced bleeding in the dot base (Miloš, Vujčić & Majnarić, 2021). It is noticeable that the horizontal and vertical diameters become narrower, which leads to a rounder dot shape, especially at 4 (Figure 4b) and 6 layers (Figure 4c). In addition, the surface tension changes, which leads to less bleeding of the UV varnish and a more precise formation of the braille dot. This was also shown with a different type of material in the study by Urbas et al. (2016), where the material was first fully coated with UV varnish, and then the braille dots were applied.

Considering that after the application of 6 layers of varnish, the height of the dot has increased and that the SEM images also show that the dot has a spherical, dome-shaped form (Figure 4c), this significantly influences the behaviour when applying the subsequent layers of varnish. It is also important that the print head was lifted after the application of 7 layers of varnish so as not to damage the dot due to its greater height. Under the influence of gravity, varnish droplets flow down the dome shape of the previously formed layers. Depending on the direction and manner in which the varnish droplets flow before polymerisation, the deformation of the dot at its base, its bleeding and its change in shape varies, as can be seen in Figure 4d when 8 layers of varnish are applied. Increased bleeding and reduced print accuracy also occur when you raise the print head and increase the distance to the print substrate. In preliminary studies, a subjective analysis was carried out to evaluate the changes in the appearance of the dot surfaces during the successive layer-by-layer application of UV varnish. It was clearly established that in all samples analysed, more bleeding occurred after applying 8 layers of varnish, i.e. after applying the first layer after lifting the print head. It is a challenge to maintain printing precision at such small dimensions, especially when a larger number of layers of UV varnish are applied and the multiple movements of the material under the print head can lead to a shift in the area to be printed. This was observed in all samples analysed, but also in other samples that were not the subject of this study. For samples produced with 8 layers of varnish, it is difficult to accurately recognise the edge of the raised dot formed with 8 layers of varnish, especially in the horizontal direction. New layers of varnish bleed and polymerise unevenly over the previously formed raised dot, making its edges much harder to see and causing the formed varnish layers to blend together. It is important to emphasise that, due to the factors mentioned, it is not possible to measure the diameter of the given dots with high precision. Therefore, the results should be taken with caution.

In eight-layer samples, the bleeding of the varnish leads to a deformation of the dot base, which probably does not significantly affect legibility or tactile sensation, but can reduce the height increases and

sometimes merge dots. This deformation can lead to increased varnish consumption and aesthetic problems that are visible to the naked eye.
With the application of additional varnish (10 layers), the diameter of the raised dot increases, and its edges become more defined. This is because the varnish remains on the new base of the dot that has formed after the application of 8 layers. Here you can also see an increase in the height of the dot, and you can see the diameters created by applying different numbers of varnish layers, as shown in Figure 4e. For the sample with 12 varnish layers, the dot diameter is also clearly defined. It approaches the standard value (1.60 mm), and the dot height continues to increase (Figure 4f).

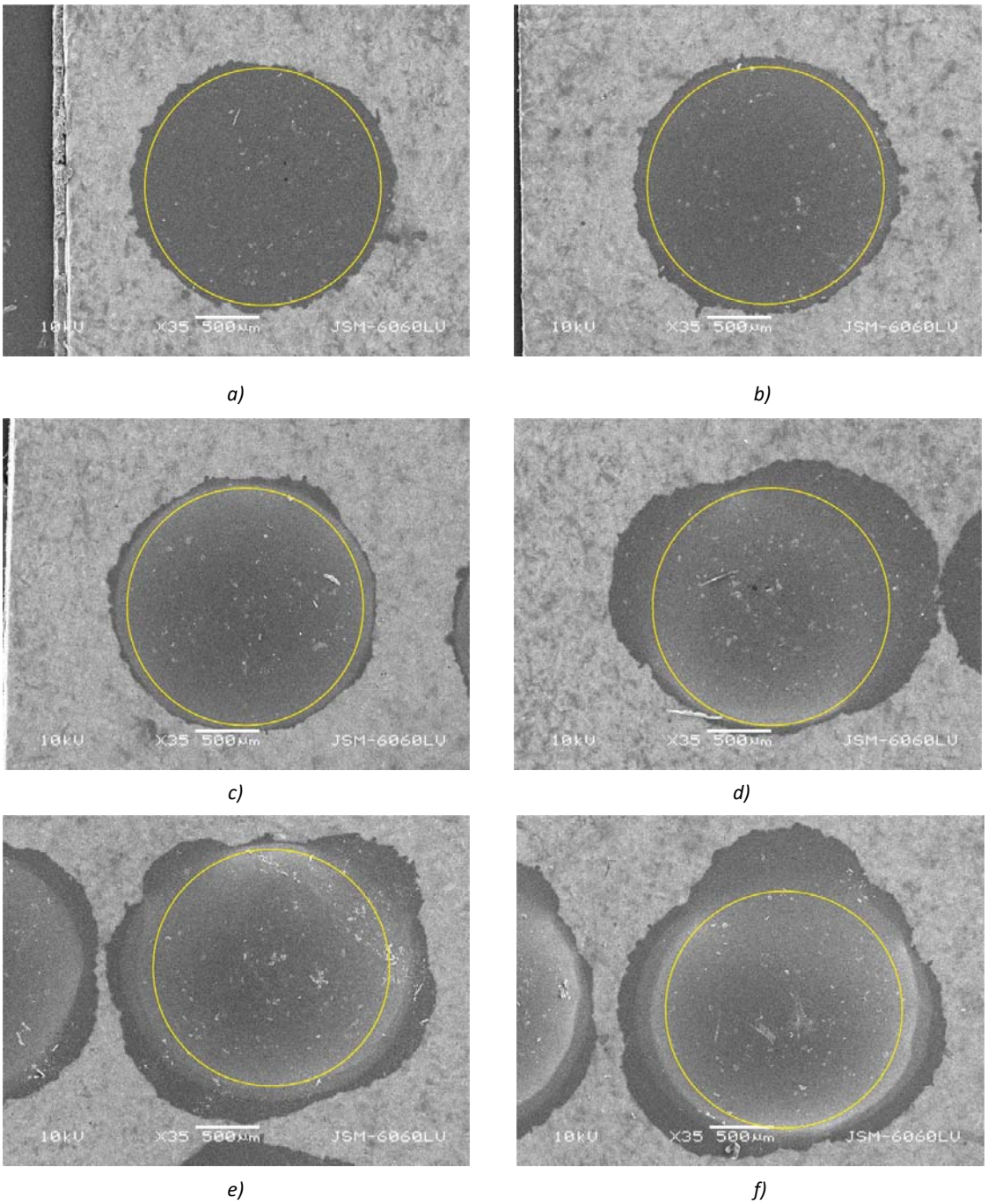


Figure 4: Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 1 (SEM; 35× magnification)

Table 2 shows the average values of the diameters of the braille dots, measured horizontally and vertically on sample 1, with the values of the standard deviation and the deviation from the standard value of the dot diameter in per cent.

Table 2: Average values of the diameter of the braille dots, measured horizontally (Hor.) and vertically (Vert.), with standard deviation and the percentage of deviation from the standard value, for sample 1

	2 layers of UV varnish		4 layers of UV varnish		6 layers of UV varnish		8 layers of UV varnish		10 layers of UV varnish		12 layers of UV varnish	
Braille dot diameter	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
Standard dot diameter	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Average dot diameter (mm)	**1.767**	**1.617**	**1.736**	**1.661**	**1.713**	**1.622**	**1.743**	**1.591**	**1.789**	**1.622**	**1.767**	**1.648**
Stdev (mm)	0.022	0.012	0.007	0.010	0.006	0.006	0.017	0.007	0.012	0.006	0.005	0.014
Deviation from the standard value (%)	10.467	1.085	8.506	3.800	7.088	1.402	8.926	-0.544	11.809	1.402	10.437	3.001

3.2 Sample 2

Figure 5 shows a diagram depicting the measured values of the diameter of the braille dots in horizontal and vertical direction for a different number of applied varnish layers: 2, 4, 6, 8, 10 and 12 for sample 2. The diagram emphasises the maximum standard value according to the Marburg Medium standard, i.e. the digitally defined diameter of the braille dots in the graphic prepress of 1.60 mm.

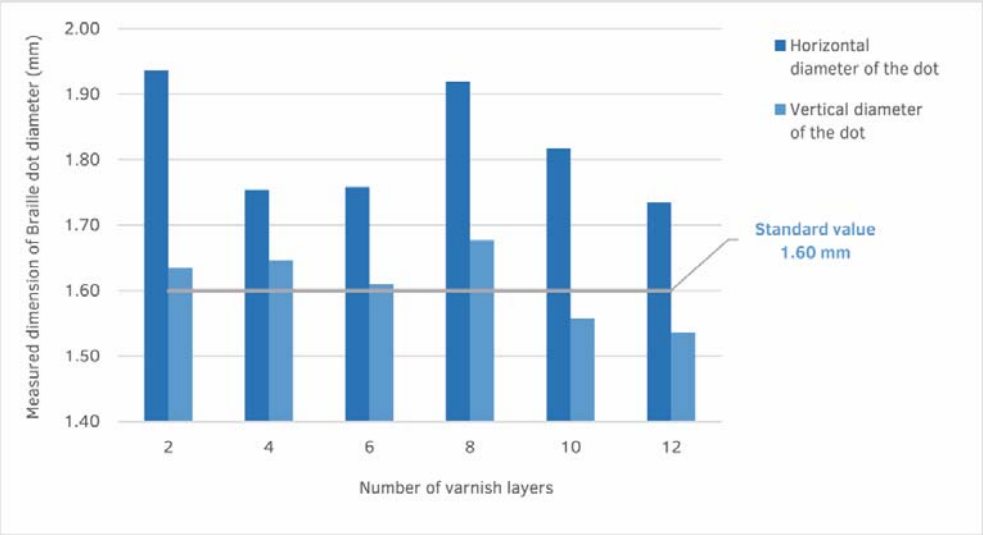


Figure 5: Measured dimensions of the diameter of the braille dots in horizontal and vertical direction printed with 2, 4, 6, 8, 10 and 12 layers of UV varnish on sample 2

In sample 2, deviations from the defined dot diameter of 1.60 mm are observed. The horizontal measurements show a larger diameter than the vertical ones, with the horizontal deformation being larger than the standard value, while the vertical measurements are closer to this value. As already mentioned, this horizontal deformation is probably due to the movement of the print head.

The analysis of the dot, which was formed by applying two layers of UV varnish, shows that the vertical diameter is slightly larger than the standard. The horizontal diameter has increased significantly to 1.936 mm, which is 0.336 mm above the standard (1.60 mm). This difference indicates an elliptical shape, as can be seen on the SEM image (Figure 6a). The dot appears "blurred" as it bleeds strongly. This is probably due to the non-absorbent printing substrate, which prevents the droplets from adhering to each other and bleeding horizontally before polymerisation.

Subsequent varnish layers are applied to already polymerised layers, which leads to less bleeding and more precise dot formation. The change in surface tension leads to an increase in height and a decrease

in bleeding at the base of the dot. The bleeding of the varnish is minimised and depends on whether and to what extent the varnish flows over the edges of the previously polymerised layers. With four layers of varnish, the horizontal diameter is 1.754 mm, which is only 0.154 mm above the standard, compared to the difference of 0.336 mm observed in a sample with two layers of UV varnish (Figure 6b). A similar trend can be observed with six layers (Figure 6c). Here, the horizontal diameter is 1.758 mm and the vertical diameter is almost ideal at 1.610 mm.

The SEM images (Figure 6c) show a greater height of the dot and a dome-like shape after six layers. After applying seven layers, the print head was lifted to prevent damage to the dot due to its increased height. Varnish droplets bleed unevenly due to gravity and affect the deformation of the dot (Figure 6d). The increased bleeding and reduced print accuracy are also due to the increased distance of the print head from the substrate. Although the deformation is noticeable in this sample, especially at the base of the dot, the edges are clearer, and we can conclude that there is no significant deformation in the shape of the dot. When examining the diameters, it can be seen that the horizontal diameter of 1.919 mm is well above the standard value and approaches the diameter measured after the application of two varnish layers. The vertical diameter has also increased slightly to 1.677 mm. As mentioned, the noticeable bleeding of the varnish due to gravity leads to larger diameters in both directions, with the diameter in the horizontal direction, being more pronounced, which is probably caused by the horizontal movement of the print head during the printing process.

After the application of ten layers of varnish, the horizontal diameter is 1.817 mm, while after the application of twelve layers it is 1.735 mm. The vertical diameter is 1.557 mm after ten layers and 1.536 mm after twelve layers, which is below the specified standard value. Here, too, a clear increase in dot height can be observed, as the varnish remains on the previously polymerised layers, which have become larger when eight layers are applied and form the basis for the subsequent layers (Figures 6e and 6f).

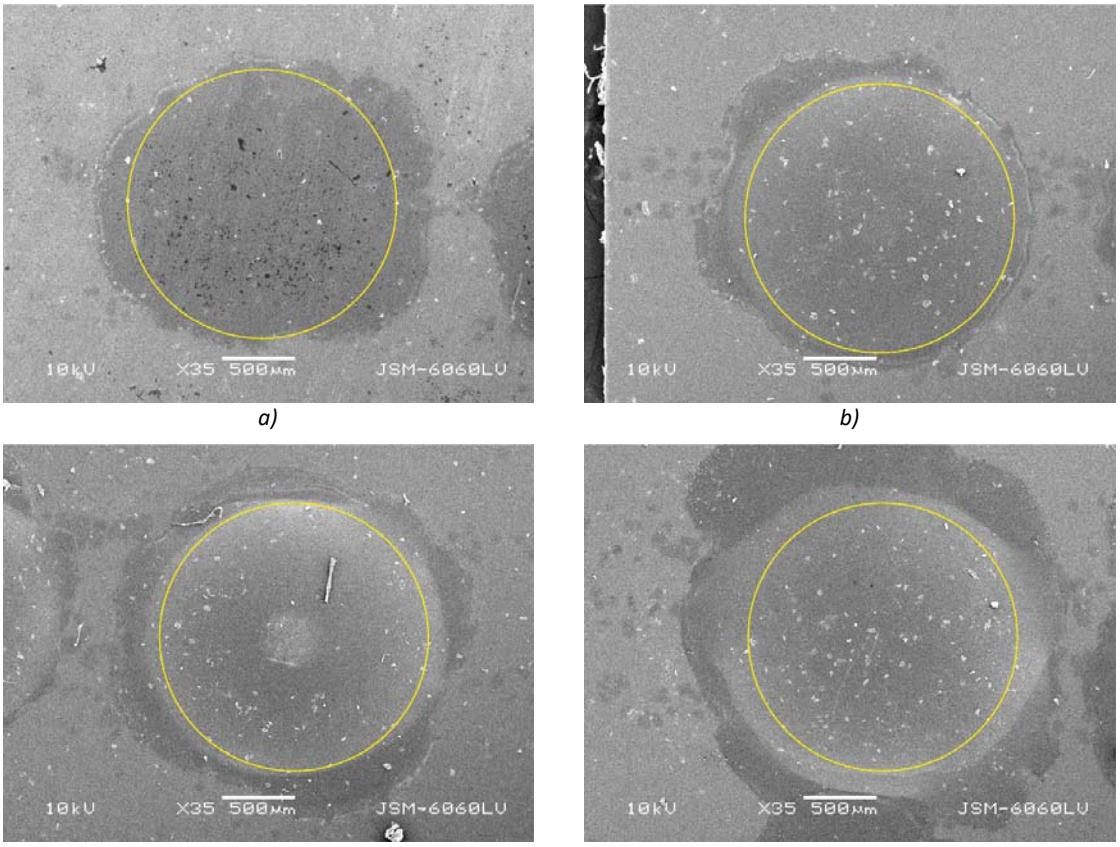
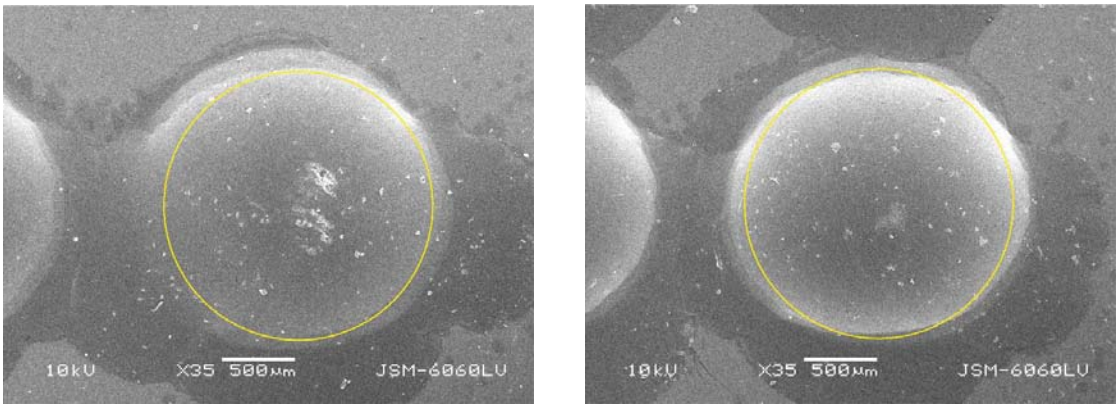


Figure 6 (part 1): Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 2 (SEM; 35× magnification)



e) *f)*

Figure 6 (part 2): Braille dot surface printed with 2 (a), 4 (b), 6 (c), 8 (d), 10 (e) and with 12 layers of UV varnish (f) on sample 2 (SEM; 35× magnification)

Table 3 shows the average values of the diameters of the braille dots, measured horizontally and vertically on sample 2, with the values of the standard deviation and the deviation from the standard value for the dot diameter in per cent.

Table 3: Average values of the diameter of the braille dots, measured horizontally (Hor.) and vertically (Vert.), with standard deviation and the percentage of deviation from the standard value, for sample 2

	2 layers of UV varnish		4 layers of UV varnish		6 layers of UV varnish		8 layers of UV varnish		10 layers of UV varnish		12 layers of UV varnish	
Braille dot diameter	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
Standard dot diameter	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Average dot diameter	1.936	1.634	1.754	1.646	1.758	1.610	1.919	1.677	1.817	1.557	1.735	1.536
Stdev (mm)	0.012	0.018	0.017	0.007	0.007	0.005	0.018	0.007	0.012	0.006	0.006	0.024
Deviation from the	21.025	2.126	9.622	2.850	9.879	0.648	19.924	4.826	13.559	-2.716	8.461	-3.983

When comparing the SEM images of sample 1 and sample 2, it can be observed that the height of the dots in sample 2 is more pronounced. This can be attributed to the non-absorbent nature of the substrate, which allows the varnish layers to remain on the surface of the sample and prevents partial absorption, as in the previous sample. In further investigations, it would be beneficial to measure the height of the dots and determine the differences in height obtained with the same number of varnish layers on different samples to determine the optimum number of layers for the desired height.

The comparison of the samples also shows that the bleeding of the varnish in sample 1 is much less pronounced, especially in samples that were printed with a lower number of UV varnish layers. This difference can be explained by the absorbent/non-absorbent properties of the respective materials. The dots in sample 1 are more precisely shaped before the application of eight layers of varnish, while the bleeding and deformation of the braille dot shape in sample 2 are noticeable from the beginning when only two layers of UV varnish are applied. Therefore, the properties of the materials, including surface characteristics, fibre direction, roughness, absorptivity and similar factors are of great importance. These properties should be further investigated to substantiate and confirm our conclusions.

Regarding the analysis itself, there are certain limitations worth mentioning. The cross-section of the dots, the appearance of their profiles, and the height values with a specific number of layers of varnish were not available during the analysis of the dot diameter and its changes with an increased number of layers. It is significant to have these representations and analyses since many assumptions and changes that occur with an increasing number of varnish layers are based on changes in dot height and profile appearance.

Furthermore, the height of the dot is a key parameter for braille readability. Miloš, Vujčić, and Majnarić (2021) concluded in their research that applying 12 layers of UV varnish results in optimal height and braille legibility. However, it is essential to verify the heights achieved with a given material and the number of layers applied, so that the optimal number can be chosen when producing braille for specific purposes.

4. CONCLUSIONS

Based on the measurements and analysis of the diameter dimensions of braille dots printed with UV inkjet technology and UV varnish, it is clear that there is a discrepancy between the digitally specified dimensions and the actual measured values. The horizontal bleed of the dots is particularly pronounced, which can be attributed to the movement of the print head in this direction and the behaviour of the varnish during application and drying. The diameter of the dots measured in the horizontal direction is consistently larger than the diameter measured in the vertical direction, while the vertical dimensions are closer to the maximum standard value of 1.60 mm, according to the Marburg Medium standard.

The application of the first layers of the UV varnish leads to an interaction between the varnish and the substrate, whereby the substrate in sample 1 absorbs the varnish, while the surface of sample 2 is non absorbent, which leads to a stronger bleeding of the varnish until polymerisation occurs. The application of the first varnish layers changes the surface structure of the samples, including their roughness, surface tension and similar properties. This has also been shown in previous studies (Urbas et al., 2016; Rotar et al., 2020), but it would certainly be beneficial for future research to investigate the properties of the analysed samples to support the conclusions drawn. Furthermore, when more layers are applied, the varnish comes into contact with the previously polymerised UV varnish layers, resulting in smaller dot deformations and better vertical formation of the dots. In the study by Miloš, Vujčić and Majnarić (2021), similar results were observed, and similar conclusions were drawn. This trend was observed in samples with 4 and 6 layers of varnish, where the dots increasingly approached a round shape and standard values.

Although previous research (Urbas et al., 2016; Miloš, Vujčić & Majnarić, 2021) has shown that braille dots are formed more accurately when applied on a previously polymerised layer, it must be taken into account that some substrates may not be suitable for varnishing before applying the braille dot and that the varnishing itself affects the surface, colourimetry, and other properties of the samples (Majnarić, Bolanča Mirković & Golubović, 2012), which could have a negative impact on the perception of the given samples and their print quality. In our opinion, the surface of the printing material should be completely coated with varnish before the Braille dots are applied to prevent the varnish from bleeding in sample 1. In the case of sample 2 (PVC foil), however, the inherent properties of the material mean that full-surface coating is not necessary. With further application of varnish layers, especially after the application of 8 layers, there is an increased bleeding of the varnish, which is attributed to the lifting of the print head and the gravity flow of the varnish from the height of the already formed dome-shaped dots. It was emphasised that in a preliminary study, in which a subjective evaluation and analysis of samples printed layer by layer with UV varnish was carried out, increased bleeding of the varnish was visible to the naked eye after the print head was lifted. This was observed in all samples analysed, not just those that were the subject of this study, and affected the precision of the dot edges, which can be clearly seen in the SEM images. Although this deformation may affect the aesthetic appearance of the dots, it is not expected to significantly affect the legibility of the braille, as the dots remain dome-shaped and are presumably tactilely recognisable.

This research demonstrated the importance of analysing the production of braille on different substrates. The self-adhesive materials used for the product labels have been carefully selected. They are two types: a paper and a PVC film, to determine whether the materials themselves have a significant impact on the formation of braille dots using UV inkjet printing technology. This impacts the accuracy of the dot edges, as shown in the SEM images. It was found that the dots on sample 1 (paper) were more clearly and precisely formed than on sample 2 (PVC film). This research enabled certain conclusions and assumptions to be made why there was a difference in the formation of braille dots, i.e., the behaviour of UV varnish on the given materials, but it would be necessary to investigate the absorptivity of the materials, their roughness, contact angle, and similar parameters to confirm the given conclusions.

In addition to the given analyses, it is recommended that future research focus on the measurement of the height of the dots, as this parameter is of great importance for the legibility of braille. Furthermore, analysing the cross-sections of the dots, performing profilometric measurements and using a 3D

microscope could provide additional information about the topography of the dots and contribute to a better understanding of the deformations that occur when multiple layers of varnish are applied. Future research could also consider the possibility of reducing the dot diameter with each subsequent layer to minimise the bleeding of the subsequent layers over the edges of the previously polymerised UV varnish layers. A series of samples could also be created where the horizontal bleed is compensated to achieve more accurate and consistent braille dots. The ability to print without lifting the print head should also be considered.

This study confirms certain conclusions from previous research (Urbas et al., 2016; Rotar et al., 2020; Miloš, Vujčić & Majnarić, 2021) conducted on other substrates, but also contributes from the aspect of analysing the behaviour of UV varnish on the given self-adhesive label materials and shows a clear difference in the formation of braille dots depending on the printing substrate. This research also opens up new ideas and provides guidance for future studies, both on these and other types of materials that could be used for the production of braille using UV inkjet printing technology. Future research should confirm the presented and provide further insights to establish clearer guidelines for the production of braille on these materials.

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PRELIMINARY STUDY ON POSSIBILITY TO USE AREA-BASED OPEN-SOURCE IMAGE ANALYSIS TOOLS IN ACCESSING SKIN TONE COLOR REPRODUCTION ACCURACY IN INK-JET PRINTING

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Abstract: *Colour is a complex and integral aspect of human visual experience, significantly impacting our daily lives by influencing emotions, behaviours, decisions, and even physical well-being. Colour perception is highly subjective, varying widely among individuals due to factors such as biological differences, psychological influences, and contextual conditions. To ensure accurate colour monitoring, objective colorimetric analysis is essential, particularly in the graphic industry where colour reproduction quality is paramount. This necessity becomes even more pronounced in the reproduction of skin tones, a critical area of research due to its association with memory colours and its influence on the perceived impression of people in images. Recent research has demonstrated that individuals with normal trichromatic vision can accurately differ subtle changes in skin colour, including slight shifts in chroma and hue towards more reddish tones compared to the actual skin shade. Objective colour reproduction analysis typically employs standard colorimetric measurement procedures, devices, and software solutions. However, commercially available devices are often expensive and robust, particularly in the objective quantification of colour reproduction on materials with specific surface properties and shapes. There is growing interest in quantitative colour measurements derived from low-cost, user-friendly software solutions paired with inexpensive imaging technologies, making objective colorimetric detection more accessible. In this paper, we investigate the potential of using two area-based open-source image analysis tools, ImageJ and Trigit, to assess skin tone colour reproduction accuracy. Targeted skin colour tones were ink-jet printed, scanned, and analyzed to extract colour coordinates using these tools, with manual measurements taken directly from the prints using a spectrophotometer as well. By calculating colour differences, we characterized the proposed colour measurement procedures. The research reviled certain advantages as well as limitations of usage of area-based open-source image analysis tools in characterizing skin colour reproduction.*

Key words: colour perception, skin tone reproduction, colorimetric analysis, image analysis tools, ink-jet printing

1. INTRODUCTION

Human colour vision can be explained through the integration of physics and biology, supported by the Young–Helmholtz theory and Newton's work in optics. According to Newton, the colour we perceive is the reflected light wavelength from an object's surface, while the remaining wavelengths are absorbed. In biology, colour vision relies on two types of photoreceptor cells in the retina: cone cells and rod cells. Cone cells, which number approximately 6 million per eye, dominate under bright conditions and are responsible for processing the three primary colours: red, green, and blue (Zeng, 2011; Woolf et al., 2021; Tjandra, Heywood & Chandrawati, 2023). These cells contain photopigments that are spectrally sensitive to specific wavelength ranges corresponding to these colours. In individuals with normal trichromatic vision, the brain processes and combines inputs from the three types of cone cells to reconstruct the observed colour. The human eye and brain then integrate this information to produce a unique signal that corresponds to a specific colour, with the number of distinguishable shades varying from person to person, ranging from 1 to 100 million colours (Zeng, 2011; Woolf et al., 2021; Tjandra, Heywood & Chandrawati, 2023).
The colour perception plays a significant role for humans, especially the colour perception of the skin. There are numerous studies highlighting the influence of facial skin tone perception not only on facial recognition but also on the interpretation of emotional expressions, health assessments, and evaluations of attractiveness (Shimakura & Sakata, 2022). Research has consistently shown that the perception of facial skin tone differs fundamentally from the perception of other colours. Individuals with normal trichromatic

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vision are capable of detecting subtle variations in human skin colour with remarkable precision. The perception of skin colour serves as a key predictor of attractiveness and is closely linked to judgments regarding an individual's health based on facial appearance (Shimakura & Sakata, 2022).

The study of skin colour has been extensive over many years due to its importance in various industries, including photography, printing, medical fields, lighting, retail, and cosmetics where accurate reproduction is essential. Accurate reproduction of skin colour is crucial in most of these applications to ensure optimal results, whether it be for visual consistency, medical diagnostics, or product matching (Wang et al., 2017). Skin colour is considered a memory colour, playing a crucial role in how people are perceived in images. With the widespread use of mobile devices such as smartphones and tablets, and the growing popularity of image capture and sharing applications, user demands have evolved beyond traditional accurate colour reproduction toward achieving preferred colour reproduction (Peng et al., 2023).

Accurately reproducing skin tones in a visually appealing manner is a crucial aspect of colour reproduction. Given that individuals often rely on their memory of object colours to assess the quality of colour reproduction, it is essential to understand the preferred colour reproduction range of skin tones and the methodology of colour measuring, for optimal preference-based colour reproduction (Zeng & Luo, 2010).

Skin colour must be accurately printed and calibrated to ensure proper colour reproduction. Utilizing a human vision detection method is inherently subjective and influenced by individual variability, potentially leading to inconsistent or inaccurate results (Tjandra, Heywood & Chandrawati, 2023).

In terms of quantifying colour, objective quantification of colours through empirical models of the colour space is required. Several methods and equations are available, with the most commonly used being the CIE L*a*b* colour space and colour difference equations (Sharma, 2018). It is hypothesized that skin tones have a lower tolerance for deviations, making them particularly important in colour management. Skin tones present a greater challenge in printing because changes or errors in colour are more readily perceptible compared to other hues.

Recently, there has been increasing interest in the quantitative colour measurement based on images captured using low-cost commercial technologies such as smartphones, scanners, and digital cameras for scientific applications. Image processing technology, a technology within the field of computer science and a important component of Industry 4.0, can be defined as a type of signal processing in which the input is an image, and the output can either be a modified image or a set of characteristics and parameters extracted from the image (Babič, 2018; Milošević et al., 2022). The advancement of affordable imaging technologies has enhanced the feasibility of objective colorimetric detection during the image acquisition process. Commonly used colour analysis software by researchers for those purposes includes ImageJ, MATLAB, Pantone Studio, Digital Colorimeter by Apple, Trigit, and various developer-customized tools (Tjandra, Heywood & Chandrawati, 2023). With this in mind, the present study explores the feasibility of utilizing two area-based open-source image analysis tools- ImageJ and Trigit- for assessing the accuracy of skin tone colour reproduction. Specifically, selected skin colour tones were printed using an inkjet printing machines, scanned, and analyzed to extract colour coordinates using the aforementioned tools. Additionally, manual measurements were conducted directly on the printed samples using a spectrophotometer. By calculating colour difference values, the proposed colour measurement procedures were evaluated and characterized. The research led to conclusions regarding the applicability of area-based open-source image analysis tools for the characterization of skin tone colour reproduction.

2. METHODS

For the purpose of this study, a test chart comprising twenty selected skin colour patches was developed (Figure 1). The chart was created using Adobe Illustrator CC, with 20 patches chosen from Adobe's original skin colour palette to represent the most commonly used skin tones in graphic design. The PDF file was prepared for printing in accordance with the colour specifications embedded in the Coated Fogra 39 profile. Printing was conducted on two different fully calibrated ink-jet printing machines: a solvent-based SOLJET Pro 3 Print and Cut XC-540, and a UV-based UV Print and Cut LEC-540, using two distinct output resolutions- 360x720 dpi and 720x1440 dpi-representing the lower and upper resolution limits, respectively. All other settings were consistent across both machines: the dither option was selected for rasterization, the nearest neighbour method was used for interpolation, and the bi-directional option was selected for print head movement. The printing substrate used was commercially available Display PP paper.

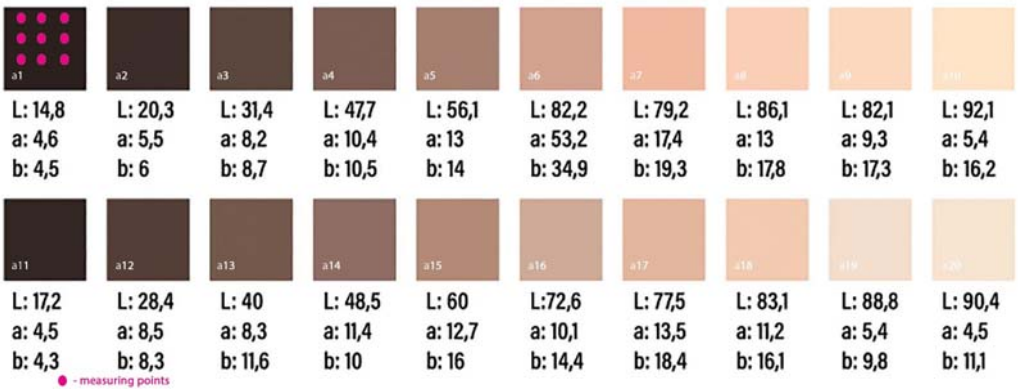


*Figure 1: The test chart and L*a*b* values of chosen samples with marked measuring points*

Colorimetric measurements of the L*a*b* values were conducted using a Techkon SpectroDens spectrophotometer (measurement geometry 0/45, illuminant D50, and 2° standard observer). Each patch was measured six times (Figure 1), and the average values were used for subsequent data analysis. The digitalization of the printed samples was performed using a CANON CanoScan 5600F scanner at native resolutions of 300 dpi, 600 dpi, 800 dpi, and 1200 dpi, with all image enhancement options disabled during scanning. The extraction of RGB and L*a*b* values from the digitized samples was carried out using two area-based, open-source image analysis tools: the latest versions of ImageJ (Figure 2a) (ImageJ, 2024) and Trigit (Figure 2b) (Trigit, 2024). In both software programs, the square selection tool was employed to define the area of interest (one colour patch). In Trigit, L*a*b* values were directly calculated, while in ImageJ, RGB values were initially extracted (Plugins > Analyze > RGB Measure) and then converted to L*a*b* values using reference XYZ values of 94.811, 100.00, and 107.304 (EasyRGB, 2024). The colour difference values, ΔE00 (EasyRGB, 2024), were calculated using the L*a*b* values obtained from both the spectrophotometer and the image analysis software. These colour difference calculations were used to characterize the proposed colour measurement procedures.

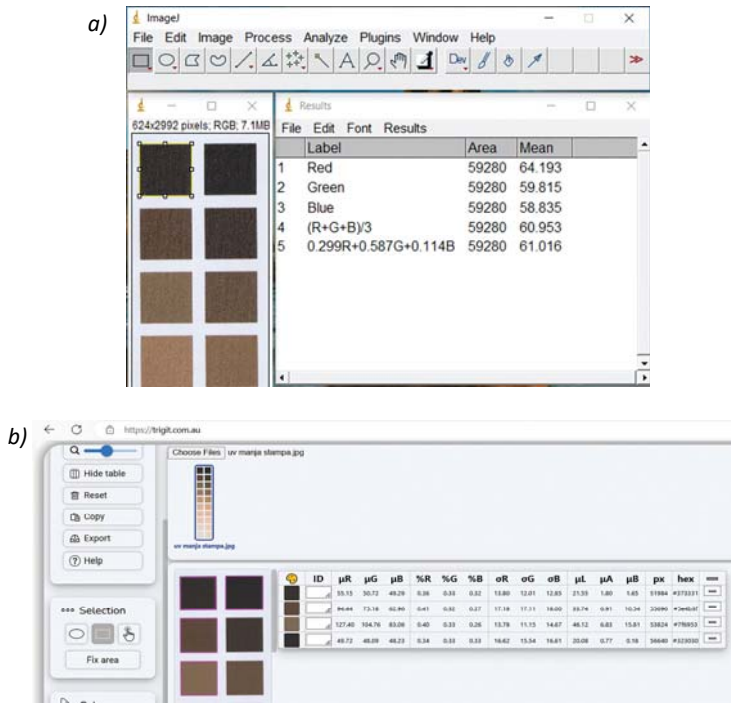


Figure 2: a) ImageJ, b) Trigit

3. RESULTS AND DISCUSSION

Figures 3–6 present the calculated colour differences (ΔE00) between the L*a*b* values of each colour patch, as measured by the spectrophotometer and those extracted from the scanned images using the open-source image analysis software, Trigit and ImageJ.

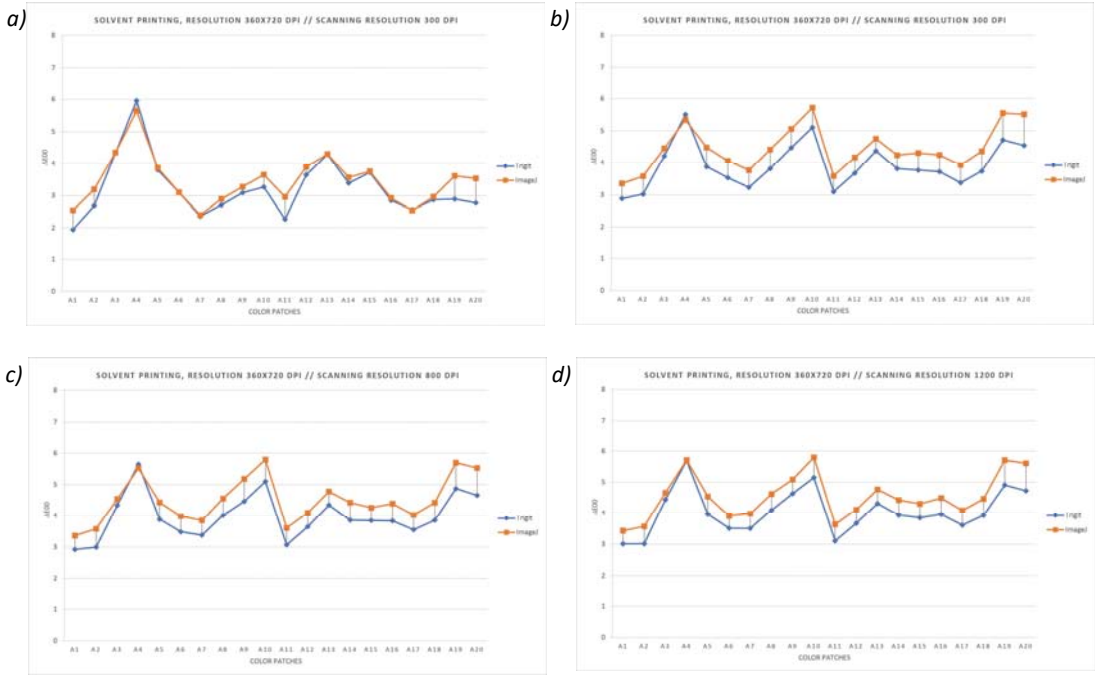


Figure 3: Colour difference values (ΔE00); solvent ink -jet printing, output printing resolution of 360x720 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 3 presents the calculated colour differences (ΔE00) for samples printed using a solvent-based inkjet digital printing machine at a lower printing resolution. As observed from the graphs, the calculated colour differences range from 1.5 ΔE00 to 6 ΔE00, with higher values for the lighter colour patches compared to the darker ones. The results clearly indicate that the colour differences between the measured L*a*b* values and those extracted in the Trigit software are lower than those obtained using ImageJ. This discrepancy may be attributed to the RGB to L*a*b* colour conversion methods employed. Furthermore, depending on the scanning resolution, these differences do not exceed 1.0 and are more pronounced at higher scanning resolutions. At lower scanning resolutions, the colour differences between the measured and extracted L*a*b* coordinates are reduced, with the lowest scanning resolution yielding the smallest colour differences.

Figure 4 presents the calculated colour differences (ΔE00) for samples printed using the same solvent-based inkjet digital printing machine but at a higher printing resolution. The colour differences range from 2 ΔE00 to 6 ΔE00, again showing higher values for the lighter colour patches than for the darker ones. A similar trend is observed, where lower colour differences are calculated between the measured L*a*b* values and those extracted in Trigit compared to ImageJ. As with the low-resolution samples, the differences are more pronounced at higher scanning resolutions but remain under 1.0. Additionally, the lower the scanning resolution, the smaller the colour differences between the measured and extracted L*a*b* values, with the lowest scanning resolution again producing the least deviation.

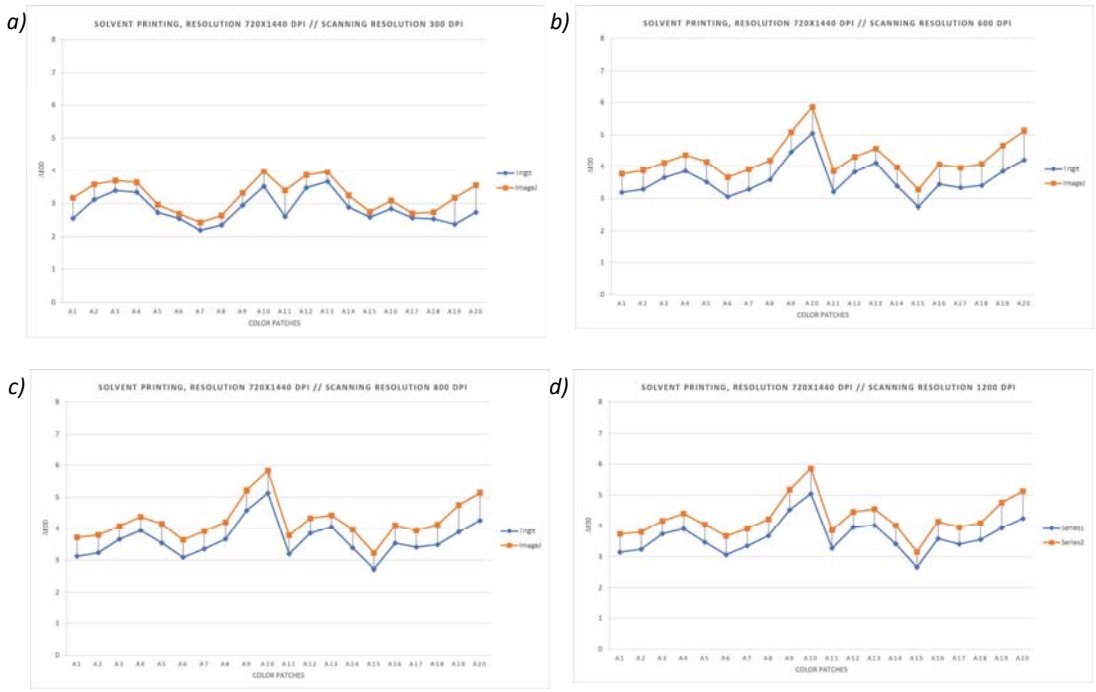


Figure 4: Colour difference values (ΔE00); solvent ink – jet printing, output printing resolution of 720x1440 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

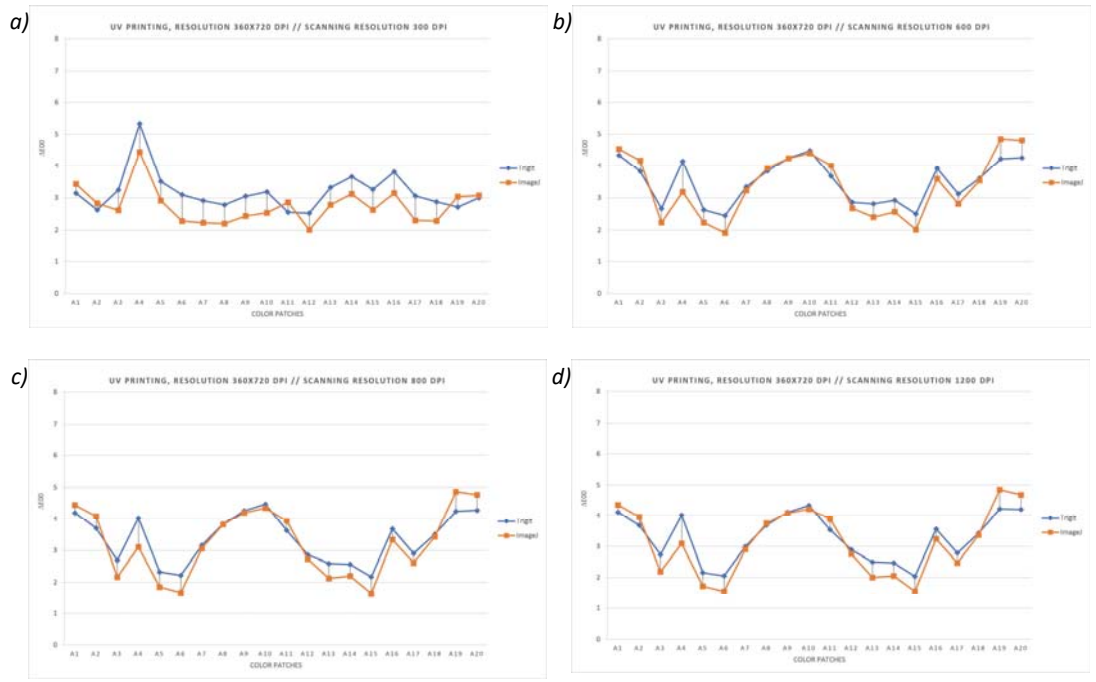


Figure 5: Colour difference values (ΔE00); UV ink - jet printing, output printing resolution of 360x720 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 5 presents the calculated colour differences (ΔE00) for samples printed using a UV inkjet digital printing machine at a lower printing resolution. The colour differences range from 1.5 ΔE00 to 5 ΔE00, with higher values observed for the lighter colour patches compared to the darker ones. Overall, the calculated colour differences are lower than those for samples printed with the solvent-based inkjet printing machine, which may be attributed to the higher image sharpness achieved with UV inkjet printing, even at lower output resolutions.

Except for the lowest scanning resolution, the lower colour differences were generally calculated between the measured L*a*b* values and those extracted in Trigit compared to ImageJ. However, it is important to note that for most colour patches, the calculated colour difference values are quite close between the two software tools, and the differences do not appear to be significantly influenced by scanning resolution. This may again be related to the higher image sharpness associated with UV inkjet printing, where higher scanning resolutions do not significantly enhance sharpness during image analysis, as might be the case with solvent-based prints.

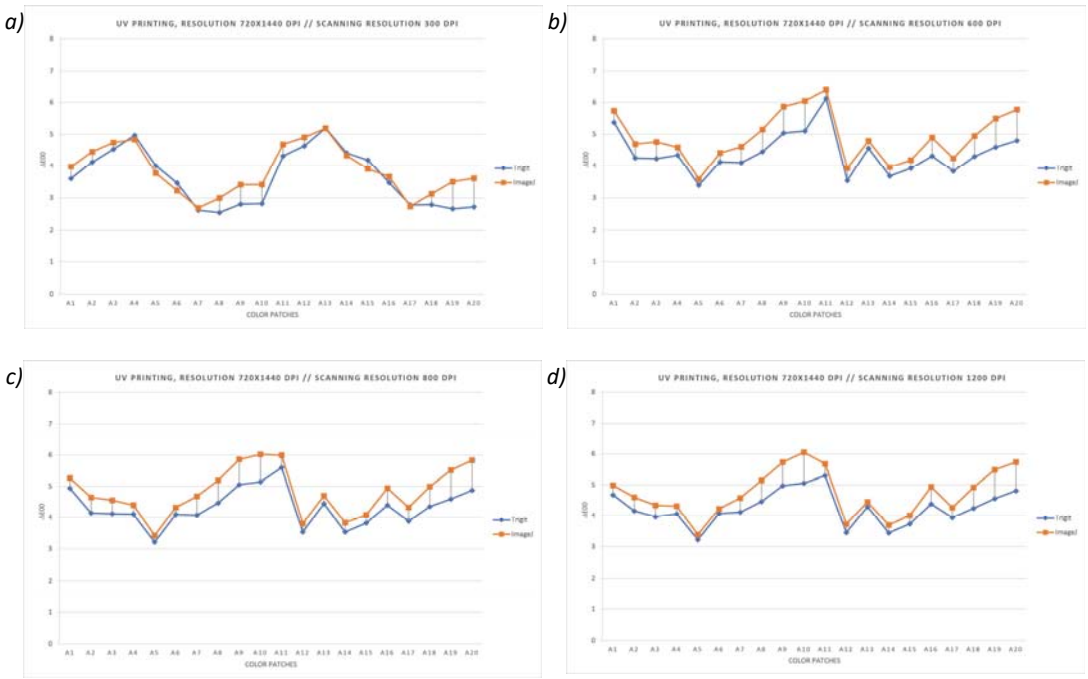


Figure 6: Colour difference values (ΔE00); UV ink - jet printing, output printing resolution of 720x1440 dpi and scanning resolution of a) 300 dpi, b) 600 dpi, c) 800 dpi and d) 1200 dpi

Figure 6 presents the calculated colour differences (ΔE00) for samples printed using a UV inkjet digital printing machine at a higher printing resolution. The colour differences range from 2.5 ΔE00 to 6.5 ΔE00, with higher values observed for the lighter colour patches compared to the darker ones. Overall, the calculated colour differences are slightly higher than those for samples printed at a lower resolution. As with the previous cases, lower colour differences were calculated between the measured L*a*b* values and those extracted using Trigit compared to ImageJ. However, these differences remain below 1.0 and appear to be largely unaffected by the scanning resolution. This may again be attributed to the higher sharpness achieved with UV inkjet printing, where increased scanning resolution does not significantly improve sharpness during image analysis, as might occur with solvent-based prints. As the scanning resolution increases, the colour differences tend to slightly increase, suggesting that lower scanning resolutions may result in marginally lower colour differences.

5. CONCLUSIONS

In this paper, we investigated the feasibility of using two area-based, open-source image analysis tools-ImageJ and Trigit-for assessing the accuracy of skin tone colour reproduction. The conducted research and data analysis led to the following conclusions:

- Quantitative colour measurements obtained from cost-free, tailor-made, user-friendly software solutions such as Trigit and ImageJ, combined with inexpensive image digitization technologies (e.g., scanning), can be characterized as straightforward and easy to perform.

- Both software tools require the manual definition of the region of interest (ROI). Trigit offers more convenient colour calculations, as it directly computes L*a*b* values, whereas ImageJ requires post-processing of extracted RGB data to derive L*a*b* values. The method of calculation (i.e., the definition of the illuminant and the standard observer via XYZ reference values) can impact the final results in both cases.
- The calculated colour differences between instrumentally measured L*a*b* values and those derived from scanned images of selected skin colour patches ranged from 1.5 ΔE00 to 6.5 ΔE00, reflecting low to highly distinguishable differences.
- Colour differences tend to be higher for lighter colour patches compared to darker ones. Trigit consistently produced lower colour differences between measured and extracted L*a*b* values than ImageJ, potentially due to differences in the methods used for calculating L*a*b* colour coordinates.
- The analysis revealed the impact of both scanning resolution and image sharpness (linked to the output resolution and printing method—solvent or UV-based) on the results. However, scanning resolution appears to have a lesser effect on colour differences compared to image sharpness.
- Generally, lower scanning resolutions resulted in lower colour differences.
- The potential for using open-source image analysis tools to assess colour reproduction accuracy is considerable. However, further investigation is needed to evaluate the influence of various printing substrates and conditions, digitalization methods and their potential, as well as colour coordinates and colour differences calculation methods in order to express with more certainty that this methodology could substitute devise-based colour measurements. This is especially important to be further investigated in the domain of accessing colour reproduction accuracy of skin colours, since even slightest changes in the reproduction could be detected by the human eye, thus methods used for monitoring and delivering accurate colour reproduction must be repeatable, stable and if possible standardized.

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THE IMPACT OF LASER ENGRAVING PARAMETERS ON THE COLORIMETRIC PROPERTIES OF STEEL SURFACES

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Abstract: *Laser engraving technology is increasingly prevalent in the graphics engineering industry due to its speed, precision, and capacity for individualization. This method is widely used for decorative metalwork, metal packaging, and signage, providing high-quality aesthetic results on various surfaces. This study investigates the impact of different laser engraving parameters, such as speed, hatching, frequency, and power, on the colorimetric properties of steel surfaces. The experiments were conducted using a fiber laser with a power of 30 W and a wavelength of 1064 nm on polished steel plates measuring 20 x 20 cm with a thickness of 4 mm. Engraved samples, each measuring 5 x 5 mm, were produced, with laser parameters varied for each sample. After engraving, each sample was analyzed under a microscope and measured using a spectrometer to accurately determine colorimetric values, offering precise quantification and analysis.*
The results indicate that engraving speed significantly affects the depth and intensity of color, with lower speeds allowing deeper oxidation and more saturated colors. Increased laser power generates greater heat, resulting in more vibrant color tones. The frequency and pulse duration of the laser influence energy distribution and heating patterns, with shorter pulses producing precise changes in colorimetric properties and longer pulses causing deeper alterations. The hatching pattern also affects the colorimetric properties due to variations in heat distribution and energy absorption. High temperatures are critical for color formation as they facilitate the oxidation process, where the oxide layer's thickness and composition determine the final color.
These findings enable designers and technicians in the graphics engineering industry to control the aesthetic aspects of steel engraving with greater precision. Moreover, the results of this study could be utilized to develop software for the automatic adjustment of engraving parameters to achieve desired color images on steel surfaces. Such software would significantly enhance the efficiency and effectiveness of laser engraving processes, offering new possibilities for creative applications in the design of metal packaging and signage. By integrating these insights, the graphics industry can achieve more consistent and high-quality outcomes, driving innovation and expanding the potential uses of laser engraving technology.

Key words: laser engraving, colorimetric properties, hatching patterns, spectrometry analysis

1. INTRODUCTION

Lasers have been widely used in industry for welding and cutting operations, but with increased technology development and progress, lasers are now being used for marking, engraving and decorative designs on various materials. Nowadays, industry product identification is of high importance for many reasons such as improving security and efficiency or brand protection (Mehta & Thakkar, 2015). This type of technology has been increasingly prevalent in the graphics industry due to its speed, precision, non-contact technique and ability for individualization. Laser engraving can provide high-resolution and sometimes permanent marks and can be applied on metallic and non-metallic surfaces. This technology does not produce waste, nor does it require printing inks or additional solvents which can be very practical and environmentally friendly (Roozbahani et al., 2020). Light Amplification by Stimulated Emission of Radiation (LASER) is a powerful and focused energy that can modify surfaces of materials. Laser color marking is a complex process of removing the top layer surface of a material. With the optimization of certain parameters, laser can create high contrast marks on a metal surface that can result in color generation due to surface oxidation when the laser beam interacts with the specific material (Maltais et al., 2016; Tsvyatkov et al., 2023). Color generation can vary depending on the chemical structure of the metal and different parameters that are set for a specific laser. Similar colors can be achieved using a different set of parameters and this area of metal colorization needs to be further investigated (Veiko et al., 2016). Color variation also depends on a laser being used for color laser marking.
In a study of laser-induced color marking (Antończak et al., 2013) it was found that initial temperature of a sample, as well as its size, does not have an impact on color variation of similar samples, while parameters such as speed and power had dominant influence on color change. They also found that lower frequencies

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gave more saturated colors. Amara et al. (2015) concluded that the difference in the thickness of an oxidized layer was responsible for different color generation on steel surfaces. This can indicate that varying speed and line distance has an influence on forming different oxide layers. In a formation of color on stainless steel study (Linggamm et al., 2021) it was found that defocusing distance, hatch distance and pulse width have a great effect on obtaining color on stainless steel surface. The study shows that the same colors can be produced with different laser parameters, but the brightness and saturation of colors can differ. Linggamm et al. (2021) also investigated roughness of the surface of the color obtained. The study concluded that roughness of the surface is an important aspect of color making where smoother surface and large value of pulse width produces brighter and lighter colors because the heat is distributed more evenly. Respectively, the rougher the surface the color gets darker. The study also found that pulse width and defocusing distance had more influence on coloring stability than hatching distance. A review on parametric optimization of laser engraving on various materials (Mehta & Thakkar, 2015) concluded that almost all laser parameters and their effects on different surfaces have been studied and that it is possible to create a proper optimization of the laser parameters for high production with great quality which could be beneficial for graphics industry.

This study investigated the effects of fiber laser engraving parameters on the colorimetric properties of steel surfaces. The laser parameters examined for color generation included power, speed, frequency, hatching, and pulse width. Representative color samples were measured using an iProfile Pro spectrometer and surface structures were observed under a microscope to identify correlations with the resulting color parameters. Additionally, the study explored the color variation that occurred when altering the angle of the laser beam while engraving larger surface areas. The findings provide insights into the relationships between various factors influencing laser-induced coloration on steel surfaces.

2. MATERIALS AND METHODS

Laser parameters from previous studies were tested and it was concluded that repeatability of gaining the same colors for different laser machines is not possible. It was necessary to conduct new tests for this specific laser with different parameters. The study was performed on JPT Mopa C fiber laser with output power of 30 W with working area of 15 x 15 cm. Laser wavelength is 1064 nm, with frequency range from 1 to 400 kHz and speed up to 7000 mm/s. The experiments were conducted on polished steel plates each measuring 20 cm x 20 cm with thickness of 4 mm. The testing procedure involved arranging 5 x 5 mm fields into a table, with the values of two parameters varying along the x and y axes, as shown in Figure 1. In each test, two parameters and their potential correlation were evaluated. Initially, parameters that were not subject to change were set to their default values.

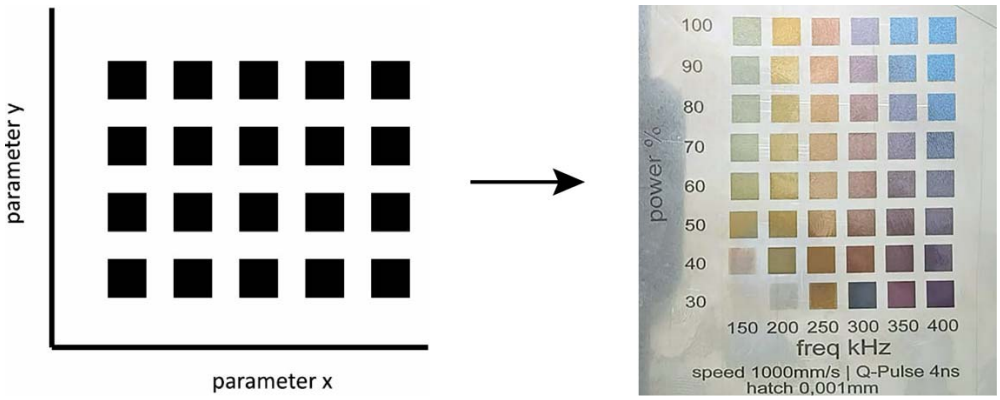


Figure 1: Laser parameter matrix for color testing

Initially, power and frequency were tested. Power values ranged from 10% to 100%, in 10% increments, while frequency was varied from 50 kHz to 400 kHz across eight steps. The hatch (line distance) was maintained at 0.001 mm, with a speed of 1000 mm/s and a pulse width of 200 ns. The initial test indicated the emergence of color within the 30% to 70% power range and between 150 kHz and 300 kHz in frequency. Subsequently, speed and hatch were examined. The speed ranged from 700 mm/s to 7000 mm/s, and hatch varied from 0.001 mm to 0.008 mm. Based on the results of the previous test, optimal values for frequency and power were determined to be 50% power and 200 kHz. The findings demonstrated that with

increasing speed and hatch, the colors faded rapidly. It was concluded that speeds above 3500 mm/s were unnecessary when power was set at 50%, and the optimal speed range was identified as 1000 mm/s to 2400 mm/s. Additionally, the most saturated colors were observed with a line distance of 0.001 mm.
The test has shown that frequency changed color, while power was toning the color from light saturated to vibrant or showing a change in similar colors such as from purple to blue. Lower pulse width gave more saturated colors with mat finish. The test has also shown a wide range of colors from yellow, orange, light red, purple and blue. 50% power row showed the most saturated colors, and that power was chosen as optimal. The next step was to test the impact of changing the Q-pulse and frequency on color formation. The results showed that low pulse widths and frequencies below 250 kHz do not produce an oxidized layer necessary for color formation. With power set to 50%, the next step was to investigate whether color could be achieved by increasing the pulse width in combination with power scaling. The results further confirmed that power alone does not influence color, and that high power combined with a larger pulse width leads to burnt areas. To generate color, power and Q-pulse values must have an inverse relationship; high pulse widths should be paired with lower power percentages, and vice versa, to achieve saturated colors on stainless steel.
With the optimal power, frequency, and pulse width determined, speed and hatch were varied. The same power-frequency test was conducted with a 0.002 mm line distance (hatch), and the resulting colors were similar to those achieved with a 0.001 mm line distance, though the order in which they appeared through frequency scaling was inverted. This test demonstrated that similar or identical colors can be obtained with different line distances, potentially accelerating the laser engraving process. However, if a larger line distance is selected, it is essential to adjust other parameters accordingly. A 0.001 mm hatch was chosen for most of the tests, as it produced a finer color structure. The drawback of using a smaller line distance is the slower engraving time. Accelerating the laser engraving process is crucial for broader commercial applications in graphic technology. Therefore, the next step was to test different speed values and assess their influence on oxidation and color appearance on steel surfaces.
The power-speed test further confirmed that power primarily modulates the intensity of colors achieved with specific parameters. Lower power values combined with higher speeds produced dull, low-saturation colors, as shown in Figure 4. The frequency-speed test (Figure 6) visually demonstrated a linear correlation between these two parameters. Similar colors can be obtained when both parameters are doubled. For example, the color in the lower-left corner at a frequency of 150 kHz and a speed of 600 mm/s can also be achieved by setting the frequency to 300 kHz and the speed to 1200 mm/s with a 0.001 mm line distance. After testing all relevant parameters and generating the necessary color palettes, the next phase involved measuring the colorimetric values of the samples. The following section presents the obtained results along with their analysis.

3. RESULTS

In this section, we present the analysis of the test samples created using various laser parameters. The samples were examined using both a spectrometer and a microscope to provide a comprehensive evaluation of the surface coloration. The spectrometer measurements offer quantitative data on the colorimetric properties, while the microscopic analysis allows us to observe the surface structure and texture in detail. By combining these methods, we aim to identify key correlations between the laser settings, surface morphology, and the resulting color stability and intensity.

3.1 Spectrometer measurements

In this section, we analyze the colorimetric values of the test fields created using various laser parameters, measured with a spectrometer. This approach allows us to quantify the color properties and identify correlations between specific laser settings and the consistency of surface coloration. By examining the spectrometer data, we aim to better understand how adjustments in production parameters influence the stability and intensity of the colors generated on the steel surface. Spectrometric curves are presented in the figures below. On the x-axis is wavelength in nanometers, values form 380 nm to 730 nm, and on the y-axis is the intensity of the reflected light.

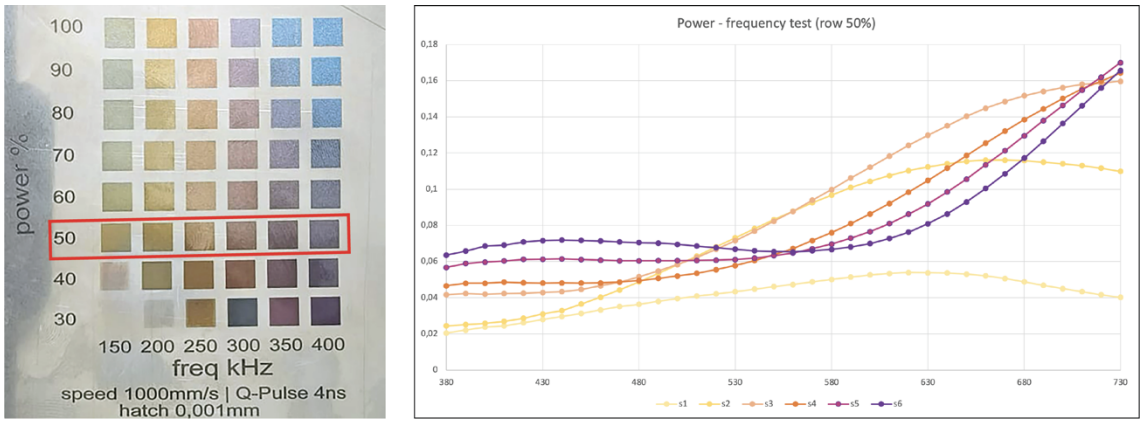


Figure 2: Power-frequency test results

The results on Figure 2 illustrate how laser power (%) and frequency (kHz) influence the color formation on a steel surface. Left side of the Image, power-frequency color grid shows the color variation on the surface at different combinations of power (vertical axis) and frequency (horizontal axis). At 50% power, which is highlighted in red, there is a clear progression of colors across different frequencies, ranging from light tones to deeper, more saturated hues.

The graph represents the relationship between power, frequency, and colorimetric values for different color categories. Different curves are plotted for color samples, showing how the colorimetric value changes with increasing frequency at 50% power. The test indicates that 50% power combined with a mid-range frequency (around 250-350 kHz) produces the most saturated and vibrant colors on the steel surface. Frequency appears to be the primary factor for controlling the hue, transitioning from warm to cool colors as the frequency increases. Power, on the other hand, seems to control the intensity of the colors, with mid-power settings generating more pronounced and diverse color variations. In summary, the combination of 50% power and frequency between 150-350 kHz seems to be optimal for achieving a range of vibrant colors.

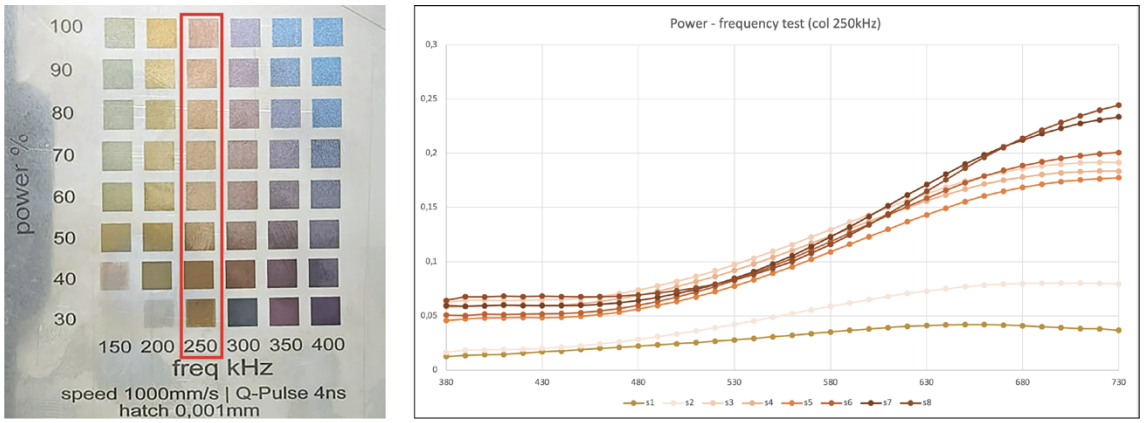


Figure 3: The influence of laser power on surface coloration

The graph on Figure 3 displays how different power levels affect color intensity and appearance at a fixed frequency of 250 kHz. As power increases beyond a certain threshold, particularly in the range power levels (50%-80%), the colorimetric values show a steady rise, indicating more pronounced color saturation. In summary, the data indicate that 250 kHz frequency is effective for producing a range of colors, but power settings need to be carefully adjusted to avoid overburning. The power ranges from 50%-80% appears to be the sweet spot for achieving the most vibrant and desirable colorations.

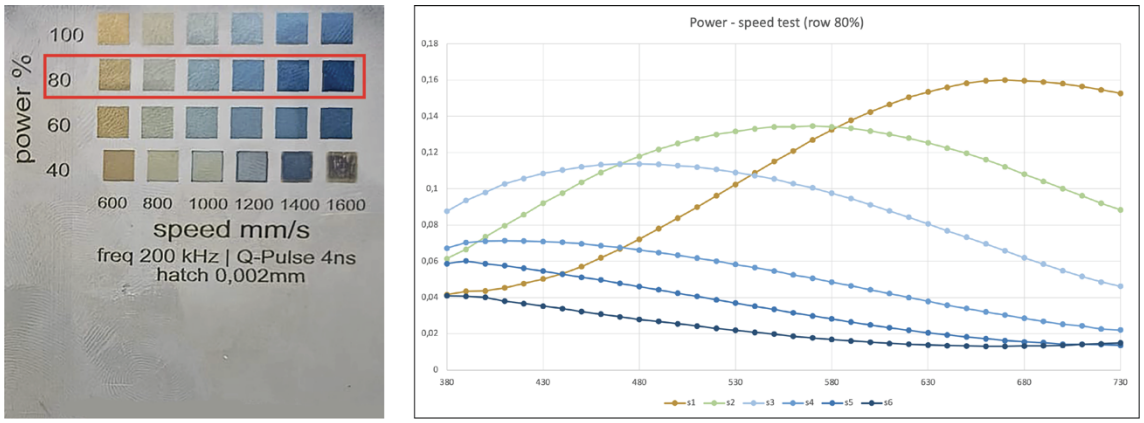


Figure 4: The influence of laser speed on surface coloration

The row corresponding to 80% power is highlighted, showing the colors obtained as the speed varies from 600 mm/s to 1600 mm/s. At 80% power, there is a progression from lighter to darker hues as speed increases. Lower speeds (600-800 mm/s) produce lighter colors, such as light blues and pale golds, and as speed increases (1000-1200 mm/s), the colors become more saturated and pronounced, with deeper blues and purples emerging. At higher speeds (1400-1600 mm/s), the colors appear darker and may show signs of overburning, with less color variation. The faster the laser moves, the less time it interacts with the material. This generally leads to less heat accumulation, which explains why colors become more intense and saturated at moderate speeds (1000-1200 mm/s).

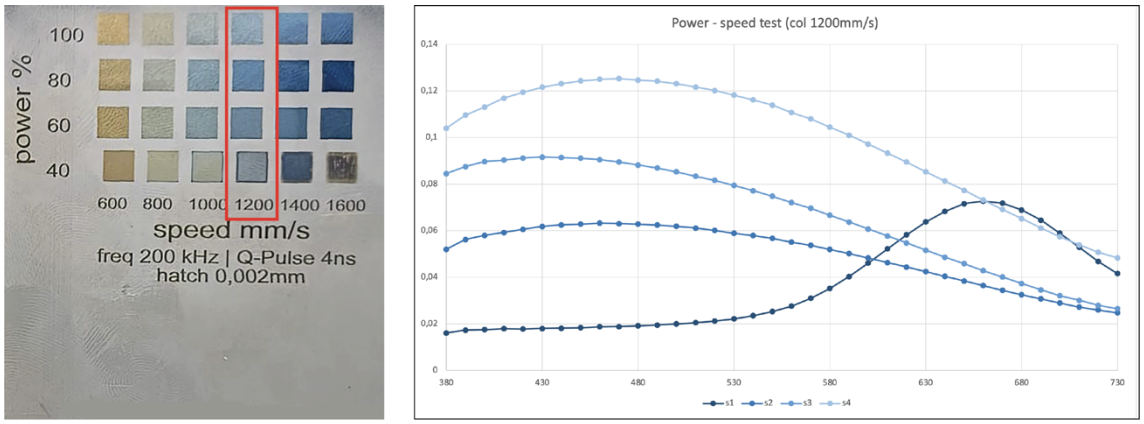


Figure 5: Power-speed test results

The highlighted column corresponds to a constant speed of 1200 mm/s with power levels ranging from 40% to 100%. The curves show a general rise in color intensity with increasing power, reaching a peak at approximately 80% power. This corresponds to the most saturated color response seen in the color grid. Beyond 80% power, the curves begin to decline, indicating that higher power levels may lead to overburning, which reduces the color intensity. The blue and purple curves (darker shades in the graph) show strong peaks, confirming that these hues are most prominent at mid-to-high power levels. Power plays a critical role in determining color saturation, with 80% power being the optimal setting for this speed. Lower power levels yield pale or weak colors, while higher power may lead to overburning.

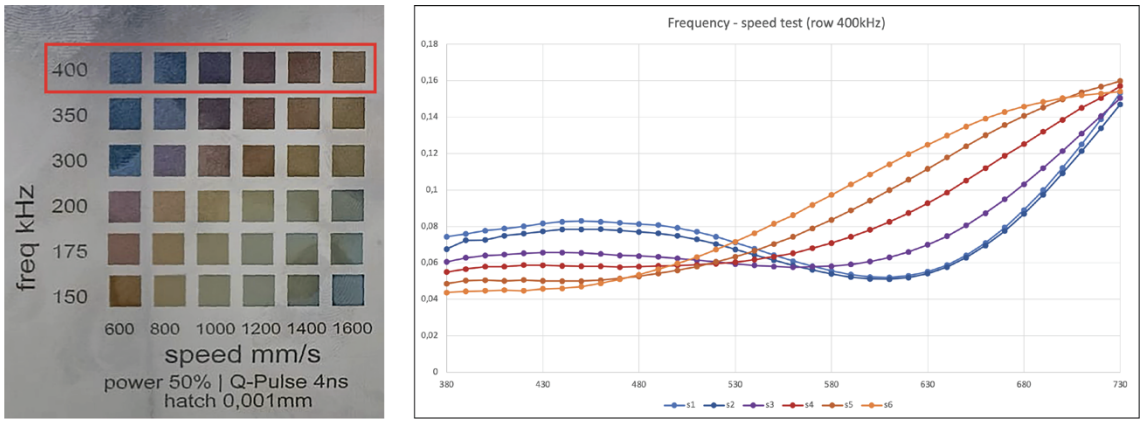


Figure 6: Frequency-speed test results at 400 kHz

The frequency-speed test at 400 kHz, illustrated by the spectral curves, reveals the relationship between color intensity and different laser parameters. At 400 kHz, higher speeds seem to amplify the intensity in both warm and cool color ranges, but the peaks for warmer colors suggest that these settings particularly enhance red-to-orange spectral regions. This implies that the combination of 400 kHz frequency and mid-range speeds (around 1000-1200 mm/s) results in the most intense and well-defined color output, particularly in the orange-to-red spectral range. These findings demonstrate the impact of laser parameters on the spectral characteristics of the surface, where controlling speed and frequency can be used to fine-tune the production of specific color hues through selective wavelength enhancement.

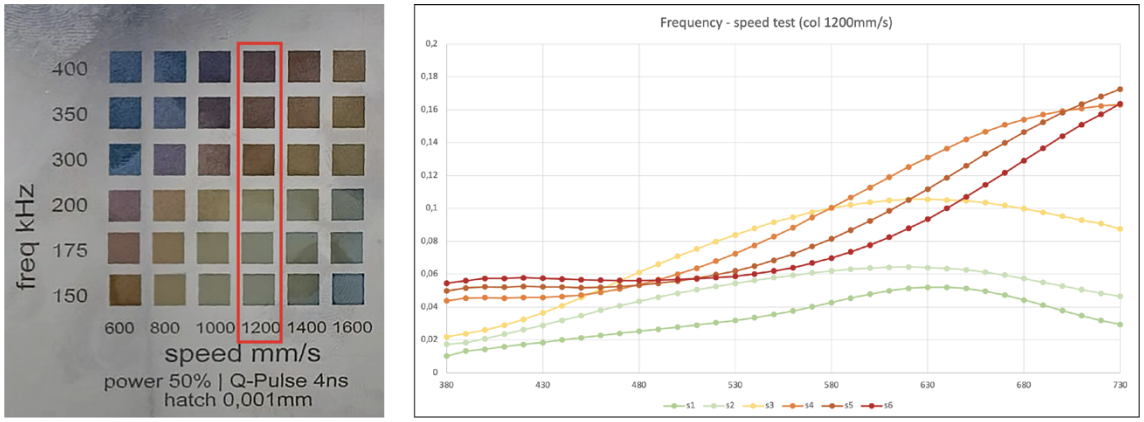


Figure 7: Frequency-speed test results at 1200mm/s

The results shown in the Figure 7 illustrate the relationship between laser frequency and speed. The color grid on the left shows how frequency impacts the color formation on the surface, while the spectral curves on the right reflect how different frequencies influence the color intensity across various wavelengths. At lower frequencies (150-200 kHz), the colors generated are lighter and less saturated, suggesting that lower frequencies do not produce the desired surface oxidation needed for strong color formation. As the frequency increases, particularly from 300 kHz to 400 kHz, the colors become more vibrant. The spectral curves support this observation, as intensity increases significantly with higher frequencies, indicating that at 400 kHz, the laser produces stronger color responses at longer wavelengths (600-700 nm). The overall relationship suggests that higher frequencies combined with a mid-range speed of 1200 mm/s enhance color saturation. Lower frequencies, on the other hand, result in muted or less saturated colors. Therefore, the findings indicate that to achieve optimal color formation, particularly for deeper and cooler tones, a combination of higher frequencies (300-400 kHz) and a speed of 1200 mm/s provides the most effective results.

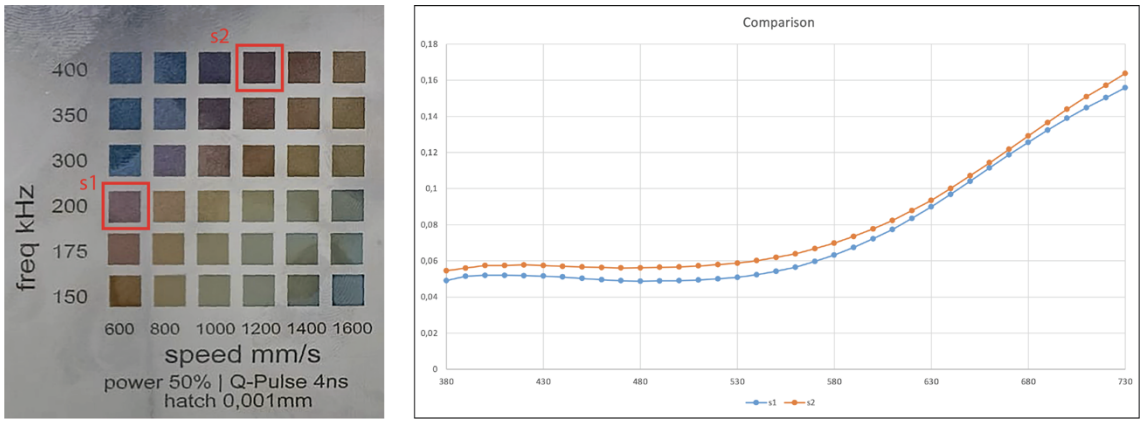


Figure 8: Comparison of two fields with the same coloration achieved using different laser parameters

The Figure 8 highlights two specific fields, S1 and S2, which exhibit similar colorimetric values but are generated under different laser frequency and speed conditions. The selected fields demonstrate how different combinations of parameters can produce nearly identical visual results. S1 is achieved with a frequency of 200 kHz and a speed of 600 mm/s, while S2 is achieved with a frequency of 400 kHz and a speed of 1200 mm/s. Despite the difference in frequency and speed settings, the spectral curves on the right show that the intensity values across the visible spectrum (represented by wavelengths on the x-axis) are almost identical for both samples. The two curves, S1 (blue) and S2 (orange), are closely aligned throughout the spectrum, particularly at longer wavelengths (600-700 nm), indicating that the colors produced in both cases are visually and spectrally similar. This result demonstrates that similar color effects can be achieved using different frequency-speed combinations. In this case, a higher frequency and speed (S2) can replicate the same color results as a lower frequency and speed (S1). This implies that there is flexibility in the laser parameters, allowing for adjustments in frequency and speed while still maintaining consistent colorimetric outcomes. This flexibility can be beneficial for optimizing engraving efficiency without sacrificing the desired color quality.

3.2 Microscope measurements

For further measurements specific colors that are representative for each main color of the spectra were chosen. Those colors were red, green, blue, white, cyan, magenta, yellow, and black. Their parameters are presented in Figure 9. The selected colors were captured under a microscope, and their surfaces were digitally analyzed to investigate the relationship between surface complexity and coloration.



Figure 9: Produced selected color samples

The selected colors are commonly used in the graphic industry and represent the primary colors, which is why they were chosen for further analysis. In this section, the reproducibility of previous results was also tested. By understanding how laser parameters affect color formation, a selected palette was created. The Table 1 presents the laser parameters (speed, power, frequency, Q-pulse, and hatch) that were used to create the selected colors based on previously collected results.

Table 1: Laser parameters of chosen colors

	red	green	blue	white	cyan	magenta	yellow	black
Speed [mm/s]	1000	1000	1000	1000	1000	1000	1000	100
Power [%]	70	20	100	60	50	40	50	60
Frequency [kHz]	300	350	150	400	350	350	150	80
Q-Pulse [ns]	4	12	4	4	7	4	6	16
Hatch [mm]	0,001	0,001	0,002	0,004	0,001	0,001	0,001	0,005

The Figure 10 presents the microscopic views of the surface textures for selected colors: Red, Green, Blue, White, Cyan, Magenta, Yellow, and Black. Each color's surface is split into two sections: the left side shows the laser-engraved colored surface, while the right side displays the corresponding thresholded binary image, highlighting the surface's complexity. The binary (black and white) side provides a detailed look at the surface structure. The white regions represent the raised or oxidized areas, while the black regions represent lower or untouched areas. The patterns differ across colors, indicating that surface complexity varies with the color produced by the laser. These observations suggest that the degree of surface complexity plays a key role in determining the final color, with the warmer and darker colors generally requiring more intricate surface structures to achieve their visual properties.

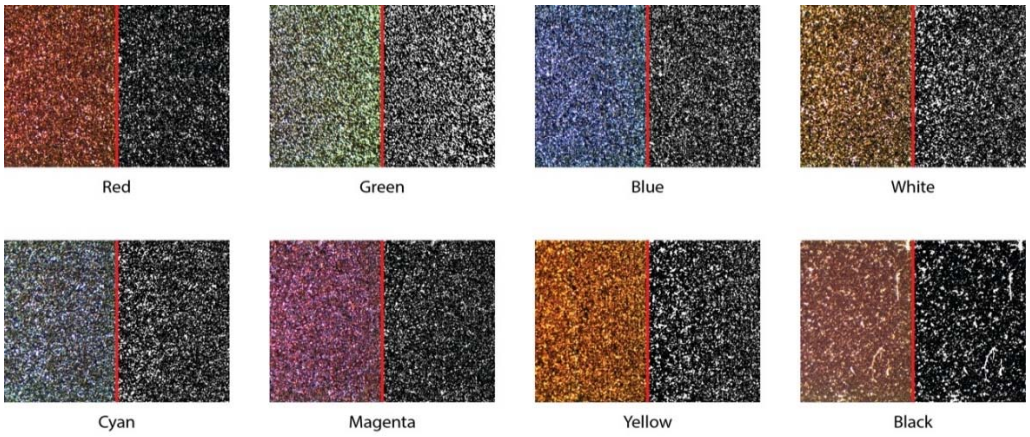


Figure 10: Surface structure complexity– left: microscopic image of the surface (35x magnification), right: thresholded sample

The analysis of surface complexity based on the binary images provides valuable insights into the role of laser parameters in color generation. However, to gain a more comprehensive understanding of surface modifications, future studies should also investigate surface roughness as a complementary parameter. By correlating roughness measurements with the observed surface complexity, a more complete picture can be obtained regarding how laser-induced texture impacts color formation. This additional data would allow for a deeper exploration of the interplay between surface morphology and colorimetric outcomes, further refining the optimization of laser engraving processes.

3.3 Working area

The Figure 11 shows the results of a test examining how changes in the working area of laser engraving affect the color output on steel surfaces. The concentric circles on the left represent different engraved areas, with diameters ranging from 60 mm to 150 mm, simulating the effects of engraving over increasingly larger surface areas. The graph on the right plots the colorimetric values for these tests, with the x-axis representing the wavelength and the y-axis the intensity of the color response. The variation in color across different working areas can likely be attributed to changes in the incident angle of the laser beam. As the engraving area expands, the laser beam needs to cover a wider surface, causing a significant change in the beam's angle of incidence. This alters the energy distribution across the surface, impacting how much oxidation and color formation occurs.

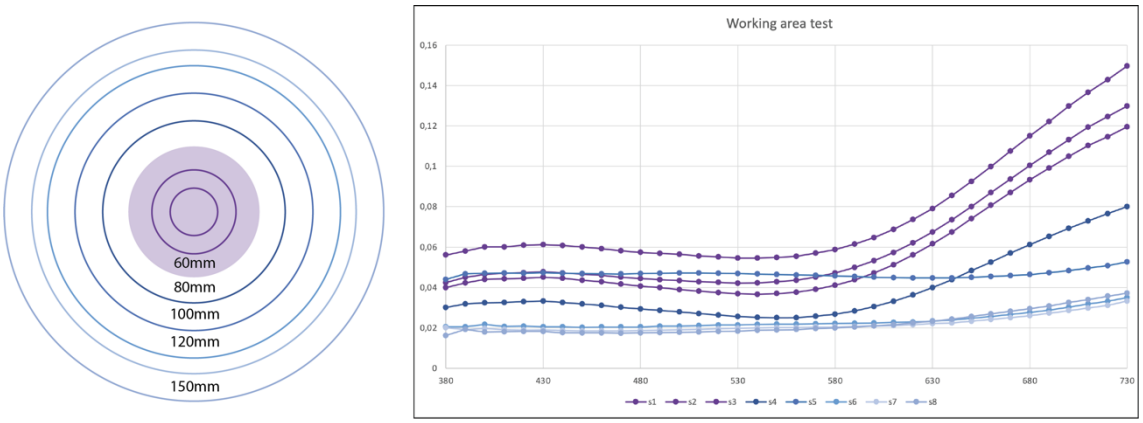


Figure 11: The influence of the laser beam angle on surface coloration

The purple curves, corresponding to smaller engraving areas, show higher intensity values, suggesting more saturated and vibrant colors when the working area is smaller, and the incident angle of the laser beam is more consistent. In contrast, the blue curves (representing larger engraving areas) show lower color intensity. This indicates that as the working area increases, the colors tend to fade or become less vibrant, likely due to the inconsistent angle of the laser beam across the surface. The results suggest that when engraving larger areas, there is a noticeable drop in color saturation and intensity, which can be directly linked to the changes in the laser's incident angle as it covers a broader surface. Smaller engraving areas produce more consistent and vibrant colors, while larger areas result in muted tones due to the variability in how the laser interacts with the surface. This highlights the importance of accounting for the working area size when aiming for consistent color results in laser engraving processes.

4. DISCUSSION

The results of this study demonstrate a clear correlation between laser parameters, such as power, frequency, speed, pulse width, and hatching, with the color and saturation achieved on steel surfaces. Variations in laser power indicate that lower power levels (below 40%) generally do not produce saturated colors, while mid-range power levels (50%-80%) yield the most vibrant hues. As the frequency increases, particularly in the range between 250 kHz and 400 kHz, the colors shift from warmer tones to cooler tones. This highlights the critical role of frequency in color control, while power modulates the intensity and saturation of the colors.

Furthermore, the tests investigating the combination of speed and frequency revealed that optimal speeds between 1000 mm/s and 1200 mm/s result in the best color saturation. Higher speeds, although reducing engraving time, lead to less saturated colors due to the reduced interaction time between the laser and the surface. Interestingly, certain colors can be achieved using different laser parameter combinations. For example, the same color can be produced with a combination of 200 kHz frequency and 600 mm/s speed, as well as with 400 kHz frequency and 1200 mm/s speed. This indicates that multiple parameter settings can lead to the same visual outcome, allowing flexibility in optimizing laser settings for different production requirements.

Experiments exploring the impact of the engraved area size showed that color changes as the surface area increases. On smaller areas (60 mm), the colors were more saturated and uniform, while on larger areas (>100 mm), color saturation decreased due to changes in the incident angle of the laser beam, which affected oxidation intensity.

5. CONCLUSIONS

Based on the results, it can be concluded that achieving optimal coloration on steel surfaces requires careful tuning of laser parameters. The optimal power range lies between 50% and 80%, while frequencies between 250 kHz and 400 kHz are most suitable for producing saturated colors. Engraving speeds of 1000 mm/s to 1200 mm/s yield the best results, and further adjustments to pulse width can enhance color precision. Additionally, it has been observed that the same color can be achieved through different combinations of laser frequency and speed, offering greater flexibility in process optimization. Finally, when

engraving larger areas, it is important to account for changes in the incident angle of the laser beam, which may affect color quality. Future research should focus on the quantitative analysis of surface roughness to further confirm the relationship between surface morphology and the resulting colorimetric values.

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THE INFLUENCE OF THE MECHANICAL RUB PROCESS ON THE COLOR CHANGE OF THERMOCHROMIC PRINTS ON TEXTILE SAMPLES

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Abstract: *The subject of this paper was to examine the impact of mechanical rubbing on the rate of colour change of thermochromic ink on textile samples. Textile samples made of polyester and cotton were printed using a manual screen printing technique with a reversible magenta leuco ink, with an activation temperature of 31°C. This paper aims to investigate how the process of mechanical rubbing affects the colour change of thermochromic samples during their cooling period, with varying numbers of rubbing cycles. To determine the relationship between the rubbing process and the rate of colour change, thermal, colorimetric, and spectrophotometric values were measured on the samples. The results indicate greater resistance of polyester compared to cotton, providing guidelines for improving the durability and resistance of thermochromic textile products. These findings have a significant impact on the development of more durable, functional textile products, reducing waste and costs and enhancing the sustainability of the textile industry.*

Key words: thermochromic inks, textile materials, rub resistance, smart textile.

1. INTRODUCTION

Thermochromic inks fall under the category of chromatic materials, characterized primarily by their response to thermal external stimuli, which can lead to a change or loss of colour. They are specialized inks that change colour in response to temperature variations. These inks contain microencapsulated active materials, specifically thermochromic pigments, dispersed within an appropriate binder. The active material determines the colour change, while the binder defines the printing and drying technology of the material (Rožić et al., 2017; Strižić Jakovljević et al.,2020). The colour change in thermochromic inks can be either irreversible or reversible. Irreversible inks can only change colour once, upon their initial exposure to the thermal stimulus, while reversible inks can change colour with each fluctuation in temperature (Tamrin et al., 2022, Jamnički Hanzer et al., 2023).

Thermochromic inks represent a significant innovation in the textile industry. The use of these inks on textiles provides numerous benefits, including aesthetic appeal, the ability to visually indicate temperature, and the potential for various applications in fashion and protective clothing (Strižić Jakovljević, 2022). Monitoring the resistance of materials to mechanical damage is essential for the quality and durability of textile products. Mechanical resistance directly affects the ability of the material to maintain its functional and aesthetic properties over time, especially under conditions of intensive use (Jamnički Hanzer et al., 2020). Understanding how different materials react to mechanical damages enables the development of better, more durable products that meet consumer needs and contribute to sustainability by reducing waste and costs

The use of thermochromic inks on textiles contributes to technological progress and improved product functionality and has a significant positive impact on the environment and the economy. Increasing the resistance and durability of thermochromic textile products reduces the need for frequent replacements, which contributes to the reduction of textile waste and has a positive impact on the environment. Likewise, more durable products reduce costs for consumers and producers, as they extend the life of textile items and reduce the need for purchases and production.

This research aims to examine the effect of rubbing on the rate of the colour change of thermochromic inks printed on textile samples. Specifically, it aims to quantify how different levels of mechanical rubbing affect the rate of thermochromic reactions and the time required for colour change at different temperatures. Based on the obtained results, the aim is to evaluate the resistance and durability of thermochromic inks on textiles, which will provide valuable information for their practical use and improvement in the textile industry.

ORCID numbers are provided at the end of the paper.

2. MATERIALS AND METHODS

The samples were prepared with the manual screen-printing technique using a reversible thermochromic magenta ink based on leuco dyes. White textile materials of different raw material compositions were used as the printing substrate because the white colour of the substrate provides the best contrast with the magenta colour. A total of six samples were examined, three samples for each type of textile material, in order to calculate the arithmetic mean value of each measured characteristic. To achieve the goal of the research, the prepared textile samples were subjected to rubbing in a different number of cycles. After each rubbing cycle, during the cooling process of the samples, measurements will be performed on the printed field. Based on the measurement results, a better understanding of the resistance of thermochromic inks to mechanical damage and the identification of key factors that influence their durability on textile materials will be enabled.

In order to achieve a thermochromic ink activation temperature of 31°C, the samples had to be heated. For this purpose, a stone was used that was placed on an induction hotplate that heated it. When the stone reached a temperature of 50°C, samples were placed on it and heated for 2 minutes so that the ink would activate, that is, lose its coloration. After heating, the samples were removed from the heated plate in order to gradually cool down and to monitor the process of returning the colour to its original state. In time intervals of 10 seconds each, thermal, spectrophotometric, and colorimetric values of prints were measured in order to determine the current temperature and colour of the printed field. After one round of measurements for each textile material, the samples were exposed to a different number of rubbing cycles, after which the same measurements were performed to determine the difference between the measurements. Within this experiment, the dry rubbing method was applied. After examining the prints, the results were analyzed and processed in order to establish the relationship between the characteristics. The ambient conditions that were present at the time of the experiment were a temperature of 22°C ± 2°C, a relative air humidity of 40% ± 2%, and an atmospheric pressure of 101 kPa ± 1 kPa.

CIE L*, a*, and b* coordinate values were obtained by colorimetric testing, for which mean arithmetic values were calculated in the data processing process for each tested sample and which were then used to calculate the absolute colour difference. The Techkon SpectroDens device is used to determine the coordinates. During the measurement, the value of the standard observer was set to 2°, the standard illumination to D50, and the polarizing filter was turned off. In the first case, the L*, a*, and b* values obtained from the first test on a certain sample are used as reference values. In the second case, the L*, a*, and b* values of each previous measurement for the same sample will be used to calculate the colour difference as a reference value. The goal of this analysis is to determine how colour has changed over time. To evaluate the mechanical degradation of the printed samples, the colour difference between the printed samples before and after the rubbing treatment was calculated using the CIE ΔE2000 formula, listed below. Each printed sample was measured 3 times at 3 different positions on the print area. The components in the formula are ΔL' difference in lightness between two colours, ΔC' difference in saturation between two colours, ΔH' difference in hue between two colours, kL, kC and kH weighting factors for lightness, saturation and hue (usually the value 1), SL, SC, and SH scalar factors to normalize lightness, saturation, and hue, and RT a rotation term that accounts for the interaction between saturation and hue. The CIE ΔE2000 formula takes into account the complex interactions between these components, providing a more accurate way to determine colour difference compared to older models.

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (1)$$

Spectrophotometers use spectral analysis to measure reflectance at different wavelengths in the visible part of the spectrum. Therefore, the spectrophotometric examination of the samples obtains spectral data values, the mean values of which are presented in the form of spectral reflection curves, and the analysis of which will determine how the change in temperature over time affects the change in the degree of reflection for the range of wavelengths of the visible part of the spectrum from 400 nm to 700 nm, taking into account the influence of different printing materials and the number of rubbing cycles. Spectrophotometric measurements allow a detailed analysis of colour change therefore it is possible to quantify colour changes caused by the rubbing of samples. These changes were interpreted in

relation to the subjective visual perception, enabling a precise evaluation of the quality and durability of thermochromic inks on textiles.
Figure 1 shows the setup of the experiment, with the position of the used devices and measuring instruments when testing the samples.

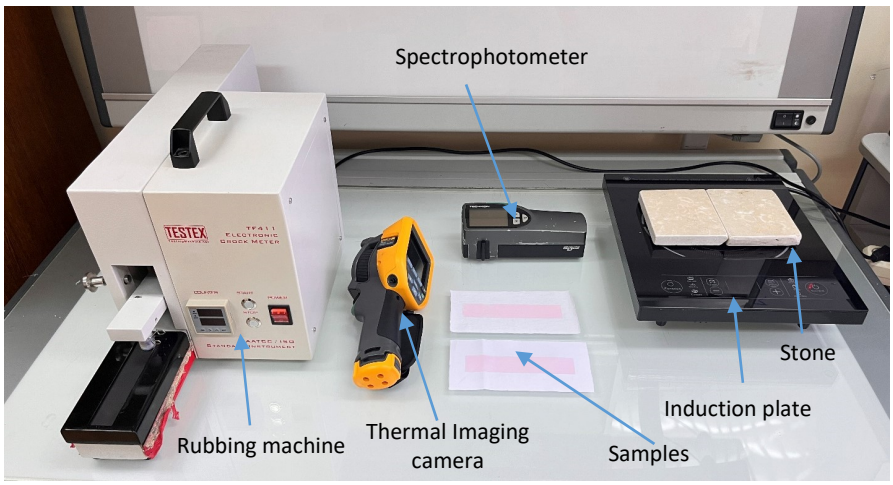


Figure 1: Experimental setup

The heating of the sample and its further measurement and analysis were performed after three cycles of 20 repetitions (20, 40, 60) of rubbing. A Testex FT411 device was used to test the color fastness of printed samples to dry rubbing. The heating was done by placing the sample on a heated stone plate, which was placed on an induction stove, at a temperature of 50°C for two minutes so that the ink would lose its color, that is, to activate it. After the ink was activated, the samples were removed from the heated plate and placed on the measuring table. Each examination was performed in a time interval of 10 s. For both one and the other type of textile material, the measurement time interval was 2 minutes due to the similar thickness of the samples.

2.1. Printing substrates

The samples were printed by manual screen-printing technique, with a 120 l/cm screen. The dimensions of the samples are 18 x 9 cm and consist of one printed field measuring 14 x 3 cm. Prints are printed on materials with different raw materials, and all samples are white. The white color was chosen because it contrasts well with the magenta printed field. The total number of samples was six, three samples each for both types of material. Two types of textile materials with different raw material composition were used. The first material used is 100% polyester (below, Sample 1). The other material that was used is 100% cotton by raw material composition (below, Sample 2). The characteristics of the samples are shown in Table 1.

Table 1: Composition and properties of water-based thermochromic leuco ink (SFXC, 2023)

Textile material	Fabric thickness mm	Fabric weight g/m²	Number of threads per unit length threads/cm		Material composition	
			Wrap	Weft	Type	[%]
Sample 1	0,405	168,4	26	20	Polyester	100
Sample 2	0,409	150,2	28	20	Cotton	100
Standard	x	ISO 3801:1977	ISO 7211-2:2024		EN ISO 1833-1:2012	

2.2. Printing ink

Magenta reversible thermochromic water-based leuco ink was used for printing all samples, which is intended for printing with the screen-printing technique on paper, cardboard, textile, and other substrates, with an activation temperature of 31°C. The activation temperature is the temperature at which the colour changes, i.e. to discoloration. Below the activation temperature, the colour returns to its

original state. The paint comes in the form of two components, binder (25 ml) and pigment (25 ml), so it is necessary to mix them in a ratio of 50:50, according to the manufacturer's instructions. After printing, the prints were dried in a COLO DRYS53A multifunctional device at a temperature of 160°C for a period of 2 minutes (SFXC, 2023).

3. RESULTS AND DISCUSSION

3.1. Thermal analysis

Temperature values for certain time intervals were obtained by thermal examination of all samples. This analysis aims to determine whether the application of mechanical damage to textile samples, such as rubbing, affects the temperature change of printed thermochromic prints during their cooling time. Figure 2 presents the results of temperature measurements for both samples before and after three rubbing cycles of 20 repetitions each (0, 20, 40, 60).

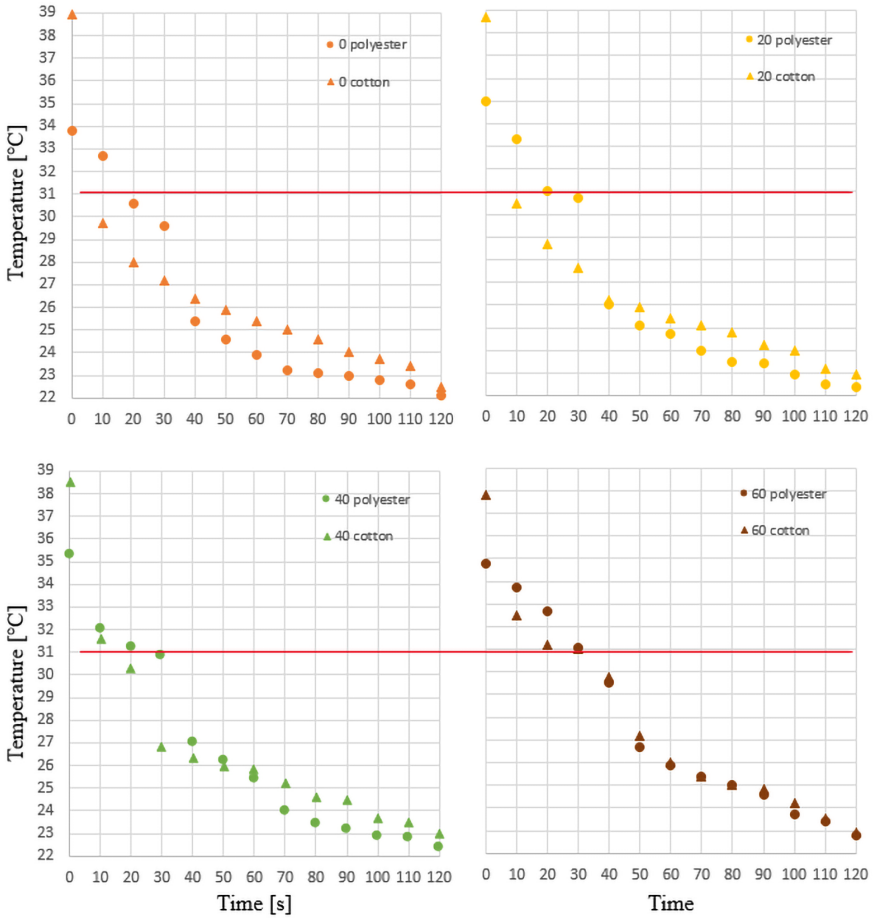


Figure 2: Comparative display of temperature dependence on cooling time for both samples

In Figure 2, it can be seen that the time to reach the activation temperature for all four states of Sample 1 and Sample 2 is different. Analyzing the temperatures on all four states of Sample 1, it is observed that the average temperature differs minimally, by about 1°C, which does not represent a significant difference. Also, it is observed that the total temperature change for the same cooling time of the samples decreases evenly, which may mean that the rate of temperature change decreases as the number of rubbing repetitions increases. The standard deviation values show that there is a relationship between the number of repetitions of rubbing and the change in temperature for individual time intervals of measurement. By analyzing the temperatures on all four states of Sample 2, it is observed that the average temperature differs minimally, by less than 1°C on the first three states and 1°C on the last state, which does not represent a significant difference. Also, it is observed that the total temperature change for the same sample cooling time decreases slightly, which also in the case of Sample 2 may mean that

the rate of temperature change decreases as the number of rubbing repetitions increases. Standard deviation values for individual measurement time intervals do not differ significantly between sample conditions, but a difference is observed before and after the last measurement cycle.
By comparing both samples in all four conditions, it is noticed that there are differences between them, although both samples have similar characteristics. Also, it is clearly observed that with an increase in the number of repetitions of rubbing, the rate of temperature change is reduced, i.e. it can be seen that the number of intervals required to reach the activation temperature is greater from the first to the last graph. Comparing Sample 1 and Sample 2, there is a noticeable difference between the recorded temperature values at the same time intervals, with the fact that this difference is not always the same, but is a little more significant in the initial measurements compared to the time after reaching the activation temperature. In addition, it can be observed that Sample 2 reaches the activation temperature faster in all four cycles, i.e. the colour change of the sample occurs faster.

3.2. Colorimetric analysis

Figure 3 shows the colour difference values for Sample 1 before and after three rubbing cycles, during a time interval of 120 seconds.

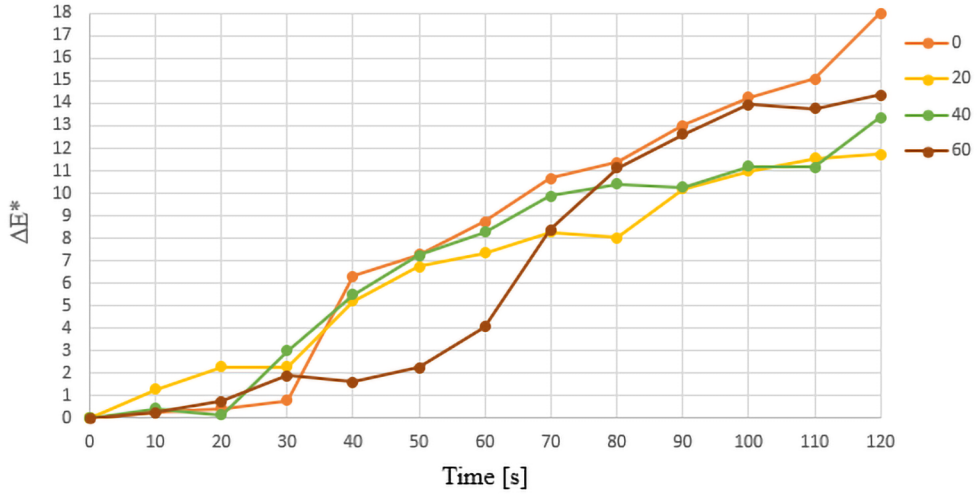


Figure 3: Comparison of the change in absolute colour difference over time for Sample 1 before and after three rubbing cycles

Analyzing the colour change values on Sample 1, it can be observed that the colour change values at the individual states of the sample are not the same and that the biggest difference in colour is observed on the sample before the rubbing process. What is also observed is that the colour changes for all sample states are in an even increase from the beginning of the measurement to the end, which is also related to the thermal measurements, because over time the temperature dropped below the activation temperature and thus the colour regained its colouring.
For the colour change values on the sample before and after the rubbing process, it was noted that there is no uniform change when observing the colour change between adjacent measurement intervals, which makes it impossible to have a relationship between those values. Also, the change values do not follow the thermal values, so that during the time immediately below the activation temperature, the biggest colour differences do not occur, but they occur randomly in some time interval for each state of the sample. It is also important to note that most of the colour differences are less than 2, which is considered a difference that is visible but still accepted as good print quality. There are also intervals where the colour difference is over 2, but even in those cases, the difference is not greater than 6. Such values suggest a clearly visible difference, but the colour does not deviate from the reference. The conclusion of this analysis is that there is no relationship between the number of times the impression is rubbed and the colour change on the same.
Analyzing the colour change values on Sample 2 from Figure 4, it can be observed that before and after the rubbing process, the colour change values on the individual states of the sample are not the same, which was expected. The biggest difference in colour is observed on the sample before the rubbing

process. It can also be observed that the colour changes for all sample states grow evenly from the beginning to the end of the measurement. This is consistent with the thermal imaging measurements, as over time the temperature dropped below the activation temperature, causing the colour to return to its original state.

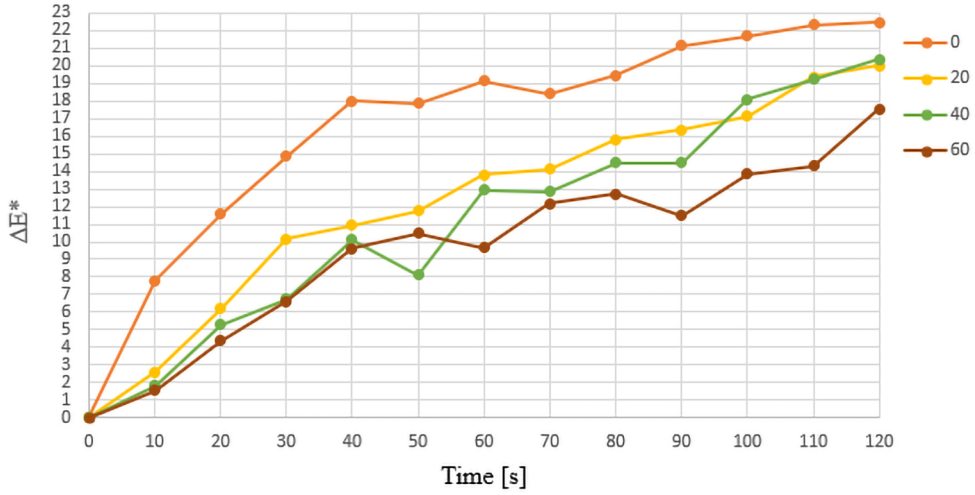


Figure 4: Comparison of the change in absolute colour difference over time for Sample 2 before and after three rubbing cycles

In contrast to the values measured on Sample 1, with Sample 2, a colour change is observed that is related to the number of rubbing cycles of the sample, that is, the number of rubbing cycles applied to the sample affects the colour change values on the sample during the measurement time of 120 seconds. The highest values of colour change were recorded on the sample before rubbing, where most values are between 1 and 2, which is characterized as a small difference. Also, the highest values were recorded around the interval when the activation temperature was reached. After the first and second rubbing cycle, the colour change value between the measurement intervals is less than 6, so the difference is visible but the colour tone is still not changed. In the case of the sample after the third rubbing cycle, the difference is, in most cases, less than 3, which is characterized as a difference that can be seen even by the untrained eye. Common to all conditions is that the greatest changes occur precisely between the intervals around reaching the activation temperature.

3.3. Spectrophotometric analysis

Spectral reflectance curves were obtained from spectral data obtained by spectrophotometric testing of samples. The analysis of the curves will determine what effect the change in the condition of the sample before and after three cycles of dry rubbing has on the change in the degree of reflection of prints for the range of wavelengths of the visible part of the spectrum.

With Sample 1, it can be seen that before the rubbing process, the maximum reflection was 74,95%, while the lowest percentage of reflection was 17,39%. The percentage difference between the maximum and minimum reflectance of the sample after the first rubbing cycle is 55,38. These results indicate that there is no decrease in reflection as the number of rubbing cycles increases; that is, 60 repetitions in three rubbing cycles do not have a particular effect on the degree of reflection of the sample. However, if we observe the moment of reaching the activation temperature, which is the main moment for evaluating the properties of thermochromic ink, in that case we see that the reflection decreases as the number of rubbing cycles increases. The only deviation occurs at the last rubbing cycle when the spectral data is higher than expected. Figure 5 shows the spectral reflectance curves (at the beginning and at the end of the measurement) for Sample 1 before and after three cycles of rubbing the material.

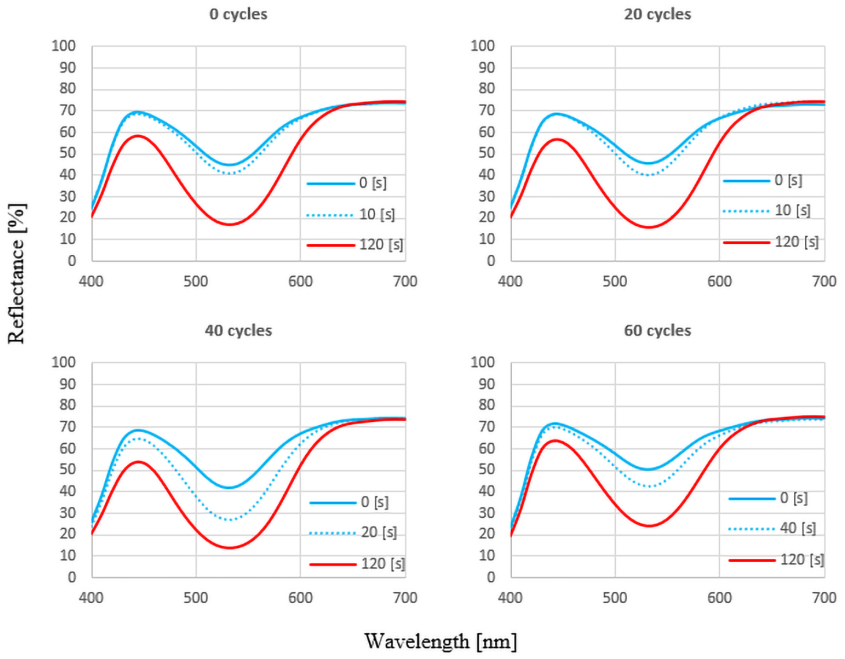


Figure 5: Comparison of maximum and minimum spectral reflectance for Sample 1

In Figure 6, it can be seen that on all four states of Sample 2, the spectral curve retains the same shape and that the obtained results are in accordance with thermal measurements because the shape of the curve shows that the reflection decreases over time. Such behaviour of the curves over time was expected, considering that over time the colouring of the thermochromic colour returns, i.e. the print on the sample is getting darker. With Sample 2, it can be seen that before the rubbing process, the maximum reflection was 77,12%, while the lowest percentage of reflection was 13,50%. The percentage difference between the maximum and minimum reflectance of the sample after the first rubbing cycle is 59,22. Observing the reflectance at the moment of reaching the activation temperature, the reflectance decreases, which was expected and suggests that there is a relationship between the reflectance and the number of repetitions of the rubbing cycle.

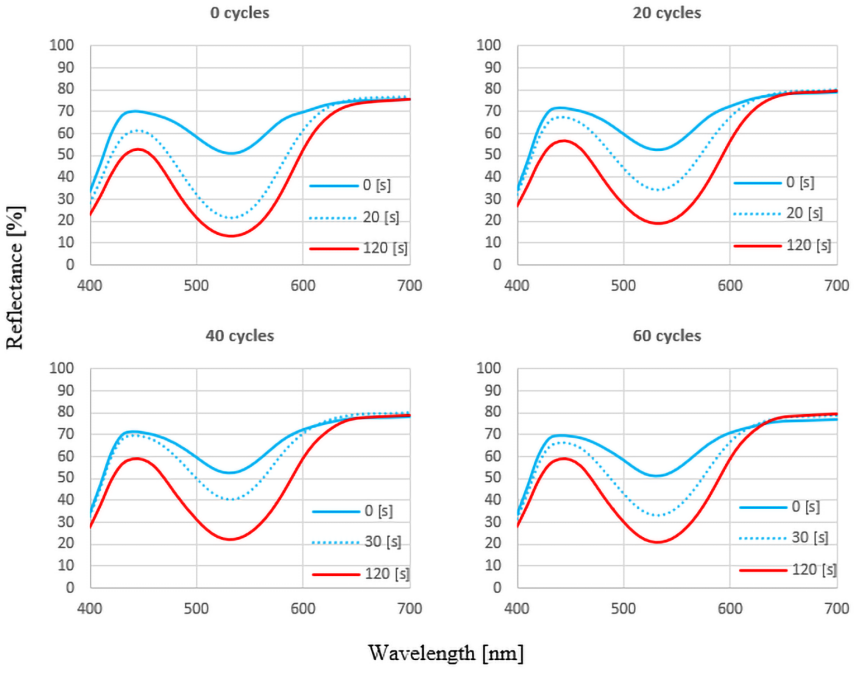


Figure 6: Comparison of maximum and minimum spectral reflectance for Sample 2

4. CONCLUSION

The investigation of the effect of wear and friction on the colour change of the thermochromic dye was carried out on textile samples made of polyester and cotton. The results showed different effects of wear and friction on these two materials. A slight degradation of the material due to wear was observed on cotton, which indicates a certain sensitivity of cotton to physical influences. In contrast, for polyester, no significant relationship was observed between colour deterioration and the number of rubbing cycles, suggesting that polyester is more resistant to abrasion and that the rate of thermochromic colour change does not depend on mechanical damage to the sample compared to cotton.
These results indicate that polyester is a more suitable material for the use of thermochromic paints in conditions where intense wear is present, while cotton can be used in applications where wear is less pronounced. Further research can focus on improving the wear resistance of cotton or on the development of new material blends that combine the best properties of both materials, which would expand the application possibilities of thermochromic dyes in the textile industry.

5. ACKNOWLEDGMENTS

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DIGITAL MEDIA



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TRANSFORMING GRAPHIC DESIGN - THE IMPACT OF AUGMENTED AND VIRTUAL REALITY ON USER INTERACTION, SECURITY AND PRODUCT PACKAGING OPTIMIZATION

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Abstract: *The rapid development of Augmented Reality (AR) and Virtual Reality (VR) technologies has profoundly influenced various sectors, including graphic design. These immersive technologies are transforming the way designers create and interact with visual content, providing innovative methods to engage audiences. This paper explores the applications of AR and VR in graphic design, with a specific focus on their roles in advertising, product visualization, security features, and product packaging optimization. In advertising, AR and VR offer brands unique opportunities to create interactive and memorable experiences. AR-enhanced print ads can turn static images into dynamic content when viewed through a smartphone, while VR campaigns immerse users in a brand's narrative, offering a level of presence and engagement unattainable by traditional media. These technologies capture attention and cultivate deeper connections with consumers by delivering personalized and interactive experiences. For product visualization, AR and VR enable designers to develop detailed and interactive 3D models. These models can be examined and manipulated within a virtual space, providing a comprehensive view of the product from all angles. Additionally, AR allows customers to visualize products in their own environments before purchasing, thereby improving decision-making processes and enhancing satisfaction. This capability is particularly beneficial in industries like automotive, real estate, and fashion, where contextual visualization significantly influences buying decisions. AR and VR can also enhance security features in product packaging. By embedding AR markers or VR verification steps, brands offer consumers a way to authenticate products, reducing the risk of counterfeiting and ensuring that customers receive genuine products. Furthermore, AR and VR technologies optimize product packaging design through virtual prototyping and simulation. This allows designers to test different packaging concepts cost-effectively and efficiently, leading to better design outcomes and reduced material waste. Despite the promising applications, adopting AR and VR in graphic design presents challenges, including the need for new skills and knowledge, potential high costs of implementation, and the necessity for continuous technological updates. However, as AR and VR technologies evolve, they possess immense potential to redefine user interaction within graphic design. AR and VR are expanding the boundaries of graphic design by offering innovative ways to create immersive and engaging experiences, enhance security features, and optimize product packaging. These technologies will significantly shape the future of user interaction, positioning graphic design professionals at the forefront of technological advancements.*

Key words: Augmented Reality**,** Virtual Reality**,** Graphic Design Innovation**,** Interactive Advertising**,** Product Packaging Optimization**,** Security Features in Design

1. INTRODUCTION

The graphic design industry is undergoing a profound transformation, driven by the rapid advancements in AR and VR technologies (Wang et al., 2024). These immersive tools are not merely augmenting traditional design practices; they are revolutionizing the way designers create, interact with, and engage visual content. By pushing the boundaries of innovation and creativity, AR and VR are opening up new dimensions in the design landscape, allowing for deeper audience engagement, enhanced security features, and optimized product packaging (Rane, Choudhary & Rane, 2023). As these technologies continue to evolve, they are set to redefine the future of graphic design, positioning designers at the forefront of technological advancements.

In the world of advertising, AR and VR have introduced unprecedented opportunities for brands to captivate their audiences. The static print ads that once dominated the advertising landscape are being transformed into dynamic, interactive experiences (Gopakumar & Dananjayan, 2023). AR allows these traditional formats to come alive when viewed through a smartphone camera, enabling users to interact

ORCID numbers are provided at the end of the paper.

with the content in ways that were previously unimaginable (Dargan et al., 2023). For instance, an AR-enhanced ad can trigger animations, videos, or even 3D product visualizations, turning a simple image into a multi-layered experience that sparks curiosity and leaves a lasting impression. This interactive approach not only captures the viewer's attention but also fosters a deeper connection with the brand, making the advertising experience more memorable and engaging.

Similarly, VR is revolutionizing the way brands tell their stories (de Regt et al., 2021). By immersing users in a brand's narrative, VR creates a sense of presence and engagement that traditional media simply cannot match. Consumers can be transported into a virtual world that reflects the brand's identity, allowing them to explore and interact with the content on a personal level (Hollebeek et al., 2020). This immersive experience often includes interactive elements, enabling users to manipulate and personalize the content according to their preferences (Montagud, Orero & Matamala, 2020). Such experiences foster stronger emotional connections, making the brand narrative not just something to watch or read, but something to experience firsthand. The ability of VR to provide a fully immersive and interactive environment gives brands a powerful tool to create more impactful and memorable campaigns (Sung, 2021).

Beyond advertising, the influence of AR and VR is extending into product visualization, a crucial aspect of industries such as automotive, real estate, and fashion (Wedel, Bigné & Zhang, 2020). Designers are now empowered to create detailed, interactive 3D models that can be examined and manipulated within a virtual space, providing customers with a comprehensive understanding of a product from every angle. This capability is particularly beneficial in industries where visual and spatial context plays a pivotal role in the decision-making process (Eswaran & Bahubalendruni, 2022). For example, in the automotive industry, potential buyers can explore a car's interior and exterior in a virtual environment, allowing them to inspect features and details that would be difficult to convey through traditional media. Similarly, in real estate, VR enables prospective buyers to take virtual tours of properties, offering a realistic sense of space and layout without the need for physical visits.

AR takes product visualization a step further by allowing customers to see how products would look and function in their own environments (Kim & Choo, 2021). This capability is especially valuable in the fashion industry, where customers can use AR to visualize how clothing or accessories will fit and appear on their bodies before making a purchase. This not only enhances the shopping experience but also helps to reduce return rates by giving customers a more accurate representation of the product. The ability to visualize products in context empowers consumers to make more informed decisions, leading to higher satisfaction and confidence in their purchases (Hilken et al., 2020).

In addition to enhancing user experience and engagement, AR and VR are also transforming the security features associated with product packaging (Hoyer et al., 2022). Counterfeiting is a significant challenge for many brands, but AR and VR offer innovative solutions to this problem (Bhattacharya et al., 2021). By embedding AR markers or integrating VR-based verification steps into product packaging, brands can provide consumers with a reliable method for authenticating products (Lin, Wu & Yang, 2021). For instance, a user can scan an AR marker on the packaging with their smartphone to verify the product's authenticity, ensuring that they are receiving a genuine item. This added layer of security not only protects the brand's reputation but also builds trust and confidence among consumers, who can be assured of the quality and authenticity of their purchases.

Moreover, the integration of AR and VR into product packaging design is leading to significant advancements in packaging optimization (Chen & Mu, 2024). Virtual prototyping and simulation tools allow designers to test various packaging concepts in a cost-effective and efficient manner, enabling them to explore a wider range of possibilities before committing to physical prototypes. This process helps designers identify and address potential issues early on, resulting in better design outcomes and reduced material waste. By allowing for more experimentation and refinement, AR and VR enable designers to create packaging that is not only more innovative and aesthetically pleasing but also more functional and sustainable (Ricci, 2024). This streamlined approach to packaging design is particularly valuable in industries where efficiency, sustainability, and cost-effectiveness are paramount.

However, the integration of AR and VR into graphic design does come with its own set of challenges. For many designers, the adoption of these technologies requires the acquisition of new skills and knowledge, which can be both time-consuming and costly (Ashtari et al., 2020). The initial investment in AR and VR tools and platforms can also be a significant barrier, particularly for smaller design studios or agencies with limited budgets. Furthermore, the rapid pace of technological advancements means that designers must continuously update their skills to keep up with the latest developments. This constant need for learning and adaptation can be daunting, but it is essential for staying relevant in an increasingly competitive industry.

Despite these challenges, the potential of AR and VR to revolutionize graphic design is immense. As these technologies become more accessible, user-friendly, and cost-effective, they are likely to see widespread adoption across the industry (Aquino, 2024). Designers who embrace AR and VR will not only enhance their creative capabilities but also position themselves at the cutting edge of technological innovation. By leveraging these tools, they will be able to create more immersive, engaging, and interactive experiences that resonate with audiences on a deeper level.

This paper provides the insights of the integration of AR and VR into graphic design is transforming the industry in profound ways. From interactive advertising and enhanced product visualization to improved security features and optimized packaging design, AR and VR are redefining the possibilities of what can be achieved in graphic design. While the challenges of adopting these technologies are real, the long-term benefits they offer in terms of innovation, user engagement, and design efficiency are clear. As the graphic design landscape continues to evolve, AR and VR will undoubtedly play a pivotal role in shaping the future of the industry, offering new opportunities for designers to create, interact, and engage with their audiences in ways that were previously unimaginable.

2. ROLE OF AR AND VR IN ADVERTISING

2.1. Interactive and memorable experiences

The integration of AR into graphic design has fundamentally changed the way brands engage with their audiences through advertising (Javornik et al., 2021). AR technology enables the creation of dynamic and interactive content that transforms traditional static print ads into immersive experiences, capturing attention and fostering deeper connections with consumers.

When viewed through a smartphone or AR-enabled device, these print ads come to life, captivating audiences with animations, videos, or even 3D product visualizations (Javornik et al., 2021). For instance, an automobile advertisement might feature a car that can be virtually placed in the viewer's environment, allowing them to examine the vehicle from all angles and interact with its features. This level of interactivity not only encourages the audience to actively engage with the content but also sparks curiosity, leaving a lasting impression.

The interactive nature of AR-enhanced advertising offers a significant advantage over traditional print ads. Rather than simply viewing a static image, the audience becomes an active participant in the advertising experience (Kayadibi, 2024). This engagement fosters a deeper connection with the brand, as the audience feels more invested in the content. Furthermore, the ability to trigger dynamic content through AR encourages viewers to revisit the advertisement, either to explore new features or to share the experience with others. This repeat engagement further solidifies the brand's presence in the minds of the audience, making the advertising experience more memorable and impactful.

2.2. Immersive brand narratives

While AR enhances the interactivity and dynamism of print advertising, VR takes user engagement to an entirely new level by immersing the audience in a brand's narrative. VR campaigns can transport users into virtual worlds that reflect the brand's identity, creating a level of presence and engagement that traditional media cannot match (Rodrigues, 2020).

In a VR advertising experience, the audience becomes a participant in the brand's story, rather than a passive observer. They can explore the virtual environment, interact with virtual objects, and personalize the experience to some extent. This immersion fosters a deeper emotional connection between the audience and the brand, as they feel a sense of presence and involvement within the narrative.

For example, a luxury hotel brand might use VR to showcase its unique accommodations and amenities. Viewers could virtually tour the hotel's suites, experience the spa services, and explore the surrounding landscape, all while feeling as if they are physically present within the environment. This immersive experience not only highlights the hotel's offerings but also creates a lasting impression, making viewers more likely to consider the brand for their future travel plans.

VR advertising also allows brands to showcase the impact of their products or services, creating a more empathetic connection with the audience (Rodrigues & Loureiro, 2022). A clothing brand, for instance, might use VR to transport viewers to remote villages, allowing them to witness the positive change their purchases bring to local communities. This type of immersive experience can evoke strong emotional responses, fostering a deeper sense of social consciousness and a stronger affinity for the brand (Cross et al., 2021).



Figure 1: Empathetic brand connection through VR advertising

2.3. Case studies and examples

The power of AR and VR in advertising is evident in the successful campaigns implemented by various brands (Balasubramanian et al., 2022). These case studies highlight innovative ways in which these technologies can be leveraged to create captivating and memorable experiences for the audience.

2.3.1. Pepsi's AR bus stop campaign

In 2018, Pepsi launched an innovative AR campaign that transformed ordinary bus stops into interactive experiences (Nucleus Vision Digital & Design Agency, 2024). When viewed through a smartphone camera, the static bus stop advertisements came to life, seemingly transporting passengers to a world filled with extraordinary events, such as alien invasions and tigers roaming the streets (Figure 2).
This AR campaign captured the attention of commuters, generating widespread buzz and social media engagement. The dynamic and unexpected nature of the content encouraged viewers to interact with the advertisements, share their experiences, and further amplify the brand's reach.

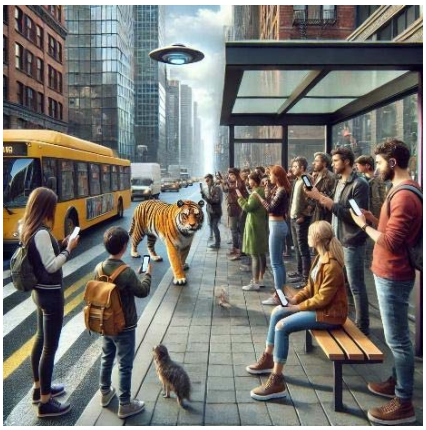


Figure 2: Bus stop with commuters experiencing an augmented reality

2.3.2. Toms shoes' VR campaign

Toms Shoes, a brand known for its socially conscious mission, leveraged VR to create a deeply impactful advertising campaign (Ngamvichaikit, 2024). The VR experience transported viewers to remote villages, allowing them to witness the positive impact of Toms' one-for-one business model, where for every pair of shoes purchased, the company donates a pair to someone in need.
By immersing the audience in the brand's narrative, the VR campaign evoked a strong emotional response, fostering a deeper connection between viewers and the brand's mission. The level of empathy and engagement achieved through this VR experience was unattainable through traditional advertising formats, making it a powerful tool for connecting with socially conscious consumers.

2.3.3. Ikea's AR furniture visualization

Recognizing the importance of contextual visualization in the home furnishings industry, Ikea has embraced AR technology to enhance the customer experience (Vaidyanathan & Henningsson, 2023). Through their mobile application, customers can virtually place Ikea furniture in their own living spaces, allowing them to see how the products would look and fit within their home environment.

This AR feature has significantly improved the decision-making process for Ikea customers, reducing the likelihood of purchasing items that do not align with their space or aesthetic preferences. By empowering customers to visualize the products in their own homes, Ikea has effectively reduced barriers to purchase and increased customer satisfaction.

These case studies demonstrate the versatility and impact of AR and VR in advertising. By creating interactive, immersive, and contextual experiences, brands can captivate their audiences, foster deeper emotional connections, and drive more effective and memorable advertising campaigns.

As the technology continues to evolve, the potential for AR and VR in advertising will only grow, with designers and marketers exploring new and innovative ways to leverage these transformative tools to engage their audiences.

3. PRODUCT VISUALIZATION AND DESIGN

3.1. Detailed and interactive 3D models

The advent of AR and VR technologies has markedly transformed product visualization in graphic design (Roberts, Page & Richardson, 2020). These immersive technologies enable the creation of detailed and interactive 3D models, offering designers a more comprehensive and dynamic approach to examining and refining their designs before finalizing them.

In a virtual space, designers can manipulate 3D models, rotating, zooming, and exploring the product from various angles. This interactivity provides insights that traditional 2D sketches or renders cannot offer. Designers can identify potential flaws, test different material choices, and adjust the product's form, function, and aesthetics with unprecedented precision.

The ability to engage with virtual 3D models enhances the design process, allowing designers to immerse themselves in the product's virtual representation. This immersion aids in understanding the product's physical properties and how it might be perceived by end-users. Additionally, the collaborative nature of VR and AR facilitates real-time discussions and feedback among design teams, even if members are located remotely, leading to more informed decisions and reducing the likelihood of costly revisions.

Moreover, the use of AR and VR opens new avenues for creativity by enabling designers to quickly generate and manipulate virtual prototypes. This iterative process helps in exploring various design concepts and solutions without the need for physical prototypes, streamlining the development process and fostering innovative design approaches.

3.2. Contextual visualization

A significant advantage of AR in product visualization is its ability to provide contextual visualization (Zollmann et al., 2021). AR allows customers to see how a product would look and fit within their own environments before making a purchase decision.

This capability is particularly advantageous in industries where the physical context of a product influences purchasing decisions, such as furniture, home decor, and interior design. For example, a customer shopping for a new sofa can use an AR app to place the sofa virtually in their living room, assessing how it integrates with existing furnishings and the overall aesthetic of the space.

Contextual visualization through AR empowers customers to make more informed choices, reducing the likelihood of returns and enhancing satisfaction. By visualizing the product in their own environment, customers can better evaluate its scale, proportions, and overall fit. This not only improves the purchasing experience but also strengthens the connection between customers and brands.

Additionally, AR enables designers to gather real-time feedback from customers by observing their interactions with AR-enabled prototypes. This feedback provides valuable insights into customer preferences and perceptions, which can be used to refine designs and ensure that the final product meets target audience expectations.

Beyond retail, contextual visualization has transformative potential in sectors such as automotive and real estate. In the automotive industry, AR allows customers to visualize a car in their own driveway or on the

street, assessing its fit and aesthetic appeal. In real estate, VR tours enable potential buyers to explore properties remotely, and AR can help them visualize how a home fits within its surroundings (Figure 3).



Figure 3: Use of AR for product visualization in a living room

3.3. Industry applications

The integration of AR and VR into product visualization and design has significantly impacted various industries, each with unique challenges and requirements.

3.3.1. Automotive industry

In the automotive sector, AR and VR have revolutionized customer interactions with vehicle models (Ahmadi et al., 2023). Customers can use VR to explore the interior and exterior of cars, customize features, and take virtual test drives, gaining a thorough understanding of the vehicle before visiting a dealership. AR further enhances this experience by allowing customers to place a virtual car in their own environment, evaluating its size and appearance in real-world contexts.

3.3.2. Real estate

In real estate, AR and VR technologies have transformed property engagement (Hou & Wu, 2020). VR tours enable remote exploration of properties, allowing customers to navigate spaces and visualize furniture arrangements. AR applications further aid by overlaying virtual properties onto the customer's current environment, helping them assess the scale and suitability of homes in relation to their surroundings.

3.3.3. Fashion and retail

The fashion and retail industries have adopted AR and VR for enhanced product visualization (Wu & Kim, 2022). AR enables virtual try-ons for clothing, accessories, and cosmetics, facilitating informed purchasing decisions and reducing returns. VR creates immersive retail experiences, such as virtual showrooms or fashion shows, fostering stronger emotional connections with brands.

These industry-specific applications demonstrate the profound impact of AR and VR on product visualization and design. By providing comprehensive and contextualized product experiences, these technologies enhance decision-making, improve customer satisfaction, and drive brand loyalty. As AR and VR technologies evolve, their potential to redefine interactions between designers, customers, and products will continue to expand.

4. ENHANCING SECURITY FEATURES IN PRODUCT PACKAGING

4.1. AR markers for authentication

Counterfeiting remains a significant challenge for many brands, undermining product integrity and eroding consumer trust. AR offers a compelling solution to enhance security features in product packaging by enabling digital authentication processes (Tizhe Liberty et al., 2024). By embedding AR markers or codes within packaging, brands can allow consumers to verify product authenticity easily (Figure 4).

When consumers scan an AR marker with a smartphone app, the app reveals detailed information about the product, such as its origin and manufacturing process, serving as proof of authenticity. This AR-based approach has several advantages over traditional security measures. The dynamic and interactive nature of AR markers is difficult for counterfeiters to replicate, making it more challenging to produce convincing fakes. Additionally, the ability to access and verify real-time product information further strengthens the security of the authentication process.

AR markers also provide a user-friendly experience, simplifying the authentication process and encouraging broader adoption. This ease of use helps build consumer trust in the brand's efforts to combat counterfeiting. Furthermore, brands can gather valuable data from AR scans, including scan frequency, locations, and engagement metrics. This data can inform anti-counterfeiting strategies, enhance supply chain security, and improve overall brand protection efforts.



Figure 4: Futuristic VR-based product verification process

4.2. VR verification steps

VR technology can complement AR by adding another layer of security to product packaging (Syed et al., 2022). VR verification steps can be integrated into the product unboxing experience, requiring consumers to interact with a virtual environment to confirm product authenticity. For example, consumers might need to examine the product's packaging in a virtual space, identify security features, or interact with a virtual representation of the product.

This VR-based approach not only enhances security but also creates a unique and engaging experience for consumers. By incorporating authentication into the unboxing process, brands can strengthen the emotional connection with their customers, making verification an integral part of the product experience. Additionally, VR provides brands with insights into consumer behaviour, such as time spent in the virtual environment and specific actions taken, which can refine product security strategies and enhance customer experiences.

However, the implementation of VR verification requires careful consideration of user experience. The process must be intuitive and efficient to avoid creating barriers or frustrations for consumers. A well-designed VR experience should be engaging and informative, ensuring that the added security measures enhance rather than hinder the overall product experience.

4.3. Implementation challenges

Despite the benefits, integrating AR and VR technologies into product packaging to enhance security presents several challenges (Alalwan et al., 2020). A significant challenge is the investment required for hardware and software development. Custom applications, specialized hardware (such as AR markers or VR headsets), and ongoing maintenance are necessary to ensure the technology remains secure and effective. This investment can be particularly burdensome for smaller brands or those with limited resources.

Another challenge is the accessibility and adoption of AR and VR devices among consumers. For the security features to be effective, consumers need access to compatible hardware and software, such as smartphones or VR headsets. In regions with lower adoption rates of these technologies, the effectiveness of the security measures may be limited.

Brands must also ensure that AR and VR security features do not create unnecessary barriers or inconveniences. The authentication and verification processes should be seamless, intuitive, and user-friendly to maintain a positive customer experience. Additionally, brands need to continuously update and improve their AR and VR security features to keep pace with evolving counterfeiting techniques and technologies.

Despite these challenges, the potential benefits of AR and VR in enhancing product packaging security are significant. These technologies offer reliable and engaging ways for consumers to verify the authenticity of their purchases, helping brands build trust, protect their reputation, and drive customer loyalty. As AR and VR technologies advance and become more accessible, their role in combating counterfeiting and strengthening product integrity is likely to grow, making them increasingly valuable tools for brands.

5. PRODUCT PACKAGING OPTIMIZATION

5.1. Virtual prototyping and simulation

The advent of AR and VR technologies has significantly transformed product packaging optimization (Rejeb et al., 2021). These immersive tools offer innovative methods for creating and testing virtual prototypes, allowing designers to evaluate various design options, materials, and structural integrity without relying on physical prototypes.

Virtual prototyping enables the creation of detailed, three-dimensional models of packaging concepts, which can be tested in a simulated environment (Corallo et al., 2022). Designers can interact with these virtual models, examining them from different angles, testing their structural integrity, and assessing their performance under various conditions. This interactive simulation provides insights that traditional methods might miss, leading to more informed design decisions.

The rapid iteration enabled by virtual prototyping streamlines the design process. Designers can make quick adjustments based on feedback and simulation results, which is particularly advantageous in industries where packaging is critical. This approach not only speeds up the design process but also reduces the costs associated with physical prototypes and minimizes material waste by addressing design flaws before production begins.

Overall, integrating virtual prototyping and simulation into packaging design processes allows for more efficient, cost-effective, and environmentally friendly solutions. AR and VR technologies enhance the optimization of packaging designs, leading to improved outcomes and a more sustainable future for packaging (Figure 5).



Figure 5: Use of augmented reality for product prototyping

5.2. Design efficiency and material waste reduction

The use of AR and VR technologies has greatly enhanced design efficiency and reduced material waste in product packaging (Shao & Min, 2021). Virtual prototyping and simulation, as previously discussed, are key to these advancements.

These technologies allow designers to create, test, and iterate on packaging concepts quickly within a virtual environment, reducing the need for time-consuming and resource-intensive physical prototypes. By simulating the structural integrity, functionality, and aesthetics of packaging designs, designers can address potential issues before moving to production.

This iterative approach not only fosters innovation and creativity but also significantly reduces material waste. Designers can refine their ideas and resolve design challenges virtually, avoiding the production of physical prototypes that may be discarded. This waste reduction is especially impactful in industries such as consumer goods, food and beverage, and e-commerce, where packaging plays a crucial role.

Additionally, the efficient design processes enabled by AR and VR contribute to indirect sustainability benefits, such as optimizing material usage, reducing packaging volumes, and enhancing recyclability or compostability (Jayakumar & Aboobacker, 2021). As the focus on sustainability grows, AR and VR technologies will become increasingly valuable in driving efficient, environmentally conscious packaging solutions.

5.3. Case studies in packaging optimization

Several leading brands have successfully integrated AR and VR technologies into their packaging optimization processes, demonstrating their practical benefits (Dalton, 2021).

5.3.1. Procter & Gamble's VR unboxing experience

Procter & Gamble utilized VR to simulate the unboxing experience of their products. This approach allowed designers to observe and analyze consumer interactions with packaging in a virtual environment. The insights gained enabled Procter & Gamble to refine packaging aesthetics, functionality, and ease of use, leading to improved product experiences while reducing the need for physical prototypes.

5.3.2. Coca-Cola's AR packaging concept testing

Coca-Cola employed AR to create virtual mockups of packaging concepts. This AR-enabled testing provided valuable feedback on visual appeal, ergonomics, and functionality, allowing Coca-Cola to make informed design decisions and reduce material waste and development costs. The ability to quickly iterate on designs in a virtual setting proved highly beneficial for optimizing packaging solutions.

5.3.3. Unilever's VR-powered packaging simulation

Unilever integrated VR into its packaging design process to create immersive simulations of packaging. This allowed designers to evaluate physical properties, structural integrity, and user experience, addressing issues early in the design phase and minimizing the need for physical prototypes. The data collected from these simulations informed decisions on materials, formats, and production processes, enhancing the sustainability and cost-effectiveness of Unilever's packaging solutions.

These case studies illustrate the substantial benefits of AR and VR in packaging optimization. By facilitating efficient design iterations, reducing material waste, and supporting data-driven decision-making, these technologies have proven to be powerful tools for brands seeking to improve the sustainability, functionality, and performance of their packaging.

As the packaging industry evolves, the integration of AR and VR technologies will increasingly play a crucial role in delivering innovative and user-centric packaging experiences.

6. CHALLENGES AND FUTURE PROSPECTS

6.1. Skill and knowledge requirements

The integration of AR and VR into graphic design presents significant opportunities and challenges. A primary challenge is the need for designers to acquire new skills and knowledge to effectively utilize these transformative technologies. Traditional graphic design has focused on static or animated visual content,

such as print layouts and digital illustrations. However, AR and VR require designers to develop competencies in creating interactive, three-dimensional content for immersive virtual environments.
Designers must gain expertise in areas such as 3D modeling, spatial design, and user interaction, along with an understanding of AR and VR platforms, hardware, and software. This knowledge is crucial for making informed decisions about the most appropriate technologies for specific projects or client needs.
To address this skills gap, design education programs and professional development initiatives must incorporate AR and VR principles and techniques. Educational institutions should update curricula to prepare future designers for the evolving landscape, while established designers should seek continuous training through conferences, workshops, and mentorship to stay current with technological advancements.
By investing in AR and VR-related skills, graphic designers can enhance their value to clients and employers, delivering innovative and technologically advanced design solutions.

6.2. Cost and technological updates

Implementing AR and VR technologies in graphic design involves significant financial and technological challenges. The initial costs can be substantial, particularly for small and medium-sized design studios, covering specialized hardware like AR devices and VR headsets, as well as custom software development.
Ongoing maintenance and updates to keep pace with rapid technological advancements further strain budgets. As new hardware and software versions are introduced, designers and brands must continuously update their tools and platforms to remain competitive.
To mitigate these financial challenges, collaborative or shared-resource models may be explored, such as pooling resources among design studios or partnering with technology providers for turnkey AR and VR solutions. Additionally, as AR and VR technologies become more accessible and economies of scale take effect, costs are expected to decrease, making these technologies more feasible for a broader range of players.
Despite these challenges, the need for continuous technological updates will persist. Designers and brands must allocate resources for ongoing training, software updates, and hardware upgrades to maintain relevance in a rapidly changing field.

6.3. Potential for innovation

The adoption of AR and VR in graphic design holds immense potential for innovation and creativity. These technologies enable the creation of immersive and interactive design experiences that surpass the limitations of traditional media. Designers can use AR and VR to transport audiences into virtual worlds, offering unprecedented ways to explore, manipulate, and engage with visual content.
This evolution will position graphic designers at the forefront of technological advancements, as the demand for engaging and memorable brand experiences grows. Designers with the skills to harness AR and VR will be highly sought after, shaping the future of the industry with innovative and impactful solutions.
Furthermore, AR and VR integration will encourage greater collaboration across disciplines. Designers will need to work closely with developers, engineers, and other technology experts, fostering new design methodologies and innovative tools. As the physical and digital worlds blend, designers will need a deep understanding of user behaviour, spatial awareness, and interactive design principles.
The potential for AR and VR to drive sustainability and environmental consciousness is also notable. Virtual prototyping and simulations reduce material waste and optimize packaging solutions, aligning with the increasing demand for sustainable practices in design.
As AR and VR technologies continue to advance, they will transform graphic design, offering new opportunities for creativity and engagement. Designers who embrace these innovations and adapt to their potential will play a crucial role in shaping the future of the field, delivering transformative design solutions that captivate audiences and redefine the boundaries of visual communication.

7. CONCLUSION

The integration of AR and VR technologies into graphic design and product packaging optimization marks a significant shift in brand-consumer engagement and design efficiency. This review highlights how AR and VR enhance user interaction, improve security features, and promote sustainability in packaging design. By creating immersive experiences, these technologies enable brands to develop memorable advertising campaigns that foster brand loyalty and customer satisfaction. AR transforms static content into dynamic

experiences, allowing consumers to engage with products interactively, which strengthens emotional connections and provides insights into consumer behaviour. Similarly, VR enhances product visualization, enabling customers to assess products in their intended environments, thereby reducing uncertainty and return rates. In product packaging optimization, AR and VR streamline the design process through virtual prototyping and simulation. Designers can test packaging concepts in a virtual space, facilitating rapid iterations and informed decision-making without physical prototypes. This approach accelerates design timelines and minimizes material waste, aligning with the growing emphasis on sustainability in the packaging industry. Brands adopting these technologies can improve the functionality, aesthetics, and recyclability of their packaging solutions, contributing to a more environmentally conscious future. Additionally, AR and VR enhance security features, addressing counterfeiting challenges by embedding AR markers for authentication and utilizing VR for immersive verification experiences. This builds consumer trust and protects brand reputations. However, successful implementation requires designers to acquire new skills, underscoring the need for ongoing education and training in graphic design. The future of graphic design and product packaging is set for significant advancements through the continued integration of AR and VR technologies. As these tools become more accessible, they will play a crucial role in delivering innovative, user-centric, and sustainable solutions that meet the evolving demands of consumers and the marketplace.

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DEVELOPMENT OF A MOBILE AUGMENTED REALITY APPLICATION FOR INTERIOR DESIGN USING UNITY ENGINE

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Abstract: *This paper details the creation of a mobile Augmented Reality (AR) application to enhance interior design processes by allowing users to place digital furniture within their physical spaces. Developed using the Unity Engine, the application leverages C# programming to provide a seamless and interactive user experience. The user interface, designed in Adobe XD, ensures functionality and aesthetic appeal, guiding users through intuitive screens and interactive elements. Three-dimensional (3D) models are integral to the application, created through manual modelling in Blender and photogrammetry using Polycam. Blender's advanced capabilities enable detailed and accurate 3D models, while Polycam's photogrammetry converts real-world objects into digital models, enhancing realism and diversity. Real-time functionality is supported by integrating Google Firebase for scalable and reliable backend services, ensuring smooth data synchronization and user-generated content storage. AR technology overlays digital information onto the physical world in real time, enhancing users' perception and decision-making in interior design. Users can visualize different arrangements and make informed choices by virtually placing and manipulating furniture, reducing uncertainty and increasing satisfaction with their design decisions. This paper also explores the historical context and advancements in AR technology, highlighting its transformative impact on various industries. The development process here combines programming expertise, creative design, and technical knowledge of 3D modelling and backend technologies, offering valuable insights and practical advice for future AR application developers.*

Key words: Augmented Reality, Unity Engine, 3D Modelling, Interior Design, Google Firebase

1. INTRODUCTION

Augmented Reality (AR) has rapidly emerged as a transformative technology, bridging the gap between the physical and digital worlds. By overlaying digital content onto real environments, AR has found applications across various industries, including entertainment, education, retail, and design. AR provides a powerful tool for visualizing and experimenting with design concepts in real-time in interior design. This technology allows users to place and manipulate digital furniture within their living spaces, offering a more interactive and immersive design experience (Rhonda et al., 2024).
This paper presents the development of a mobile AR application specifically designed for interior design, utilizing the Unity Engine as the primary development platform. The goal of the application is to enable users to visualize furniture layouts in their homes, helping them make more informed decisions during the design process. The app integrates several technologies, including C# programming for interactive features, Adobe XD for user interface design, Blender and Polycam for 3D model generation, and Google Firebase for real-time backend services. Together, these tools create an intuitive and visually appealing solution, enhancing user engagement and decision-making in interior design.

1.1 Augmented Reality (AR)

Augmented Reality (AR) is a technology that blends digital content with the real world, allowing users to interact with virtual elements in real time. Unlike virtual reality, which immerses users in a wholly digital environment, AR enhances the physical world by overlaying information, graphics, and 3D models onto real surroundings. This unique capability has made AR a versatile tool across a variety of industries, offering new ways for users to engage with both digital and physical spaces (Cipresso et al., 2018).
The concept of AR has roots dating back to 1967 when Ivan Sutherland, a Harvard professor, and his student Bob Sproull developed the first head-mounted display system, famously known as "The Sword of Damocles." This early device allowed users to experience computer-generated graphics overlaid onto their real-world view, marking the inception of augmented reality. However, the term "Augmented Reality" was officially coined in 1990 by Tom Caudell, a researcher at Boeing, who was working on a system to assist workers in airplane construction by overlaying digital information on their tasks. This

ORCID numbers are provided at the end of the paper.

system allowed workers to visualize complex assembly instructions, laying the groundwork for future AR developments (Colocation America, 2018; Mealy, 2018).
AR technology has evolved significantly, becoming commercially available and widely adopted, especially through mobile devices. With the integration of AR into smartphones and tablets, the technology has become accessible to millions of users worldwide. Companies like Apple and Google have made major strides in AR development with the creation of ARKit for iOS and ARCore for Android, providing developers with powerful tools to create immersive AR experiences. Additionally, platforms like Vuforia, Easy AR, and Snapchat Lens Studio further expand the possibilities of AR development, enabling a wide range of applications in gaming, retail, education, and interior design. The mass adoption of AR has been further fuelled by advancements in hardware, such as AR glasses and headsets, which continue to push the boundaries of how AR can be integrated into everyday life (TechTarget, 2023).

1.2 Development of AR applications for Interior Design

The integration of Augmented Reality (AR) into interior design has transformed how users approach space planning and decoration. AR applications allow users to visualize furniture and decor in real-time, within their actual living environments, providing a practical and immersive solution to traditional design challenges. By overlaying 3D furniture, appliances, and decor models onto physical spaces, users can experiment with various layouts, styles, and arrangements, understanding how their choices will look and feel before making any physical changes (Medium, 2024).
The ability to manipulate virtual objects within a real environment helps users make more informed decisions, eliminating much of the uncertainty associated with interior design. This technology also facilitates collaboration between clients and designers, as both parties can visualize potential design solutions together, ensuring that the end result meets expectations. The rise of AR in interior design has empowered users to take a more hands-on approach to their projects, giving them greater control and flexibility in shaping their spaces.
As AR technology continues to evolve, its applications in interior design are expected to become even more sophisticated. This will allow for more advanced interactions, enhanced realism, and broader accessibility across different platforms. Whether for home renovations, office space planning, or retail store layouts, AR offers an innovative tool that enhances creativity, efficiency, and user satisfaction in the design process.

1.3 Mobile AR application Development using Unity Engine

The Unity Engine has become a popular choice for developing mobile AR applications due to its versatility, powerful feature set, and cross-platform capabilities. Unity offers a robust development environment that simplifies the creation of interactive and immersive AR experiences. With built-in support for ARKit and ARCore, Unity allows developers to seamlessly integrate augmented reality functionalities into both iOS and Android devices, making it ideal for creating applications that can reach a wide audience (Daily.dev, 2024).
Unity enables real-time 3D rendering in mobile AR application development, providing smooth and responsive user interactions. Developers can use Unity's scripting language, C#, to manage the application's logic, such as object placement, scaling, and user interaction. Additionally, Unity's asset pipeline supports importing 3D models, textures, and animations from external tools like Blender, making integrating high-quality graphics into the application easier.
Another key advantage of Unity is its comprehensive toolset, which includes debugging, performance optimization, and testing features. This ensures that AR applications perform efficiently on mobile devices with varying hardware capabilities. Unity also offers extensive documentation and a wide array of plugins, making it a flexible and developer-friendly platform for creating innovative and user-centric AR applications.

1.4 User Interface and User Experience Design

In the development of AR applications, User Interface (UI) and User Experience (UX) design play a crucial role in ensuring the application is both functional and intuitive. A well-designed UI guides users through the application seamlessly, allowing them to interact with AR features without confusion or difficulty. In AR interior design applications, the interface must be simple and clear, allowing users to easily navigate through furniture options, placement tools, and customization features.

UX design focuses on how users feel when interacting with the application, aiming to provide an engaging and satisfying experience. For AR applications, this means creating a smooth flow from one task to another, minimizing the complexity of interactions, and ensuring that visual elements and controls are easy to understand. The AR experience must be immersive without overwhelming the user, and interactions such as tapping, dragging, and rotating objects should feel natural and responsive.
The design process typically involves prototyping and testing through tools like Adobe XD or Figma, where designers can experiment with different layouts, interactions, and design elements. User feedback is essential during this phase, as it helps refine the interface to meet the needs and expectations of the target audience. An effective UI/UX design in AR applications ensures that users can fully engage with the technology, making their interaction with the virtual elements intuitive, enjoyable, and productive (Interaction Design Foundation, 2016).

1.5 3D modelling for AR applications

3D modelling is a critical component in the development of AR applications, as it creates the virtual objects that users interact with in their real-world environment. High-quality 3D models enhance the realism and effectiveness of AR experiences, making them more engaging and useful. For AR applications, especially in fields like interior design, the accuracy and detail of these models are essential for providing a believable and immersive experience (RebusFarm, 2023).
The process of creating 3D models for AR involves various techniques and tools. Manual modelling using software such as Blender allows for detailed and customized object creation, enabling designers to produce intricate and high-fidelity representations of furniture and decor. Blender's powerful features support the creation of complex geometries, textures, and animations, which are crucial for ensuring that virtual objects look and behave realistically in an augmented environment.
Additionally, photogrammetry techniques, employed through applications like Polycam, enable the conversion of real-world objects into digital 3D models by capturing and analysing multiple photographic images. This method enhances the diversity and authenticity of the 3D assets, allowing users to place realistic representations of actual items into their virtual spaces. Combining these modelling techniques results in a rich and varied set of digital assets, significantly improving the quality and utility of AR applications.

1.6 Backend Services and Data Management

Effective backend services and data management are fundamental to the functionality and performance of AR applications. They ensure seamless interaction and reliable data handling. In AR applications, backend services support various critical functions, including real-time data synchronization, user-generated content storage, and overall application performance.
Google Firebase, a popular backend solution, provides a comprehensive suite of tools for managing these aspects. It offers real-time database capabilities that enable instantaneous updates and synchronization of data across multiple devices, ensuring that users experience a consistent and up-to-date AR environment. Firebase also handles user authentication, cloud storage, and analytics, allowing developers to manage user data and track application performance efficiently.
Furthermore, backend services support complex interactions within AR applications, such as saving user preferences, tracking design changes, and enabling collaborative features. By leveraging robust backend infrastructure, developers can ensure that the application runs smoothly, scales effectively with growing user numbers, and provides a reliable and engaging experience. Effective data management and backend services are essential for maintaining the integrity and efficiency of AR applications, allowing users to interact with digital content effortlessly while ensuring the application remains responsive and functional (MoldStud, 2024).

2. AR APPLICATION DEVELOPMENT

The application's development process includes several stages, from configuring the development environment using Unity Engine and integrating core functionalities to designing the user interface, creating 3D models, and linking the application to a real-time database. Each of these steps is essential for ensuring that the application functions smoothly and delivers an effective user experience.

2.1 Setting Up the AR Environment

Once a new project is created, it is crucial to integrate specific packages to support augmented reality (AR) application development. By accessing the Package Manager Window, developers can explore and manage the various available packages and sub-packages within the development environment.
The essential packages to be imported and installed include:

- AR Foundation,
- Google ARCore XR Plugin,
- Apple ARKit XR Plugin,
- XR Interaction Toolkit,
- Universal Render Pipeline, and
- TextMeshPro.

After integrating the required packages, the project is configured by setting specific values and specifications to ensure optimal performance on mobile devices. For Android, in the Player Settings window, it is essential to disable Multithreaded Rendering for compatibility with older devices. Auto-Graphics API should be turned off, and OpenGLES53 should be selected in the Rendering group. IL2CPP should be set as the Scripting Backend, ARM64 should be enabled, and the minimum supported Android version should be specified (Figure 1). For Apple devices, only the minimum iOS version needs to be defined. Once these configurations are complete, the Google ARCore and Apple ARKit packages through the XR Plugin Management tab must be activated (IBM, 2021).

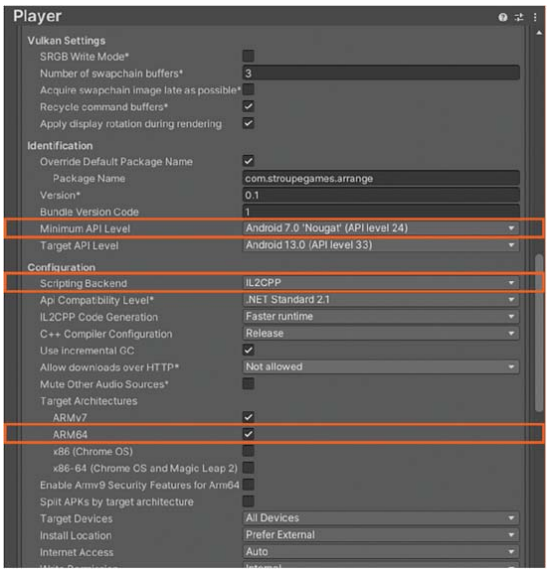


Figure 1: Player Settings

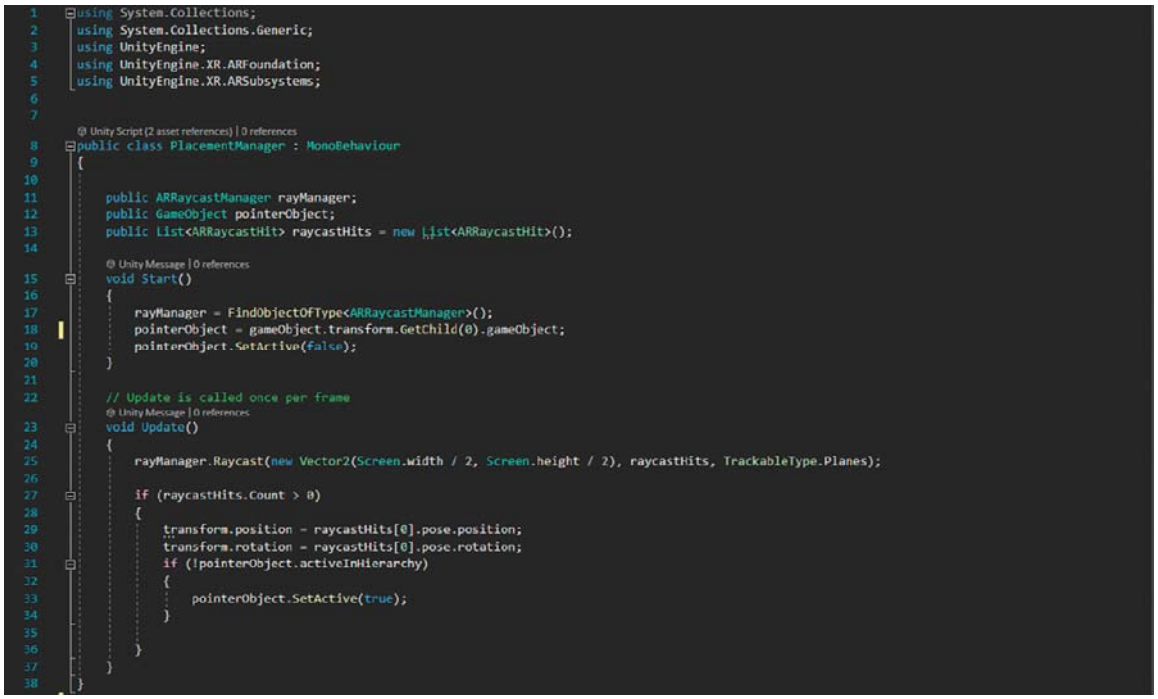
After configuring the key application parameters, the Universal Render Pipeline (URP) package is integrated. URP is a rendering system designed to provide high-quality graphics and optimal performance across both computers and mobile devices (Unity Technologies, 2024).
Once the application is optimized and the URP system implemented, a scene is created to establish the workspace for defining and applying necessary elements such as scripts and models.
A key aspect of AR applications is utilizing physical cameras, specifically the device's camera. AR Sessions and XR Origin are set up to define the application as an AR application, view the real world through the camera lens, and detect vertical and horizontal surfaces. The AR Plane Manager component is added to the XR Origin object to enable surface detection. Once the detected surfaces' appearance is defined through the AR Plane object and its material, and referenced in the AR Plane Manager component, the XR Origin, or the device's camera, displays these surfaces by generating a mesh of polygons on the recognized physical planes.

2.2 Basic Furniture Manipulation Functions Implementation

The fundamental functions for manipulating furniture or scene objects that are necessary for this type of application include:

- instantiating objects in the scene,
- moving instantiated objects and
- rotating instantiated objects.

Instantiating objects involves creating copies of predefined models using C# scripts and the Instantiate() method. The placement of these objects is determined using the Raycast technique, which involves projecting directed rays to gather information about the impacted surfaces or previously placed furniture in the scene (Unity Technologies, 2024). The AR Raycast Manager component is attached to the XR Origin object, making the device's camera the source of these rays. The script ensures continuous raycasting towards the centre of the device's screen. When the rays hit detected horizontal surfaces, an identifier is displayed, marking where the selected furniture will be placed. The script responsible for casting a ray to place furniture instances at the intersection point of the ray and the detected surface is called the PlacementManager script and is illustrated in Figure 2.



```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.XR.ARFoundation;
using UnityEngine.XR.ARSubsystems;


@ Unity Script (2 asset references) | 0 references
public class PlacementManager : MonoBehaviour
{

    public ARRaycastManager rayManager;
    public GameObject pointerObject;
    public List<ARRaycastHit> raycastHits = new List<ARRaycastHit>();

    @ Unity Message | 0 references
    void Start()
    {
        rayManager = FindObjectOfType<ARRaycastManager>();
        pointerObject = gameObject.transform.GetChild(0).gameObject;
        pointerObject.SetActive(false);
    }

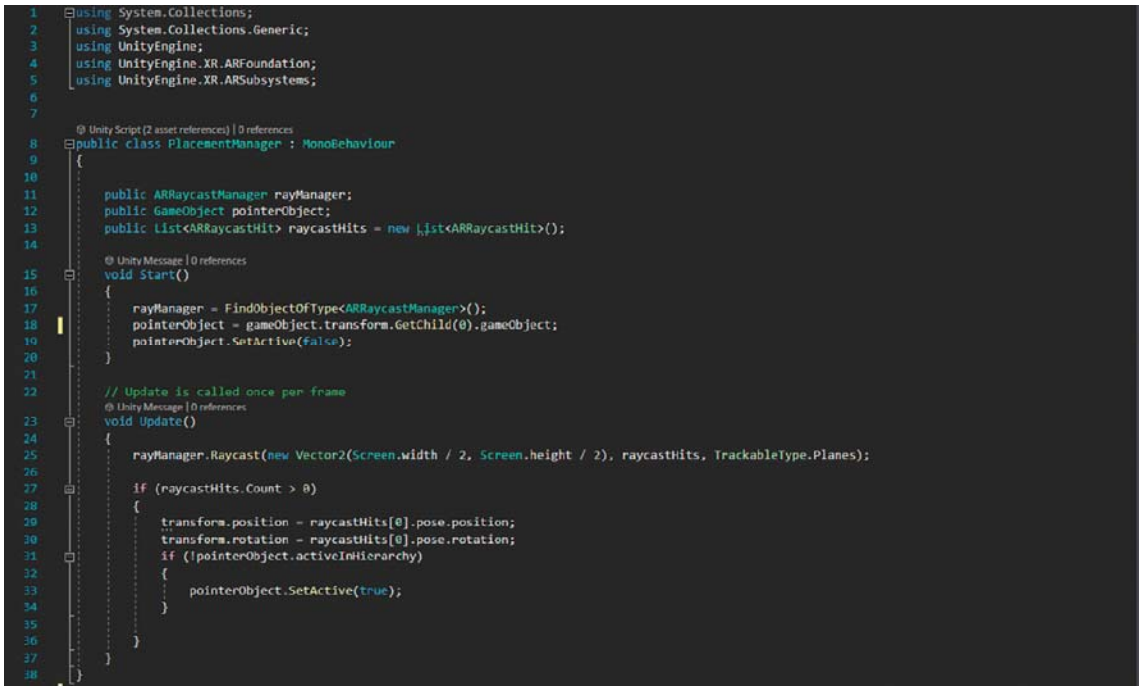
    // Update is called once per frame
    @ Unity Message | 0 references
    void Update()
    {
        rayManager.Raycast(new Vector2(Screen.width / 2, Screen.height / 2), raycastHits, TrackableType.Planes);

        if (raycastHits.Count > 0)
        {
            transform.position = raycastHits[0].pose.position;
            transform.rotation = raycastHits[0].pose.rotation;
            if (!pointerObject.activeInHierarchy)
            {
                pointerObject.SetActive(true);
            }

        }
    }
}
```

Figure 2: PlacementManager script

Moving objects works similarly: rays are cast towards the touch point when the screen is touched. If a ray hits and identifies a previously instantiated object, the object is anchored to the touch point until the screen is released. This functionality is defined in the SelectObjects script (Figure 3).



```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.XR.ARFoundation;
using UnityEngine.XR.ARSubsystems;


Unity Script (2 asset references) | 0 references
public class PlacementManager : MonoBehaviour
{

    public ARRaycastManager rayManager;
    public GameObject pointerObject;
    public List<ARRaycastHit> raycastHits = new List<ARRaycastHit>();

    Unity Message | 0 references
    void Start()
    {
        rayManager = FindObjectOfType<ARRaycastManager>();
        pointerObject = gameObject.transform.GetChild(0).gameObject;
        pointerObject.SetActive(false);
    }

    // Update is called once per frame
    Unity Message | 0 references
    void Update()
    {
        rayManager.Raycast(new Vector2(Screen.width / 2, Screen.height / 2), raycastHits, TrackableType.Planes);

        if (raycastHits.Count > 0)
        {
            transform.position = raycastHits[0].pose.position;
            transform.rotation = raycastHits[0].pose.rotation;
            if (!pointerObject.activeInHierarchy)
            {
                pointerObject.SetActive(true);
            }

        }
    }
}
```

Figure 3: SelectObjects script

Rotation is managed based on the relative position of two fingers touching the screen and occurs exclusively around the vertical axis of the object.

2.3 Design and Implementation of the User Interface

User Interface (UI) design involves visually creating the layout and appearance of software or devices that use screens for user interaction (BrowserStack, 2023). This design process is facilitated by Adobe XD, which provides a comprehensive set of tools. A segment of the User Interface is displayed in Figure 4. The visual components of the application include:

- the welcome and loading screen,
- the main application screen,
- the product category selection menu,
- the submenu for product categories and the display of products in each category,
- the individual product details screen,
- the screen for placing products in the physical environment including manipulation features and
- the settings menu.

After exporting the graphical elements from Adobe XD, they are imported into Unity Engine by dragging them into the project window and setting their texture type to Sprite (2D and UI). These elements are integrated within the Canvas object in Unity Engine, which encompasses the entire application's UI. All menus, buttons, images, and text elements within the Canvas are defined along with their respective functions and methods.

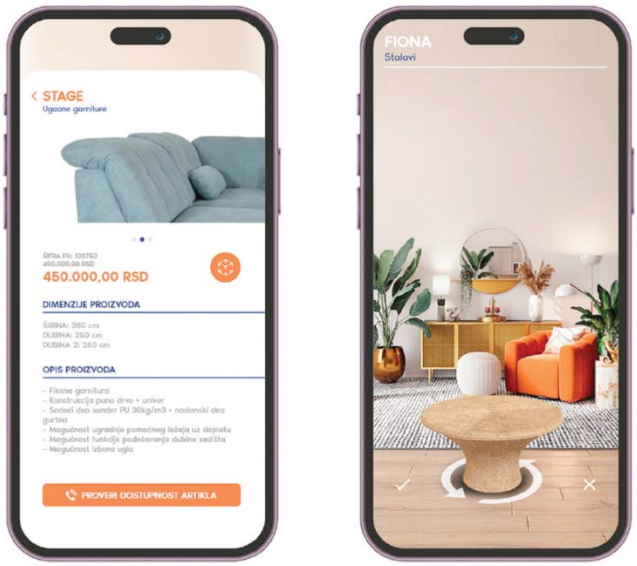


Figure 4: AR application User Interface

Unity Engine also supports the import of external fonts, which are processed using the TextMeshPro package to create a font atlas, enabling the use of custom fonts.

2.4 Creation and Preparation of 3D Models

In this research, the creation and design of three-dimensional models are accomplished through two main methods:

- manual modelling using Blender and
- photogrammetry with Polycam.

For instance, in Blender, the design of a Himalayan salt lamp begins with a basic 3D cube. This cube is modified using the Subdivision Surface modifier to create a more detailed polygon mesh, and the Displace modifier is applied to shape the mesh into an irregular, natural form (Figure 5a). The Decimate Geometry function is used to optimize the polygon mesh. The lamp's base and material are also created based on a texture image of the Himalayan salt lamp, resulting in the 3D model depicted in Figure 5b.

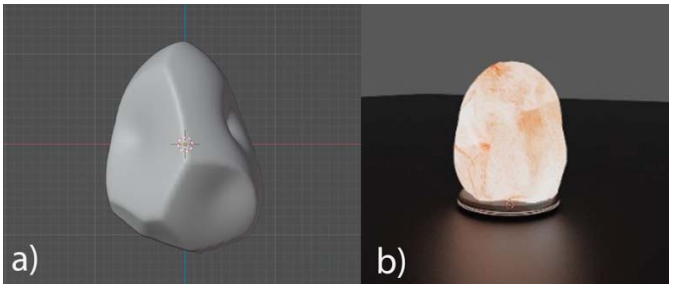


Figure 5: Himalayan salt lamp, a) manual 3D modelling after modifier applied and b) the final result

When exporting a 3D model from Blender, it is crucial to include the model and its applied textures and materials.
For photogrammetry-based 3D model creation, the real-world object- such as a coffee table in this case-is photographed from multiple angles. These photos are then processed using Polycam, resulting in a 3D model that may exhibit significant distortions and may not meet the standards for an accurate representation (Figure 6). Users expect a faithful digital reproduction when selecting and viewing items for purchase within the application.



Figure 6: Coffee table photographs and final 3D model

2.5 Integration of Firebase Database and Storage

The application only loads data and models that the user selects to optimize memory usage. The application employs the Firestore Database to store essential product information and Firebase Storage to handle images and furniture models. Before these services can be used, Firebase must be integrated into the Unity project, and a database and storage must be set up on the Firebase platform, linking the project to Firebase services through the Firebase console.
Once integration is complete, the database and storage are organized into the following hierarchy:

- all products,
- room,
- product type,
- individual product,
- product details.

Product data, models, and images are retrieved in real time as the user selects items, utilizing predefined methods from the Firebase package.

3. RESULTS

This research paper details the development of a mobile augmented reality application designed to enable users to place digital furniture within their physical space. The application was built using Unity Engine, with 3D models created in Blender and Polycam. Google Firebase was employed for backend services.
The outcome is a fully functional AR application that allows users to virtually position and adjust furniture in real-world settings using mobile devices. Additionally, the project includes a comprehensive workspace with all the required packages and configurations for developing this type of application (Figure 7).



Figure 7: Display of the application on the device

The key stages in developing the application involve setting up the development environment, implementing features for placing and moving furniture, designing the user interface, creating 3D models, and integrating with Firebase for data storage.
This application provides a user-friendly and enjoyable method for planning and visualizing interior design. It allows users to see how specific furniture items would look in their own space, assisting them in making informed purchase decisions.

4. DISCUSSION

The development of Augmented Reality (AR) applications is a multifaceted endeavour that integrates various disciplines, including programming, creative design, 3D modelling, and backend management. This discussion examines the critical aspects of AR application development, with a focus on the AR application, which allows users to visualize and manipulate furniture in their physical spaces.
One of the primary challenges in AR development is configuring the development environment effectively. For AR application integrating essential AR packages within the Unity Engine was pivotal. The inclusion of AR Foundation, Google ARCore XR Plugin, and Apple ARKit XR Plugin provided the necessary tools for creating a seamless AR experience. These packages facilitated interaction with real-world environments and ensured cross-device compatibility. The successful implementation of these technologies highlights the importance of selecting appropriate development tools and configuring them correctly to build a robust AR application.
The technical complexity involved in the application's core functionalities-such as furniture placement, movement, and rotation-underscores the sophisticated nature of AR development. Utilizing Raycast techniques for precise object placement exemplifies the detailed understanding required in spatial computing and user interaction. The implementation of these features using C# scripting illustrates the significant effort needed to create a responsive and intuitive AR experience.
Another crucial element is designing an engaging user interface (UI). The use of Adobe XD to create visually appealing screens and integrate these designs into Unity Engine through the Canvas system demonstrates the role of UI in enhancing user experience. Thoughtful design of interaction points, including welcome screens, product selection menus, and settings, ensures easy navigation and effective user engagement. The incorporation of external fonts and graphical elements further refines the application's appearance, emphasizing the importance of a polished and professional design.
The creation of 3D models, whether through manual modelling in Blender or photogrammetry using Polycam, adds another layer of complexity. The article emphasizes the significance of accurate and realistic 3D models in enriching the AR experience. Detailed discussions on modelling techniques, including texture mapping and optimization, highlight the skill required to produce high-quality models that enhance the application's realism and functionality.
Backend services and data management are critical for managing real-time data and user-generated content. The integration of Firebase services allows for efficient data storage and retrieval, ensuring that the application remains responsive and reliable. The hierarchical organization of product data within the Firestore Database and Firebase Storage exemplifies the structured approach necessary for effective data management.

5. CONCLUSIONS

The development of an AR application is a complex, interdisciplinary process that demands a blend of programming expertise, creative design, and technical knowledge in 3D modelling and backend technologies. This article provides a comprehensive overview of the development process, from initial concept through to implementation and optimization, offering valuable insights and practical advice for creating AR applications. By balancing technical performance with user experience, developers can achieve a successful and effective AR application. This approach is crucial for meeting the demands of modern applications and ensuring a satisfying user experience.

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https://doi.org/10.24867/GRID-2024-p21 Original scientific paper

THE IMPACT OF THE MODEL`S GAZE DIRECTION ON THE USER EXPERIENCE

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Abstract: *The direction of a model's gaze in a photo can have varying effects on how users perceive an interface. The psychological state of the person in the image can be interpreted by viewers by focusing on the model's gaze. In advertising, however, gaze direction plays a different role, as it can guide the viewer's attention to specific elements as intended by the designer. This paper aims to explore whether the model's gaze direction influences user experience. For the research, a prototype of an online store was developed, featuring a model whose gaze is directed left, right, and straight ahead in different photos. An eye-tracking camera was used to monitor eye movement during the study. The results are displayed as heat maps, highlighting the areas of the interface that received the most attention and were viewed for the longest time.*

Key words: gaze direction, advertising, user experience, eye tracking

1. INTRODUCTION

Eye gaze direction is a crucial element in face processing and social communication, influencing how efficiently facial expressions of emotion are perceived and processed (Hu et al., 2017; Adams Jr & Kleck, 2003). Research has shown that direct eye gaze captures and retains attention to faces, suggesting its significance in human interaction and visual processing (Bindemann et al., 2005).

The direction of human gaze is a critical aspect of non-verbal communication, significantly influencing interpersonal interactions and emotional responses. When a person looks directly into another's eyes, it encourages feelings of trust, security, and positive feedback. Eye gaze serves multiple functions during social interactions, allowing individuals to effectively exchange social signals and comply with social norms, enhancing communication and connection.

Eye contact is crucial for establishing and maintaining interpersonal relationships, as it conveys attention and intent, and can influence emotional states such as trust and anxiety (Cañigueral & Hamilton, 2019; Davidhizar, 1992). Even in images with human faces research on eye gaze has indicated that, observers typically direct their attention quickly to the facial areas (Cerf, Frady & Koch, 2009).

In the context of advertising, studies have demonstrated that a model's gaze direction can significantly impact viewer attention and engagement. Hutton and Nolte investigated that participants looked longer at product in advertisements when the model's gaze was directed toward the product (Hutton & Nolte, 2011). This finding is particularly important in the digital advertising, where online users are more oriented on goals and critical of ads compared to print media (Deshwal, 2016), highlighting the potential impact of subtle design factors like gaze direction on advertising effectiveness.

Online shopping has become extremely popular in recent years, and there are various reasons why people prefer to shop online. Some of these reasons include: convenience, the ability to compare competitors and speed (Kavitha, 2017). Online shopping requires efficiency and respondents should enjoy the purchasing experience (Perea y Monsuwé, Dellaert & De Ruyter, 2004).

User Experience (UX) refers to the various perceptions that arise from using a specific product or system. This encompasses all physical and psychological reactions, as well as emotions that occur during and/or after its use. The experience results from the presentation of information, functionality, and performance provided by the system (Mirnig et al., 2015). A good interface is one that allows the user to focus on the information and their goals, rather than on how the interaction is executed (Galitz, 2007).

Furthermore, the results of the research in the paper "Effects of Model Eye Gaze Direction on Consumer Visual Processing" (Figure 1) show that direct and indirect gaze yield different outcomes in advertising. It has been demonstrated that direct gaze captures the viewer's attention and prompts them to fixate exclusively on the model's face in the image. If the model's eyes and head are directed at a specific part of the text or product, viewers will look at that point for a longer duration (Wang et al., 2018).

ORCID numbers are provided at the end of the paper.

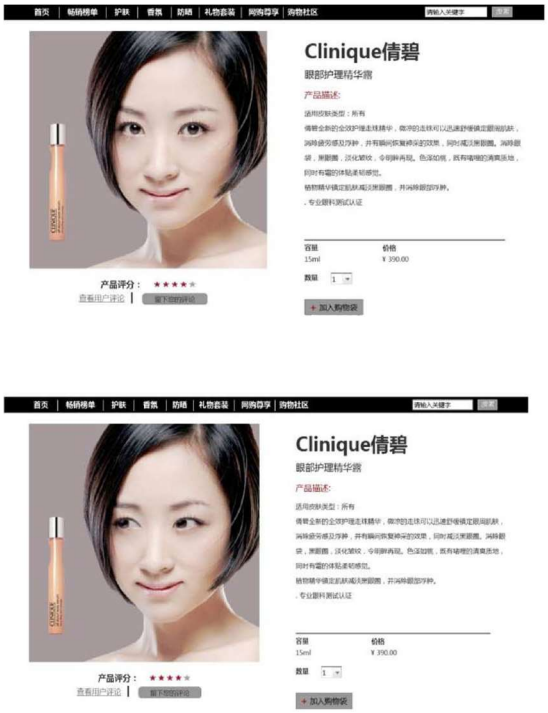


Figure 1: Examples in experiment of Wang et al., 2018
Direct gaze on the top picture and averted gaze on the bottom picture

2. METHODS

The aim of this research is to examine whether the gaze or direction of the model's look in a photograph affects the user's experience. For the purposes of the research, three examples of an online jewellery store were created. The photographs used for conducting the research are original, as are all the text and logo used in the research example. Model in the photograph is directed to a different side in each example (right, left, straight). The assumption is that the gaze of the model in the photograph will draw the respondent's attention to a specific part of the website. On the first of the three examples, the model is wearing earrings and looking to the right. In the second example, the model looks to the left and is wearing sunglasses. The third example shows the same model wearing a necklace and looking straight ahead. The variable parameters are jewellery, price, title (name of the jewellery) and text (description). They contribute to the realism of the e-commerce itself and allow the user to remain interested and focused. However, the most important parameter that changes and is tested is the person's gaze in the picture. The basic design and elements of the e-commerce remain the same in each example.
79 students of the University North between the ages of 19 and 25 took part in the survey. Calibration could not be successfully completed for some participants, which is why the results of eight students were excluded from this analysis. The test was successfully completed by 40 male and 31 female participants.
Measurements were conducted using the Gazepoint GP3 Desktop eye-tracking device, with data processed by the Gazepoint Analysis 3.5.0 software. The eye-tracking device was recalibrated for each participant. Participants faced the screen directly, maintaining a distance of 60 to 80 cm from it. Each participant viewed three examples of a web store sequentially, with each example displayed for 10 seconds. The analysis of the research results was performed using heat maps.

3. RESULTS AND DISCUSSION

Heat maps are graphical representations of data that use cold and warm colours to indicate intensity of user interaction. When used with gaze tracking devices they indicate which areas are of most interest. High-intensity areas are coloured red, and low-intensity areas are indicated with blue. The colourless areas were either skimmed or not observed at all. For this reason, the results of this research are presented with the

help of heat maps. The results presented in this paper show the intensity of gaze for the 2nd second and for the complete duration of the observation.

3.1 Heat map analysis for 2nd second of viewing

From the display of the heat map for first example (Figure 2), it is clear that the respondents have an intense focus on the title. This focus aligns with the direction of the gaze of the person in the picture. To a lesser extent, they also look at the face and they ignore other elements of the online store. This is the 2nd second of viewing, so it can be concluded that the look of the model from the picture immediately at the beginning of viewing directed the subject's attention to the title itself.

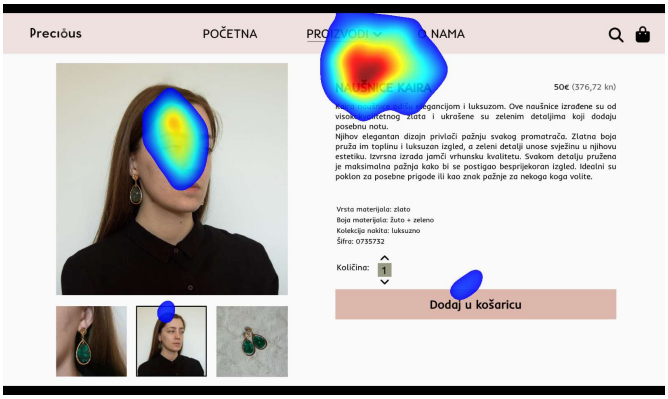


Figure 2: Heat map showing the intensity of gaze for the 2nd second of observation. Sample version is a right-facing model

Figure 3 shows the left-facing model and if compared with previous example (Figure 2) there is visible difference. In this example (Figure 3) direction of gaze is mostly focused on face of the model, title of product and a little bit on the smaller images. According to this it can be concluded that the participant's attention was dispersed and the model's orientation did not significantly influence the direction of their gaze.



Figure 3: Heat map showing the intensity of viewing for the 2nd second of observation. Sample version is a left-facing model

In Figure 4, it is evident that the respondent's attention was mostly focused on the model's face. However, they also looked with great interest at the first item in the small picture gallery, namely the necklace.
From the three displayed images (Figure 2, Figure 3, Figure 4), it can be seen that the gaze of the model in the photograph significantly influenced the respondents' attention within the 2nd second of viewing.



Figure 4: Heat map showing the intensity of viewing for the 2nd second of observation. Sample version is a front-facing model

3.2 Heat maps analysis for all ten seconds – average

When taking the average of all 10 seconds of viewing, the results in Figure 5 show that the respondent's primarily focus on the direction of the gaze of the person in the image, while almost ignoring all other elements and the remaining text. There are hardly any areas, except for the title and the model's face, where the heat map is yellow.

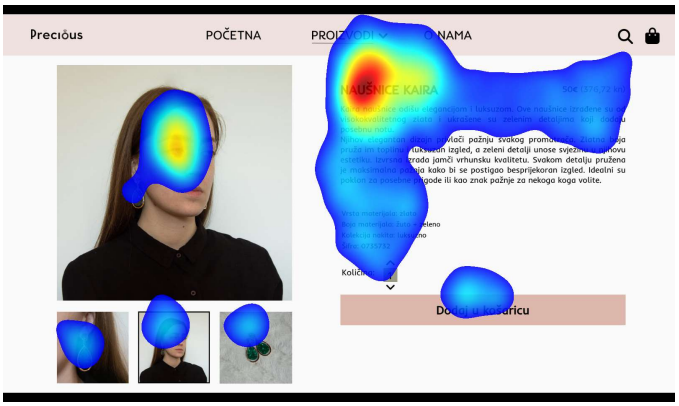


Figure 5: Heat map showing the overall results, right-facing model

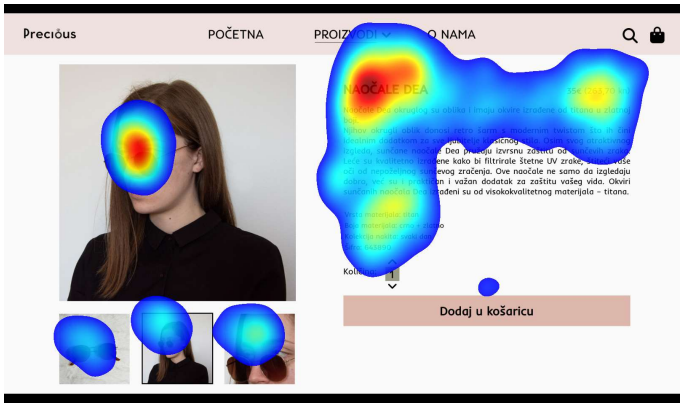


Figure 6: Heat map showing the overall results, left-facing model

Figure 6 showing the overall results for left-facing model, indicates that the entire text is viewed with slight emphasis on the title. The heat map in Figure 7 is very similar to Figure 6, but much more attention is focused on the text as well as the small images that provide more detailed views of the product being purchased.

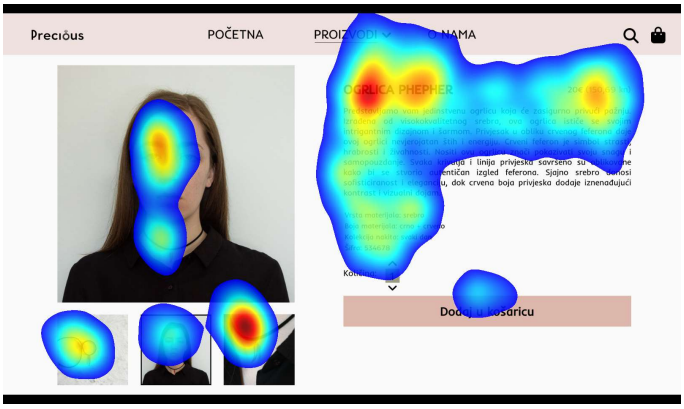


Figure 7: Heat map showing the overall results, front-facing model

From these three photographs (Figures 5-7), it can be concluded that the gaze of the model in the image significantly influences the respondent. If the model is looking straight ahead, the respondent's attention is scattered across the entire interface of the online store. However, if it is necessary for respondents to focus on a specific part of the online store, this is achieved by directing the model's gaze directly at that point.

4. CONCLUSIONS

The success and functionality of an online store depends on numerous factors, and there are often debates about whether the most important element on a website, or in this case an online store, is the text, the headline, or the photograph. It often turns out that the most important factor is the photograph itself, or more specifically, its content.

In this paper, the focus was on the photograph itself, particularly the gaze direction of the model in the image. The influence of gaze direction on the viewer is certainly an interesting area, and based on the conducted research, it can be concluded that proper positioning of the model in the photograph can have a positive effect on the effectiveness of the online store.

The results of this research were presented for the 2nd second of viewing the online store and the average of all ten seconds of viewing. The reason for focusing on the 2nd second of viewing is to allow designers to see what respondents notice first and how long they stay on that part of the web page. Often, this initial glance is crucial for the purchasing decision.

Analysing the research results, it can be concluded that the direction of the model's gaze in the image significantly influences users. If the goal is for viewers to focus their attention on the model, the model's gaze should be directed straight at the user. However, if a specific part needs to be highlighted, the model's gaze should be directed towards that point. This way, users will pay more attention to the desired area. A direct gaze and a gaze directed outside the frame can be beneficial if the aim is for respondents to view all interface elements evenly. Through this method, designers can influence users and guide them to notice specific areas of the design.

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THE DEVELOPMENT OF MOBILE APPLICATIONS FOR PET SITTING

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Abstract: *Nowadays, the presence of pets in family households is increasing. There are more and more studies are carried out on the effects of pets on human health, physical activity, stress levels, feelings of anxiety or happiness and similar parameters. At the present time, pets are not only animals, but also family members. Regardless of this fact, it is not always possible for owners to be with them due to various obligations and responsibilities. Owners want to ensure that their pets are always in safe hands. The innovative application discussed in this article is a solution for owners whose goal is to find quality care for their pets while they are away. The application offers all the necessary functions for easy and fast communication between the parties involved, finding and booking a guarding service. Owners can describe their pets in detail, including all their unique needs and behaviors, so that potential sitters can assess their compatibility and ability to provide quality care. On the other hand, sitters can create their own profile and highlight their experience so that owners can find the ideal candidate for pet care.*

Key words: user experience, user interface, pets, mobile application

1. INTRODUCTION

Users are the main actors in the interaction with the application and, taking this into account, the application design plays a key role in creating a good and positive user experience. To increase user confidence in the service offered by the application, it is necessary to create an intuitive and attractive user experience that is easy to use and navigate. User interface design and user experience play a very important role in today's technology and design world. User interface design consists of guidelines, workflows, colour palettes, design process, and design thinking, while user experience includes the processes of using the application itself and its simplicity or complexity (Sharma & Ankit, 2021). It is important to emphasize that the interface design can simultaneously deter or attract potential users of a particular application. In order to develop and create the best possible user interfaces, there are many guidelines and principles that designers follow when designing a product (Thornsby, 2016). The user interface is the graphical appearance of the application. It consists of buttons that the user can click on, text that the user can read, images, sliders, text input fields and all other elements with which the user can interact. This includes the layout of the graphical elements on the screen, transitions, interface animations and every single microinteraction. Each visual element, the user's interaction with the application or animations must be designed individually. Some user interface designers are also graphic designers. They are responsible for creating an attractive user interface that visually fulfils the purpose of the application. They must also ensure that each individual element functions consistently (Medium, 2019). There are many different principles, so Adobe has defined the four most important principles for user interface design, namely:

- put the user in control of the user interface,
- create a product that enables pleasant interaction,
- reduce the mental load and
- maintain consistency of the user interface (Babich 2019).

A good user interface gives the user a feeling of control. For each action of the user, the system should show a clear reaction, i.e. feedback linked to the action point. It is necessary to consider the type of interaction. For example, when the user clicks on a button, it is necessary to provide an indication that this action has been performed and that the user is waiting for feedback from the system (usually something simple, such as changing the colour tone of the button or micro-animations) (Stevens, 2021). As user experience becomes key to customer loyalty, the UX designer becomes an important member of the organization. Anyone who creates a digital product, be it an application or software, can successfully meet the needs of users with the help of a UX designer (Browne, 2023). User experience is all about the overall experience of using a product, not just its appearance. Defining user experience can be challenging as it encompasses different areas such as design, research, usability, functionality and the like. The general

ORCID numbers are provided at the end of the paper.

definition of user experience refers to the process of developing physical or digital products that are useful, easy to use and provide a great experience throughout the interaction. In short, user experience encompasses the following questions - why, what and how the user uses the product. It starts with the question of why the user has the desire or need to use the product. The "what" question explains what the users do with the functions and features that the product offers, and finally, the "how" question refers to how the users access the product's functions through the user interface (Canziba, 2018).

2. THE PROCESS OF CREATING MOBILE APPLICATIONS

Like most other disciplines, UI and UX design has its own process. They follow a user-centred design process that is divided into several phases:

- discovery and planning,
- strategy,
- researching the user experience,
- analysis,
- design and
- production.

In order to create a high-quality product in the end, it is very important to strictly follow all these phases. Before the designers start the actual product design, they need to define the problem that the product is supposed to solve. Defining the problem is the most important, but also the most difficult phase of the process. It is necessary to consolidate all the research and objectives and integrate them into several general problem areas that can be solved by a single product. This involves a process that identifies the key user needs and aligns them with the objectives (Chew, 2021). It is always a good idea to write a problem statement as early as possible in the research phase, as this can be very helpful in setting goals (Rosala, 2021).
The problem description should include the actual background of the problem, questions such as why the problem has arisen, how users are currently solving the problem and what it is essentially about. You also need to create an empathy map, developed by Dave Gray, co-founder of strategy consultancy Xplane. This is a powerful visualization tool designed to help teams use emotional intelligence to gain insight into their target audience. The tool provides a common thread to identify the thoughts, feelings, motivations, desires and needs of the target group. For example, developers could use an empathy map to consider how users react to a new device or a particular pain point (Mind Tools, 2024).
Empathy maps give an insight into the user as a person as a whole and are not chronological or sequential. The "utterances' section contains what the user says during the interview, ideally with verbatim and direct quotes from the research. The "Thoughts" section records what the user is thinking about. It is important to ask what is on the user's mind, what is important to them, and to pay attention to what the user is thinking and what they are not willing to express and share. The "does" section includes all actions that the user performs. Research has shown that it is important to find out what the user does and how they do it. The "feelings" section reflects the user's emotional state. What worries the user, what pleases him, how does he feel when he uses the product? Humans are complex beings, so it is quite normal for there to be contrasts between the sections. This is why designers often come across inconsistencies - positive actions but negative quotes. The designer's job is to investigate the cause of the conflict and resolve it (Gibbons, 2018). Figure 1 shows an example of the use of the empathy map.

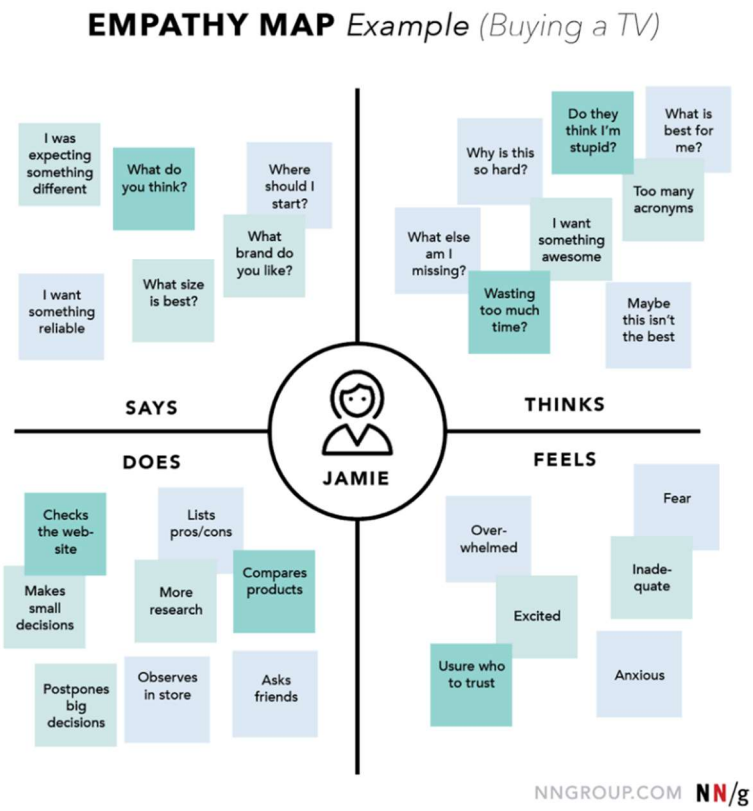


Figure 1: Example of the use of the empathy map

Personas are fictitious potential users of an application that designers create on the basis of research. Creating personas helps to understand users' needs, experiences, behaviour and goals. To create something useful and usable, you generally need to focus on a clearly defined group of users, i.e. a group of people with common characteristics and needs. The more similar the user population is, the greater the likelihood that the product will be tailored precisely to their goals and needs. Personas are therefore detailed descriptions of fictitious people that are created on the basis of thorough, very specific information about real people. They are used to describe the goals, expectations, motivation and behaviour of actual users (Marsh, 2016). Why do people visit a website? What are their expectations and what are they looking for? What excites them? As designers, we create personas iteratively. We divide users into manageable groups and represent each of them with a typical persona. For example, for an application that helps students calculate expenses, ''Amy'' represents an eighteen-year-old female adjusting to student life. Using Amy as an example, you can see how this application helps students in their daily life and activities. It was assumed that Amy is new to online banking, lives in a dorm and works on weekends. Her goal is to save money (Interaction Design Foundation, 2016).
Once all personas have been described in detail, the next step is to create a user journey or user scenario. The user journey represents the way in which a user accesses a website or application to complete a task. When successfully executed, the user journey identifies ways to fulfil the user's needs and eliminate any points of frustration (Kaplan, 2024). A user scenario is a very useful technique for a deeper understanding of user motivations, needs and concerns.

2.1 Wireframe and UI design

The user interface is the most important element of a computer system or product. If the interface is poorly designed, users' ability to utilize the computing power of applications can be severely limited. User interface design begins with identifying the user, the tasks they want to perform, and the environmental requirements. Once all tasks are identified, user scenarios are created and analyzed to define a set of

interface objects and actions. In many cases, the user interface shapes the user's perception of system quality (Sridevi, 2014).
Since the design of user interfaces is a very complex field, UI designers have many tasks in their role. Not only do they have to ensure that the user interface is particularly attractive and easy to navigate, but they also have to consider the psychological aspect of the design. To successfully design a user interface, they need to understand the user and be aware of how each design element affects the user experience. It is also their job to ensure consistency throughout the digital product by developing a specialized library of user interface patterns and style guidelines. Ultimately, UI designers focus on designing an attractive user interface that aligns with organizational goals (Jaye, 2023). The role of the UI designer is crucial in creating an intuitive and user-friendly interface. Every aspect of the design must be carefully considered and it is important to recognize how it affects the end user.
Before the designer starts developing the UI design, it is necessary to start with the wireframe. Wireframing is a method of designing digital products on a structural level. It is usually used to set up content and functions on a page, taking into account user needs and the user experience.

2.2 Testing mobile applications

Mobile application testing is the process by which applications developed for mobile devices are tested. The main goal is to test the functionality, usability and stability of the application. Testing is the most important step before an application is launched and is crucial for its survival in today's market. To ensure the best possible quality for end users, the app is also tested from other aspects, such as performance, security and user interface. Apps need to be tested on different mobile devices and operating systems to check their compatibility, usability and consistency. When testing mobile applications, testers should have a variety of skills and master multiple testing techniques to find as many bugs as possible in different environments and scenarios (Testsigma, n.d.). There are more than 9,000 different mobile devices, and in the real world, end users can install and use apps on any device. The application must be optimized for each device to work smoothly. The increasing use of mobile devices will also encourage the development of advanced mobile applications designed to facilitate access to various services. Companies need to ensure that their mobile applications are optimized and ready for future, more advanced smartphones. This can only be achieved by testing and optimizing applications on the latest mobile devices. Mobile application testing helps to achieve good esthetics - i.e. UI design, performance and functionality of applications on different devices (BrowseStack, n.d.).

3. EXPERIMENTAL PART

3.1 Definition of the problem

The aim of this work is to develop an application that meets the specific needs of pet owners and caretakers. Based on the hypothesis that there is a significant need for a tool that simplifies the process of communicating, booking and finding reliable caregivers, the research focused on developing a user-oriented, secure and highly functional application. By integrating advanced features such as detailed profiles, reviews, GPS tracking of the pet's location and a secure communication platform, it is expected to significantly improve the user experience and increase user confidence in pet sitting services.
The pet sitting mobile application is a solution that enables easy communication, searching and booking of appointments with sitters. Owners have the ability to describe their pet in detail, including specific needs and behaviours, so that potential pet sitters can assess their compatibility. Pet sitters can create profiles highlighting their experiences, making it easier for owners to find the ideal pet sitter. With a rating system that enables the sharing of experiences and recommendations, the app contributes to the transparency and reliability of the service and provides a comprehensive tool to solve the challenge of finding a reliable pet care provider.
The problems faced by users are as follows:

- finding reliable pet sitters,
- clear communication between both parties,
- safety of the pet and trust in the caretakers,
- simple and intuitive reservation system,

- tracking the location of the pet,
- ensuring service quality,
- attracting qualified pet sitters and
- building trust.

The objectives of the research are as follows:

- Understanding user needs and pain points - insight into the specific needs and challenges pet owners face when looking for a pet sitter, as well as the concerns and requirements of sitters themselves.
- Trust and reliability factors - exploring the factors that contribute to building trust and reliability between pet owners and sitters, including communication methods, vetting processes and user reviews.
- Examining user behaviour - analyzing how pet owners and sitters currently search for and use pet sitting services, including their preferences for online platforms and frequency of use of the service itself.
- Identifying opportunities for improvement - identifying areas where the current pet sitting experience can be improved or simplified, such as streamlining the booking process, improving communication features or implementing additional safety measures
- Gathering feedback on existing solutions - feedback from pet owners and sitters who have used similar apps or services.
- Market trend research and competitive analysis - researching market trends, new technologies and competitive offerings in the pet care industry to identify potential gaps, opportunities and areas of differentiation.
- User satisfaction measurement - measuring the effectiveness and impact of a pet care app.

3.2. Target group and in-depth survey

The target group comprises several different profiles of people. On the one hand, these are professionals with demanding jobs and long working days who occasionally need a pet sitter - while they are at work, when they have to go on a business trip or when they just want to relax. They need reliable pet sitters who will take proper care of their pets when they are away. They prefer a simple booking process and clear communication. Another group are people who travel frequently and need a pet sitter on a regular basis. They need flexible and reliable sitters who can adapt to their schedule. In addition, there are pet owners with special needs, such as pets suffering from various illnesses or pets with behavioural problems - they therefore require special care. Such pets need experienced and professional caregivers who are willing to cater to their special needs and provide them with special care when required. Older pet owners who are restricted in their mobility or have health problems that make it difficult for them to look after their pets independently are also part of the target group. They are looking for help from caring and reliable pet sitters who can help and support them with basic pet care tasks such as feeding, grooming and walking. They are looking for patient and empathetic people. Finally, there are the pet sitters themselves, people who offer pet sitting services as a part-time or full-time job, often out of love for the animals and a desire to help pet owners in their community. With all this information about the target group, it is possible to define several personas. An empathy map was created for each person.
For research purposes, an in-depth interview was conducted with four people belonging to different categories of people from the target group in order to gather as much information as possible about potential users. User interviews provide a deep insight into who our users are, their lives, their experiences and their challenges. When designers and developers know certain information about potential users, it is much easier to find and design an appropriate solution to their problems.
Before you start creating the wireframe, you need to create a user scenario. The scenario looks like this: Sara works at a marketing agency known for its extremely fast and stressful work pace and is looking for a sitter for her Labrador, Max. Suddenly she finds out that she has to stay at work until late at night. The most important thing for her is that the future housekeeper is reliable and that there is the possibility of easy booking and communication via messages.

3.3. Creation of a wireframe

After thorough research and questioning, the next step is to create a wireframe for the app before the actual UI design is created. By creating a wireframe, a basic layout of the elements on the screen can be established, taking into account the needs of the users and the intuitiveness of the application. Creating wireframes allows designers to correct structural errors and improve usability before committing to design details. Wireframe testing has become very popular to effectively identify problems with the intuitiveness of an application. To avoid spending hundreds of hours designing an application only to find that it's unusable in the end, it's very important to conduct testing at the wireframe stage. Jakob Nielsen popularized the idea of performing simple tests on early product models such as wireframes with only five users and identified the most important usability errors that can lead to the failure of an application (Angeles, 2024).
In order to test the intuitiveness of the application, three tasks were designed in which the respondents go through the most important functions of the application. The aim is to determine the degree of intuitiveness and user-friendliness of the application and to eliminate any shortcomings. Respondents were presented with a scenario in which they had to put themselves in order to solve a problem using the application. The first task was: "You need to go to a business meeting in another city. You can not take your dog with you because you will not have time to look after him properly. You research all the options available to you to find a person who can look after a dog and suddenly come across the WagWatch app.''
The interviewees had to create their profile in the application. The next step and task was to define and post a request for pet care, through which a person can reach the ideal candidate who will take care of the dog. In addition to the next task of define and posting a request, respondents also had the task of describing the home screen and the options they see on it, and describing their experience in setting up a request.
After completing the basics and posting the request, respondents move on to the final task where they must respond to the notification from the trustee who responded to the posted request. Respondents must look at the profile of the person who wants to take care of a pet and describe what they see there.
Respondents completed all tasks with ease and without difficulty, indicating the exceptional intuitiveness and simplicity of the WagWatch application.

3.4. Interface design and prototyping

After creating the wireframe, the next step is to create the design of the user interface. When developing a design, it is important to keep some of the following guidelines in mind:

- Colour selection - the colour palette must match the theme of the application, encourage users to interact with the design elements and ensure a good composition between all elements (hierarchy).
- Font - it is important to choose simple and legible fonts. It is recommended to use fonts that are suitable for smaller screens (an example of fonts that should be excluded from the selection are various display fonts that attract attention and are mostly used on billboards).
- Size of elements - the elements on the user interface should be large enough to be visible and accessible to users on their cell phones, and care should be taken to arrange the elements correctly so that the user experience is intuitive.
- Navigation bar - contains all the main menus and should be clearly visible so that users can easily navigate through the different areas of the application. The most important components of the navigation bar are the icons, which should be clear and simple.
- Creating and testing flows - trying out different ways to solve an important task in the application itself and testing with users to determine the intuitiveness of the flow.

The application was created with Figma, while the icons were drawn with Adobe Illustrator. First, the components are created, elements that are repeated several times throughout the design. Creating components makes the designers' work easier, as they act like building blocks from which the entire application is constructed. Editing one component affects all other elements of the design, i.e. the designer only has to make a change to one component, which is then applied to all elements of the application (variables - child element created from the main component - parent element).

The icons have been drawn in Adobe Illustrator in a modern geometric and minimalist style so that the application is not cluttered and all screens appear clean and transparent (Figure 2).

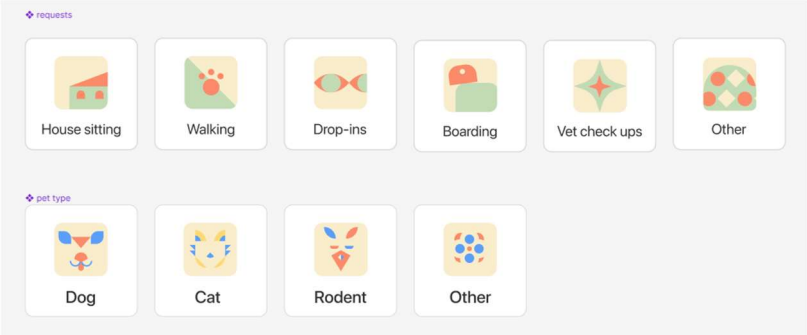


Figure 2: Display of icons

The colour palette consists of four colours: Blue (#54A0FF), Beige (#FAEDCA), Orange (#FF8966) and Green (#C1DBB3). Beige, orange and green are soft shades. Soft shades have a calming effect and in the context of an application whose main function is to give pet owners a sense of security and reduce stress, the use of soft shades is a good choice. The blue colour is mainly used to highlight the buttons. Figure number 26 shows the icon.
Figure 3 shows the onboarding of the application.

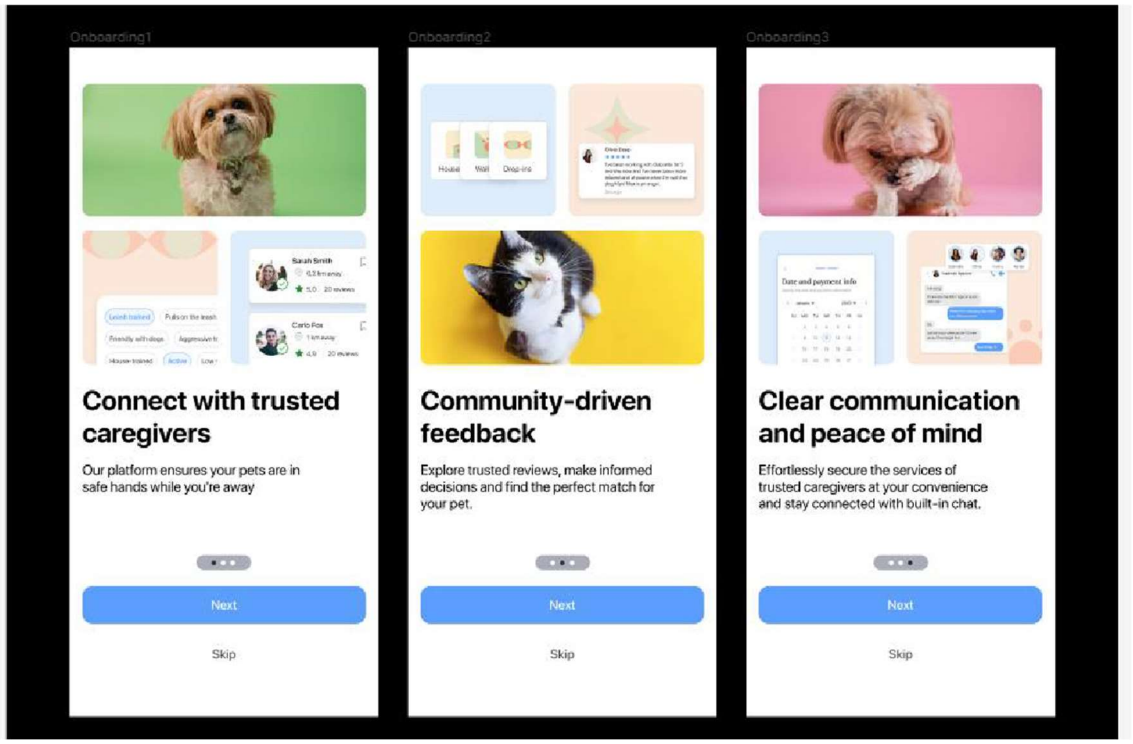


Figure 3: Presentation of the onboarding

The next step is to create a prototype of the application. With Figma, you can create a high-fidelity interactive prototype that closely resembles the final product. The purpose of the prototype is to show as accurately as possible how the final product would work. Figure 4 shows the layout of the pet owner profile.

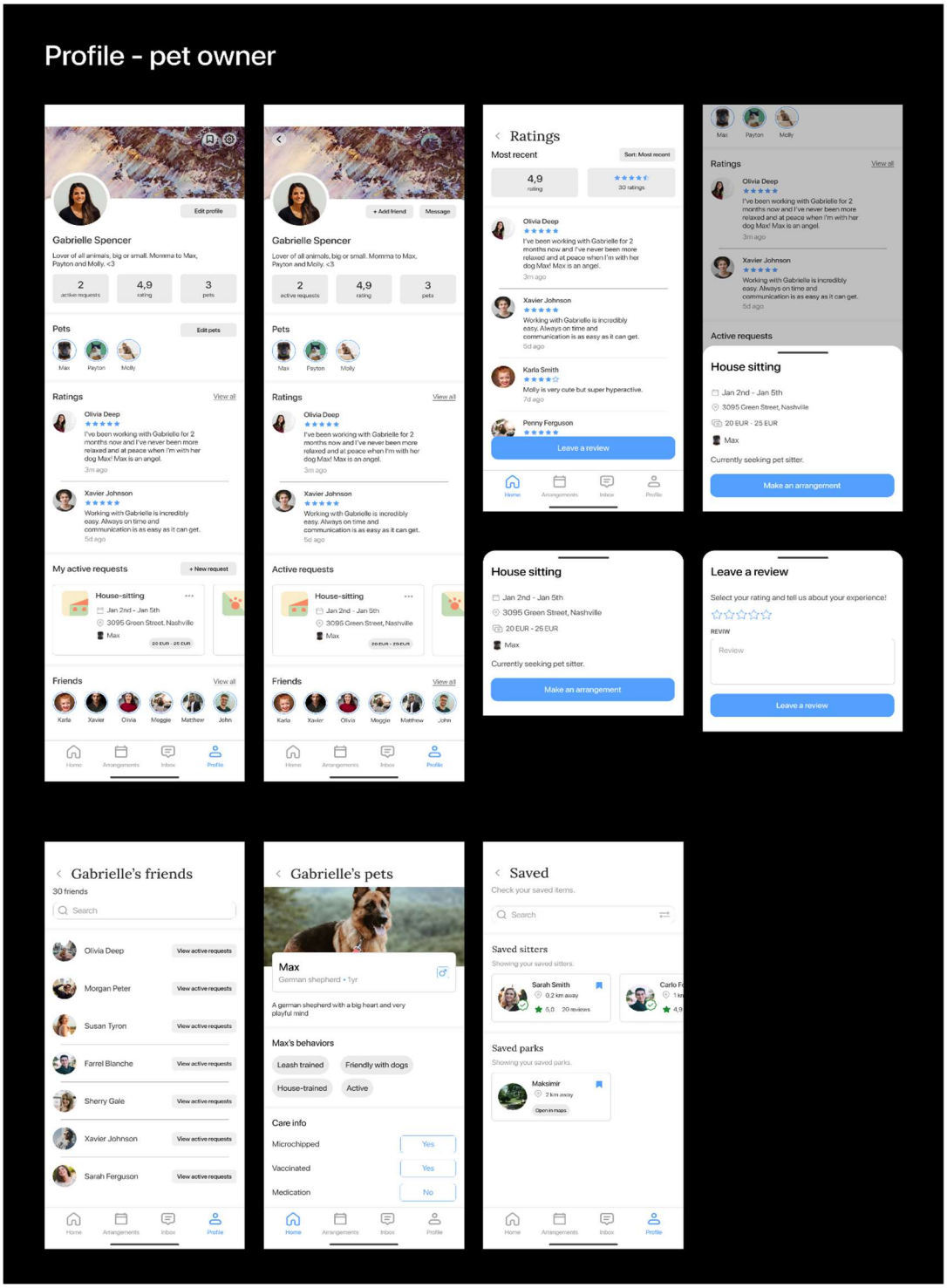


Figure 4: Presentation of the pet owner profiles

This prototype was also used to examine the functionality and intuitiveness of the application. Usually, the entire application is not prototyped, but only the processes that are of central importance. In this example, these would be questions that are defined in advance for testing - such as the key functionality, i.e. the process of creating requests within the application. Figure 5 shows a screenshot of the prototype in Figma.

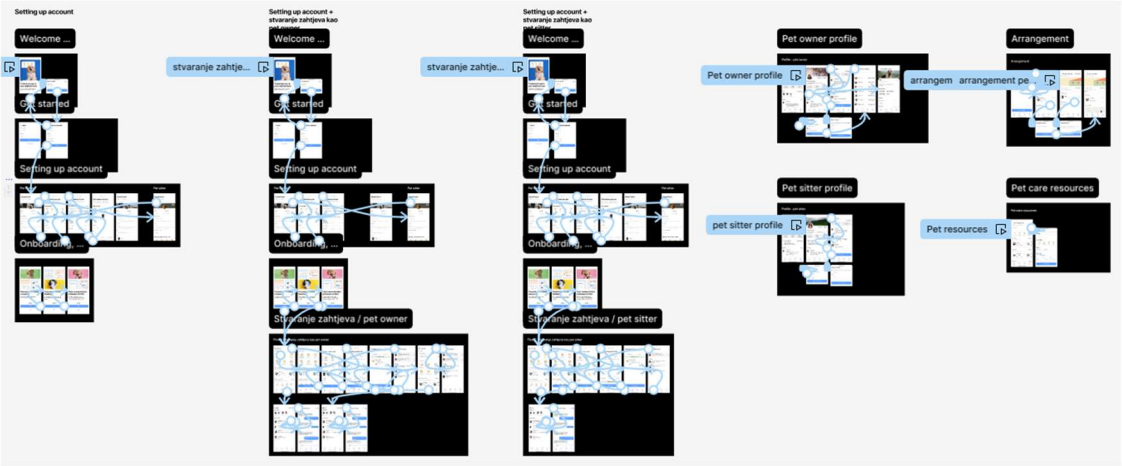


Figure 5: View of the prototype in Figma

3.5. Testing the application

Throughout the process of creating mobile or web applications, from the initial conceptual sketches to the final design refinements, testing with users should be a constant process. In this way, it is possible to discover usability issues, confirm design decisions and ultimately create the best possible user experience.

The final stage of the development of the WagWatch application is testing with potential users. The application was tested with a total of 30 users. The first part of the testing consisted of an introduction in which I introduced myself as the designer and author of the application and briefly described the application to be tested. The first part of the test was about convincing the potential users that their opinion is very important and that they should express all their emotions and opinions out loud, whether they are positive or negative. It is also important to emphasize that they are not being tested, but the application, and that expressing an honest opinion does not hurt anyone. After the first part of the test, users move on to solving tasks. Users were given a link to the Figma prototype and the tasks. The tests were conducted live to observe the way users use the application. It is important not to reveal too much information and details about the application so that the users can find a solution themselves.

In the first task, the users were asked to create their user account. They particularly liked the onboarding graphics and the pet icons. When asked whether more questions should be asked about the pet during registration to make the description more detailed, users replied that registration would then be too long and tedious and that the current level of detail was perfectly adequate.

In the second task, users were asked to successfully create a query. All users solved this task without difficulty. Some commented that they liked the way the application guided them to the next step - everything is intuitive and when there is a more complicated part, the application offers an explanation in smaller font under each heading, and the buttons are large enough and convey their purpose. In this task, users were asked to find a way to send a message to someone and get to the notifications. All of them solved these subtasks successfully. The only criticism from users was that the Quick Chat area could be a little larger.

In the third task, the users had to find out where the ratings of the individual profiles were located. It is clear that the ratings are located on the people's profiles, and everyone successfully completed this task. The users liked the design and appearance of the profile. What is particularly good is that each individual profile contains an overview of the user's active requests and these requests can be booked directly from the profile.

The fourth and final task was to share the location with the animal owner. This task was also successfully solved, but one of the suggestions is that there is an element like a "floating bubble" that is present in all parts of the application so that users know that their request is currently active and that they can access it from any screen application or mark an active request in the reminder section.

5. CONCLUSIONS

The development of applications requires a deep understanding of the needs and wishes of many users. Successful user interface and user experience design for applications requires a user-centred approach that involves very detailed research and testing to ensure that functionality and design meet all user expectations.

This process began with defining the goals, a thorough market and competitor analysis, followed by user research to determine their wants and needs. All the information gathered was used to define the functionality and design conceptual sketches that could be continuously tested and adjusted to make the design intuitive and user-friendly. The result was an innovative application, WagWatch, aimed at pet owners and pet sitters. The application offers all the key functions for easy communication, searching and booking of babysitters.

Design is an ongoing process that never ends, so the development of an application will never really be complete. There will always be new features that can be introduced to solve different problems and new ways to improve the usability of the design. In addition to functionality, the design of the user interface is also crucial to the success of an application. A consistent and carefully designed colour palette, iconography, typography and graphics can go a long way in creating an attractive user experience that adds value to the application itself and encourages users to use it more often.

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MICRO-INTERACTIONS WITHIN USER INTERFACES

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Abstract: *This article examines the impact of micro-interactions on the user experience of digital products. A well-structured information architecture with beautiful illustrations is no guarantee for good user experience. It is the small details that can make the experience of digital products more entertaining, more intuitive and closer to people. Small additions make the product more appealing and give users an element of feedback or satisfaction when completing a task. These details, called micro-interactions, are feedback-based events that help users complete a task while making it interesting. The paper explains the process of creating micro-interactions based on the four main components, which are: triggers, rules, feedback, and modes of operation and loops. Warning micro-interactions as well as positive and negative feedback are designed. The impact of the micro-interactions on the user experience was examined through testing the designed prototypes.*

Key words: micro-interaction, user experience, feedback, prototype, prototype testing

1. INTRODUCTION

Cognition and emotion cannot be separated; human cognitive thoughts lead to emotions. It is the emotional system that determines whether a situation is safe or not, whether something that happens is good or bad. Cognition provides understanding, while emotions provide value judgments. A person without a functioning emotional system has difficulty making decisions. Human cognition and a functioning emotional system are present in the use of all digital products. If emotions are not taken into account when designing user interfaces, people are left to draw their own conclusions about personality, and these conclusions can be negative or indifferent (Norman, 1990). The world of user experience design is growing rapidly and there are many ways to improve the user experience, including analyzing potential users, good information structure, and thoughtful written content. Many product designers know that a good user experience is much more than just usability. A good user experience also has a lot to do with the look and feel of a product, but when it comes to designing a great look and feel, nothing contributes more than small details like microinteractions. Although they are small, microinteractions have a huge power to make the experience of using a product more effective and emotional for the user. That's why we say that details are not just details, they create design. Digital interfaces are essential to everyday life in today's fast-paced online world. Users' interactions with them shape their experience and perception of the products they use, whether they are shopping online or using social networks. When completing small tasks, most users are unaware that they are constantly encountering micro-interactions. By incorporating user insights, using consistent design elements and prioritizing engagement, micro-interactions can be created that meet user expectations and contribute to product success (Gapsy Studio, 2024).

2. MICRO-INTERACTIONS

In the field of user experience (UX) design, one of the most important aspects is microinteraction. Micro-interactions are small, subtle interactions that users have with a digital product or service. They can be as simple as clicking a button or as complex as an animation that provides feedback to the user. These small details may seem insignificant, but they can have a significant impact on the overall user experience. Microinteractions are not product features, but they are just as important. They differ from features in size and scope. Features are usually complex (multiple use cases) and time-consuming, while microinteractions are simple, short and easy. For example, the music player is a function and the volume control is a microinteraction within this function (Kolte & Rao, 2024).
Microinteractions in digital products are most commonly used for:

- the execution of a task (mostly in simple applications where one microinteraction represents the entire application),

ORCID numbers are provided at the end of the paper

- the connection of devices with each other,
- Interacting with a single data element, such as humidity or temperature,
- controlling an ongoing process, e.g. changing the TV channel,
- adjustment of settings,
- displaying or creating a small piece of content, e.g. a status message and
- switching a feature or function on or off.

2.1 The importance of micro-interactions

Considering that the user interface should keep the user informed of what is happening by providing feedback. The app should not leave the user in the dark - it should inform the user about the status of the system, and micro-interactions can help provide appropriate visual feedback (Boyd & Bond, 2021; Nielsen, 2012). Micro-interactions are important for any digital product because they enhance the user experience by providing immediate feedback and increasing the overall usability of the product. Micro-interactions provide visual feedback on system status and prevent user errors (Antal, 2022). When the user clicks the button and sees the animation, it gives them visual confirmation that their action was successful. If a user makes a mistake and sees an error message, they know what went wrong and can take steps to correct the error. In addition, micro-interactions can also create an emotional connection between the user and the product. For example, a playful animation or sound effect can evoke a feeling of joy, while an error message can trigger frustration. These emotional connections can influence how users perceive the product and how satisfied they are with it overall. Furthermore, these interactions can strongly influence the personality of the brand and the user's loyalty towards it. Micro-interactions can help guide the user through a product or service and give them visual cues as to what actions they should take or what information they should provide. They make it easier for users to achieve their goals and increase the likelihood that they will return to the product in the future (Batchu, 2018). An enjoyable experience means more than just ease of use — it needs to be engaging, and this is where micro-interactions can play a macro role by contributing positively to the look and feel of a product or service (Joyce, 2018).

2.2 Examples of the most common micro-interactions

Micro-interactions can be found in almost all digital products, and every day designers and developers come up with new microinteractions to improve the interaction with their product and increase user satisfaction. Some of the most common micro-interactions in applications and websites are:

- contact and newsletter subscription forms,
- buttons in social networks,
- call-to-action buttons,
- touch and hold elements on the screen,
- horizontal scroll buttons,
- bars to indicate progress,
- audio and/or visual feedback,
- click/float to show images or text,
- page transitions and
- hover animations on buttons or linked images.

3. EXPERIMENTAL PART

In the experimental part of the work, prototypes of simple actions in mobile devices were created, which the user encounters daily through microinteractions. The goal of creating a prototype is to show how much micro-interactions within the interface influence the user experience, i.e. the feedback that the system or application transmits to the user. Before a prototype could be created for each micro-interaction, the basic components of microinteractions had to be defined: triggers, rules, feedback and repeat loops (Figure 1) (Saffer, 2013).



Figure 1: Model of the emergence of microinteractions

Before designing a rule, one must clearly define what the goal of the microinteraction is. The goal of the first designed microinteraction is to warn the user about the changes that occur when the SIM card is turned off. The user's goal is to switch off the SIM card, and this is linked to the rules of this microinteraction. The rules of the microinteraction can be most easily illustrated with a flowchart that graphically depicts the user's path to the goal and the encounter with the microinteraction (Figure 2).

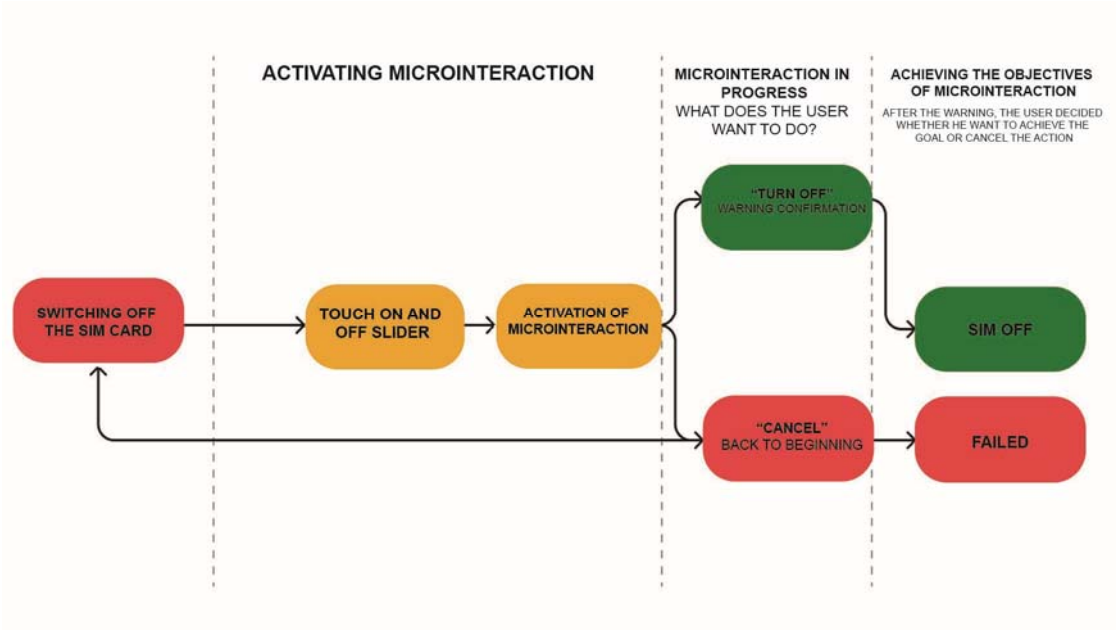


Figure 2: Flowchart for micro-interactions in user alerts

This action can be accompanied by further micro-interactions, e.g. tactile through the vibration of the device and visual through animations and visual feedback. In this example, subtle feedback was also used by changing the color and appearance of the switch as well as a pleasant animation when performing the action. The second micro-iteration developed for research purposes in this thesis has positive and negative feedback. The goal of the user is to upload the file, while the goal of the microinteraction is to provide feedback to the user about the success of the upload, with a separate microinteraction for success and failure. Even the small and often overlooked design features, such as the small animation that shows when something is uploaded, are of great importance. This is an example of a microinteraction - a functional and interactive detail of a particular digital product that is intended to enhance its use (Lagerquist & Samuelsson, 2021). It is activated by a manual trigger or microinteraction rules that require the user to hold the icon and drag it to the desired location. The time required to load the file is replaced by a pleasant animation of the progress bar, which also indicates a microinteraction and is linked to the main interaction that provides the most important information about success (Figure 3).

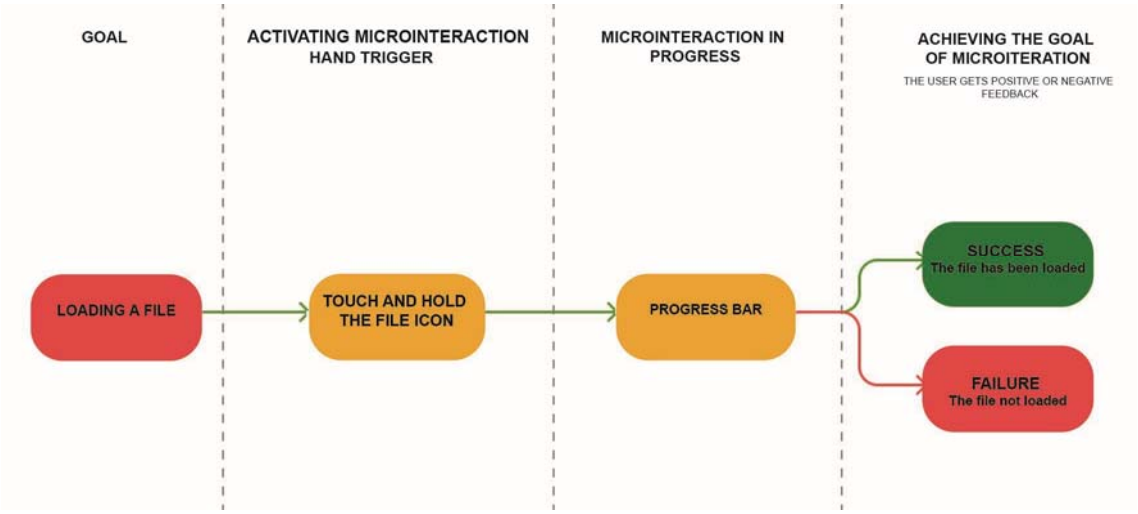


Figure 3: Flowchart for microinteractions with positive and negative feedback

3.1 Creation of the prototype

The prototype was created in Figma. For previously designed microinteractions, components were created that are connected by interactions to investigate the effects of the microinteractions on the users. All components needed to create microinteraction prototypes were designed according to the principle of atoms and molecules. All components used are native components of the Android system. Atomic design is considered a method for creating reusable components in a design system. There are 5 different levels in atomic design, atoms, molecules, organisms, templates and pages (Figure 4).

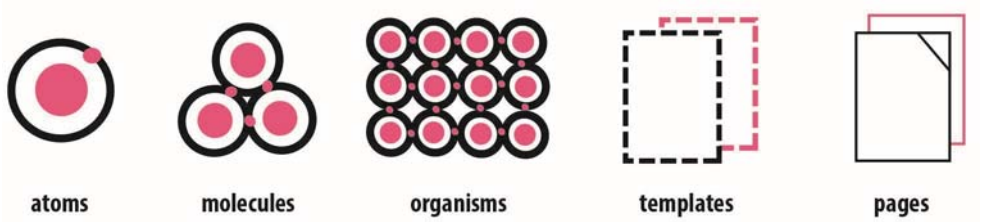


Figure 4: Atomic design

3.1.1 Atoms

They represent the smallest unit of UI elements and cannot be broken down further, e.g. Lego bricks. They serve as the basic building blocks of the user interface. Some examples are colors, fonts, animations and individual images. For the prototypes for removing the sim card and loading the file, the finished native components had to be changed. Text and color styles were created and icons were added.

3.1.2 Molecules and organisms

Molecules are groups of atoms that are linked together and can take on various new properties. They form relatively simple elements of the user interface that work together as a whole. Some examples are: Form tag, search input and buttons.
Organisms are relatively complex user interface components made up of groups of molecules and/or atoms. Most organisms can function independently without relying on other elements on the page. Some examples are: Navigations, sidebars, forms and pop-ups. The native components used to create the organisms were used for the prototypes created, the status bar, lists, dialog boxes, etc.

3.1.3 Templates and pages

Templates are pages without actual content and provide the basic structure of the design content. Basically, they assemble organisms into a proper website layout (Figure 5).

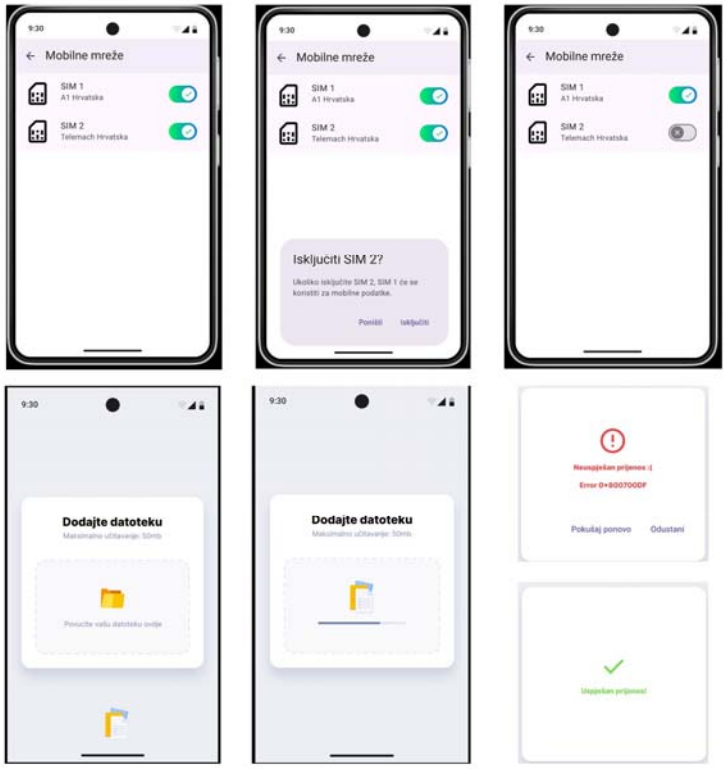


Figure 5: Templates for prototypes

Pages are specific instances of templates that show what the final user interface will look like when the actual representative content is present (Frost, 2016).

3.2 Adding interactions between components

After all components, organisms and pages have been completed, interactions between the components must be added to make the prototype usable and ready for testing.
The prototype consists of three parts:

1. Hotspot - a place where the interaction takes place. The hotspot can be the frame itself or an object within the frame. A hotspot can be located on any object, e.g. a button, an icon or a title.
2. Link - an arrow or "noodle" that connects a hotspot to a destination.
3. Destination - the place where the link ends. In most cases, the destination must be a top-level frame (Figure 6).

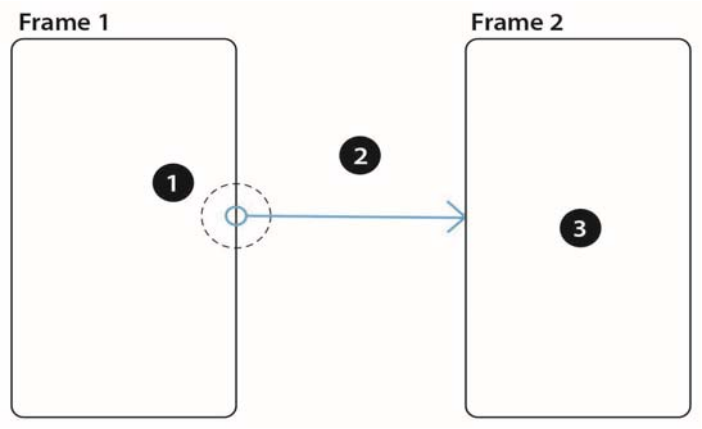


Figure 6: Parts of the prototype

Once an interaction is created, the interaction details model is used to configure the following (Figure 7):

A) Trigger - Defines what type of interaction sets the prototype in motion, e.g. a mouse click or a touch gesture.

B) Action - defines what type of event occurs when the user interacts with the focus point, e.g. switch to another frame or switch on an overlay.

C) Destination - defines where the interaction ends. This can be another screen in the prototype or a layer that appears above the current screen. Not all interactions have a target, e.g. the Back trigger automatically returns to the previous screen.

D) Animation settings - you define how the prototype moves from one screen to the next.

E) State management – click here to clear the properties and state of the object when navigating within and between frames.

F) Add action - add another action to the same trigger.

G) Closing the interaction details model.

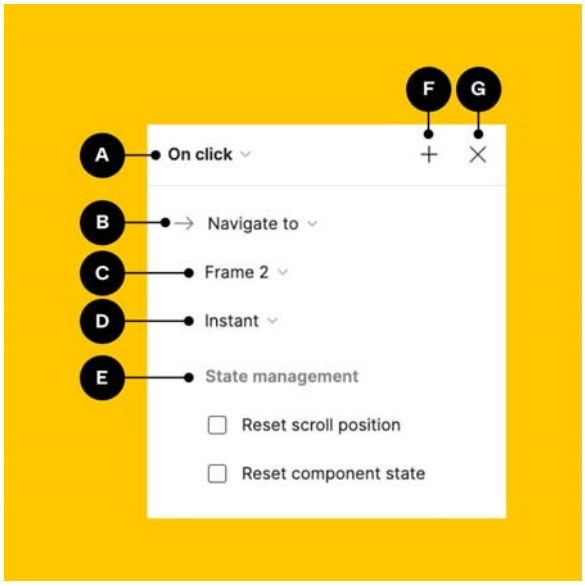


Figure 7: Configuration of the interactions

4. TESTING THE PROTOTYPE AND ANALYSING THE RESULTS

Prototype tests and user tests of the previously designed microinteractions were carried out. The test was carried out with 30 test subjects. The test was created via the Maze platform (Maze, n.d.), which enables direct testing of the Figma prototype. In addition to observing the time it took to achieve the goal, respondents were asked questions about the individual parts of the prototype and their experiences with them. For testing purposes, 3 surveys were created, i.e. one test for each prototype. The target group is people aged up to 30 years.

4.1 Prototype 1 - Microinteraction for user warning

For this microinteraction, a prototype was tested with four additional questions relating to the respondents' experiences. The average duration of the survey was 9.3 seconds.

Using data from the Maze analytics platform, it was found that the first screen of the prototype takes the longest time, as users read the prototype's instructions on this screen. Important information relates to the second screen, as this is when the micro-interaction is activated. It can be seen that users spend an average of two seconds on this screen, which indicates that the user reacts clearly and quickly to the system message, i.e. the warning message (Figure 8). The user reacts positively to the warning message and proceeds to remove the SIM card. As this is a test and users are given a specific target, all users are expected to switch off the SIM card regardless of the warning.

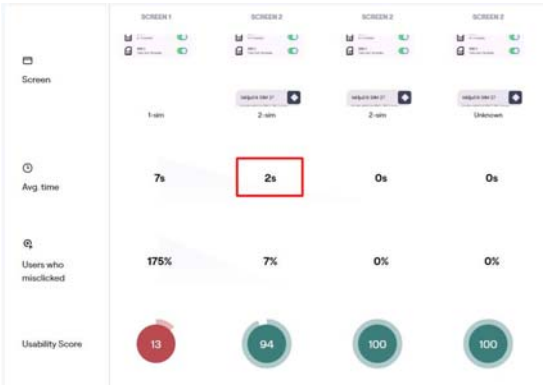


Figure 8: Display of the test results of the warning prototype

In the survey part of the test, questions were asked about the warning message, the subtle animation of the switch and the overall impression of the interaction. The goal of this part of testing test is to uncover human behavior and get feedback on the user experience during testing.
Respondents were asked a question about the warning message. In microinteractions, the warning message is the main carrier of information that can have a direct impact on the user experience. In the prototype example, we used a standard message that each mobile device displays when we want to disconnect one of the SIM cards. The native component of the Android system was used for the layout of the dialog box (Figure 9).

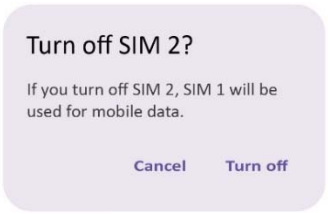


Figure 9: Warning message

The results obtained show that 81% of respondents consider the message to be useful and timely. Therefore, this type of warning is appropriate and users find these micro-interactions very useful, especially when it comes to more sensitive actions. Of the remaining 19% of respondents, 13% consider the message useful but are not satisfied with the message and the performance of the microinteraction. The results of this research confirm the fact that users are confronted with the same or similar microinteractions on a daily basis and find them very useful in almost all applications in which they appear.
As part of the main notification microinteraction, there are some more subtle visual feedbacks to the user in this example. Because these are subtle microinteractions, users are usually unaware that they are interacting with them.
Animations are found in almost all parts of user interfaces, most commonly in the role of microinteractions. The prototypes tested had animated switch components that change color from gray when they are off to a gradient of green and blue when they are on (Figure 10). To investigate the impact of this change on the user, a question was asked about the switch animation.



Figure 10: Two switching states

Based on the results obtained, it was found that 26% of respondents were not sure or did not like the animation. A large number of respondents, namely 74%, confirmed that this animation is pleasant and likable. Thus, this secondary micro-interaction strongly influenced the final impression of the respondents. That is, after the user turned off the SIM card, the switch made this action better and more pleasant for the user with a matching animation and color change. This is confirmed by 71% of respondents who think that the switch has a good visual indication for "on" and "off". The remaining proportion of respondents would change the colors and shape of the icons.

4.2 Prototype 2 and 3 - Microinteraction for positive and negative feedback

In this part of the test, the effects of positive and negative feedback on users were examined. The test took the form of an A/B test in which respondents tested two prototypes of the same end goal and answered questions about the experience of using the two prototypes.
In the first part of the test, respondents had the task of dragging the file icon to the marked location. The tested microinteraction appeared at the end of the action, i.e. on the last screen of the prototype, after the loading bar was filled. In the first prototype, the test subjects received a success message in green, in the second prototype an error message in red (Figure 11).

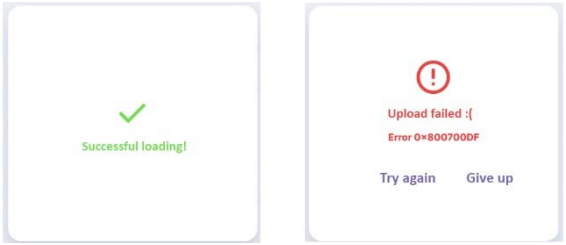


Figure 11: Success and error messages

The statistics obtained show that, on average, respondents took between 10-16s to reach the goal, of which 3s were spent loading the progress bar. The initial microinteraction of dragging the file icon was the trigger for all users to activate the microinteraction, which took an average of five seconds per user.
The second part of this test focused on users' impressions of the prototypes tested. For each of the examples, a question was asked about the feedback the system gave them.
In the case of an error message, the results are split. Part of the respondents consider this message to be good and normal, and another part think that this message has a direct impact on their mood, i.e. it is frustrating. This data confirms the relationship between design and microinteraction with the user's emotions.
As the description of the specific reason for failure was intentionally omitted when creating the prototype, 26% of respondents agreed with this opinion. In such microinteractions, it is therefore most important to explain the error that occurred to the user as clearly and precisely as possible.
As feedback is of great importance for the loyalty and commitment of users to a brand, product or application, a question was asked about the impact of success or failure on users. The first question related to the user's impression after completion. All users rated the unsuccessful prototype as a bad impression, while 70% of respondents rated the successful prototype as a good impression. As already mentioned, the feedback on success should therefore have been better designed visually and provided with an additional illustration or animation.
The next question relates to failure. The aim of this question was to determine the behavior of users when they encounter a failure, i.e. to what extent this affects the user experience.
The results of the test show that the largest number of users avoid the resulting problems. That is, 41% of users would still remain loyal to the product, with a high probability that the system would report the same error message.
The same proportion of users would use the application less or abandon it, while 19% of respondents would have a guilty conscience. It can be concluded from this that messages of this type also influence the emotional state of the user. Errors are an integral part of any application or interface, and it is very

important to pay attention to messages, colors, but also to a person's emotional connection with the product when designing it.
For both prototype examples, a micro-interaction for loading and a progress bar were used. After the user dragged the file icon, a bar with animation and color appeared on the screen, visualizing the progress of the process (Figure 12).

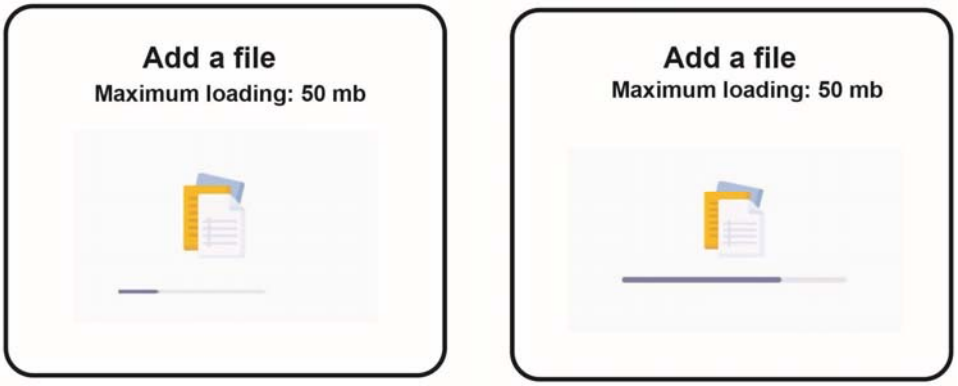


Figure 12: Progress bar

The progress bar, i.e. the animation that gives the user the impression that the page is loading, created a false sense of progress among the respondents in the case of the negative information example. For example, 44% of users surveyed thought that the progress bar was unnecessary with this microinteraction, while 33% of users thought the opposite.

5. CONCLUSIONS

When developing digital products, it's all about the details. Microinteractions provide appropriate feedback about the user's current action. Microinteractions are not product features, but they are just as important. Users encounter them every day. User testing has shown that special attention should be paid to the choice of shapes, colors, etc. in the design. Well thought-out and creative micro-interactions significantly improve and contribute to the design and user experience. When testing the prototype carried out in this paper, it was found that a poor error message is frustrating for users. Research has shown that in such situations users often ignore the problem, whereas the correct message should help them and offer a solution. The feedback the user receives has a direct impact on their mood and actions. It can therefore be said that microinteractions create an emotional connection between the user and the product. These connections have a direct impact on the user's perception and experience of using the product. Designing microinteractions is about finding the right way to make the desired interactions as pleasant as possible without overdoing it. These small details make the design and user experience special and create a strong connection between the user and the product.

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OBJECTIVE VIDEO QUALITY COMPARISON OF USER-GENERATED CONTENT PLATFORMS

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Abstract: *Uploading videos to platforms for sharing has been a core feature of the internet for nearly two decades. Advances in video encoding algorithms, their standardization, and increased computational power have significantly improved the visual quality of online videos. This paper evaluates the video quality across several popular platforms, including YouTube, Facebook, and Vimeo. Using three test sequences with varying content characteristics, the study employs full-reference objective video quality metrics-VMAF, PSNR-HVS-M, and MS-SSIM-to assess video quality at resolutions supported by all platforms. The results provide insights into the comparative performance of each platform in delivering high-quality video.*

Key words: PSNR-HVS-M, video, quality, VMAF, MS-SSIM, VOD, compression

1. INTRODUCTION

Video on Demand (VOD) has become the dominant mode of content consumption in recent years, with numerous platforms offering a wide range of media, including movies, series, television shows, and music videos. These platforms typically deliver professionally produced content created by film studios, television broadcasters, or the streaming services themselves, continuing a model that has been in place for over a century, though continually enhanced by technological advancements in production, distribution, and consumption.

In parallel, the internet has given rise to a new category of content-videos created by users for users. Platforms like YouTube, among others, have enabled this type of user-generated content to thrive, offering diverse content that ranges from entertainment to educational videos. This shift in content creation has reshaped how video is produced, distributed, and consumed globally.

A key challenge for video platforms, whether hosting professional or user-generated content, is to deliver the best possible audiovisual quality while minimizing data usage and ensuring compatibility across a wide range of devices and formats. Efficient video coding standards and encoding settings are critical to achieving these goals. Fortunately, there are multiple methods available for evaluating and optimizing the visual quality of streamed video. This paper examines the visual quality of selected video platforms that host user-generated content, focusing on the encoding strategies employed and their impact on user experience.

2. FULL-REFERENCE OBJECTIVE VIDEO QUALITY EVALUATION TECHNIQUES

Video quality assessment (VQA) is vital for ensuring a high-quality viewing experience in various applications such as streaming, broadcasting, and video conferencing. Full-reference (FR) objective metrics assess video quality by comparing a test video to its original, undistorted reference version. These methods are particularly valuable as they offer objective, reproducible measures of video quality. This chapter will explore several widely-used FR objective video quality metrics, including Peak Signal-to-Noise Ratio (PSNR), PSNR-Human Visual System (PSNR-HVS), PSNR-HVS Masking (PSNR-HVS-M), Structural Similarity Index (SSIM), Multiscale SSIM (MS-SSIM), and Video Multimethod Assessment Fusion (VMAF). The discussion will focus on how each method operates, its advantages and limitations, and how VMAF integrates various approaches to improve upon traditional techniques.

2.1 Peak Signal-to-Noise Ratio (PSNR)

PSNR is perhaps the most basic and widely used objective metric for video quality assessment. It is calculated by comparing the pixel-wise differences between the reference video and the distorted video,

ORCID number is provided at the end of the paper.

using the mean squared error (MSE) as a measure of the distortion. The formula for PSNR is given by Equation 1:

$$PSNR = 10 \times log_{10}(\frac{MAX^2}{MSE}) \quad (1)$$

Where MAX is the maximum possible pixel value (for instance, 255 for 8-bit video), and MSE is the mean squared error between the pixel values of the reference and test video frames. PSNR is often favored because of its simplicity and ease of implementation. Despite its widespread use, PSNR has notable limitations. It does not take into account the human visual system (HVS), meaning that it often fails to correlate well with subjective human perception of video quality. Specifically, PSNR treats all pixel errors equally, even though the HVS is more sensitive to certain types of distortions (such as those occurring in high-contrast or edge areas). As a result, PSNR may report small numerical differences in pixel values as major quality losses, even when these differences are not perceptually significant (Gonzalez, 2009).

2.2 PSNR-Human Visual System (PSNR-HVS)

To address the shortcomings of PSNR, PSNR-HVS incorporates certain properties of the human visual system. One of the key improvements is the integration of the Contrast Sensitivity Function (CSF), which models the sensitivity of the human eye to different spatial frequencies. In essence, PSNR-HVS weighs the frequency components of the image based on the HVS's sensitivity to different frequencies. This allows the metric to prioritize distortions that are more noticeable to humans, improving its correlation with subjective quality assessments. While PSNR-HVS offers better alignment with human perception than traditional PSNR, it still only accounts for basic aspects of the HVS. Specifically, it models contrast sensitivity but does not include other important perceptual phenomena, such as visual masking. Thus, while PSNR-HVS is an improvement over PSNR, it remains limited in its ability to accurately reflect subjective visual quality in all situations (Egiazarian et al, 2006).

2.3 PSNR-Human Visual System Masking (PSNR-HVS-M)

PSNR-HVS-M builds upon PSNR-HVS by incorporating a more comprehensive model of the HVS, including visual masking effects. Visual masking is the phenomenon where certain visual details become less noticeable in the presence of other visual stimuli, particularly in textured or high-contrast regions of a video. By modeling this effect, PSNR-HVS-M can better account for areas of the video where distortions might be less visible to human observers, leading to a more accurate reflection of perceived video quality. Compared to both PSNR and PSNR-HVS, PSNR-HVS-M demonstrates improved correlation with human perception, particularly for content with complex textures or motion. However, this comes at the cost of increased computational complexity. Additionally, PSNR-HVS-M may not always perform optimally across different types of video content and compression schemes, as the degree of visual masking can vary depending on the scene (Ponomarenko et al., 2007).

2.4 Structural Similarity Index (SSIM)

SSIM represents a shift from traditional pixel-wise comparison methods like PSNR and its variants. Instead of focusing on absolute differences between pixel values, SSIM measures the structural similarity between the reference and distorted videos. It assesses three components: luminance, contrast, and structural information (the local spatial pattern of pixel intensities). SSIM is computed over local windows, and the final SSIM score is the mean of all local comparisons. The mathematical formulation for SSIM is based on comparisons of luminance, contrast, and structure between corresponding windows in the reference and distorted images. This approach allows SSIM to focus on preserving structural information, which is more important for human perception than mere pixel-level accuracy. As a result, SSIM tends to correlate better with subjective quality assessments than PSNR. However, SSIM is not without limitations. While it performs well for certain types of distortions, it can still fail to capture quality degradations in videos with more complex content. Additionally, because it operates on local windows, SSIM may not capture quality variations that occur over larger regions of the video (Wang et al., 2004).

2.5 Multiscale Structural Similarity Index (MS-SSIM)

MS-SSIM extends SSIM by introducing a multiscale analysis, which better reflects the multiresolution characteristics of the HVS. In MS-SSIM, the video is analyzed at multiple scales by progressively downsampling the reference and test videos. SSIM is computed at each scale, with more weight assigned to coarser scales where human perception is more sensitive to structural changes. By incorporating information across multiple scales, MS-SSIM provides a more robust assessment of video quality, especially for videos with varying levels of detail. MS-SSIM typically achieves higher correlations with subjective quality scores than single-scale SSIM and can better capture complex distortions such as those introduced by compression. While MS-SSIM offers significant improvements over SSIM and PSNR-based methods, it is computationally more intensive due to its multiscale nature. Additionally, its performance can still be limited by specific types of visual artifacts that are not well captured by structural similarity metrics (Wang et al., 2003).

2.6 Video Multimethod Assessment Fusion (VMAF)

VMAF is a more recent development in FR video quality assessment and differs significantly from the previously discussed methods. Developed by Netflix, VMAF is a machine-learning-based approach that combines multiple video quality metrics (including SSIM, PSNR, and motion information) into a single, unified score. VMAF uses subjective quality scores from human viewers to train its model, allowing it to better predict perceived video quality. One of the key strengths of VMAF is its ability to integrate information from multiple metrics, making it more robust across a wide variety of video content and distortions. VMAF not only includes traditional pixel-based metrics like PSNR but also incorporates features related to motion and temporal artifacts, which are important for video quality. Additionally, VMAF allows for customization, enabling its model to be fine-tuned for specific use cases or content types. Compared to metrics like PSNR, SSIM, and even MS-SSIM, VMAF consistently achieves higher correlations with subjective quality assessments. This makes it one of the most accurate and reliable FR metrics for modern video quality assessment tasks. However, VMAF is computationally demanding due to its use of multiple metrics and machine learning models. Moreover, VMAF's performance is highly dependent on the quality of the training data used to develop the model, meaning that it may need to be retrained for new content types or viewing conditions (Li et al., 2016).

3. STREAMING SERVICES

Table 1 summarizes the features of the selected platforms, focusing on key factors such as the maximum allowed file size and support for various frame rates, including high frame rate content, which was critical in the context of this paper.

Table 1: Multimedia features of selected video platforms

	Maximum upload filesize	HFR	HDR support	Surround sound	3D video	360° video	25/30 FPS
YouTube	256 GB (verified account)	Yes	Yes	5.1	Yes	Yes	Both
Facebook	4GB (regular user)	No	Tonemapping	No	Yes	Yes	Both
Instagram	Unknown	No	Tonemapping	No	No	No	Both
Vimeo	1GB Free	Yes	Tonemapping	7.1	Yes	Yes	Both
Dailymotion	4GB Free 64GB Premium	Yes	No	No	No	No	Both

3.1 Video Platform Selection

For this study, five video platforms offering video upload and sharing services were selected for evaluation:

- YouTube: A video-sharing platform owned by Google, boasting 2.5 billion users worldwide. It supports a wide range of video formats and resolutions, making it one of the most popular platforms for content creators.
- Facebook: A social network owned by Meta with over 3 billion users. Facebook allows users to share videos on personal profiles, pages, and groups, and supports a variety of video resolutions.
- Instagram: Also owned by Meta, Instagram has 2 billion users and focuses primarily on short-form video content through its Reels and Stories features, although longer videos can be uploaded to IGTV.
- Vimeo: A SaaS-based video hosting and sharing service with 300 million users. Vimeo is widely used by creative professionals and offers high-quality video uploads with extensive customization and privacy settings.
- Dailymotion: An online video-sharing platform owned by Vivendi, which supports a broad range of video content types and has a user base of millions globally.

Some platforms were excluded from this evaluation due to limitations that would have impacted the study's objectives. For instance, X (formerly known as Twitter) was not included because it restricts video resolution to 720 p for free users, with 1080 p available only to Premium subscribers. Additionally, at the time of writing, the platform experienced issues with video encoding, as illustrated in Figure 1. Twitch, a streaming platform focused on gaming, was also excluded. While Twitch allows video uploads, this feature is restricted to Affiliate or Partner accounts, which were not available for this study. Table 2 provides an overview of the available resolutions and video coding standards used by the selected video platforms. It is important to note that these platforms do not apply all supported formats to every video; certain formats are reserved for specific resolutions, popular content, or premium users. For the purposes of this quality evaluation, only the resolutions supported by all platforms were considered.

Table 2: Supported resolutions and available video coding standards of selected video platforms for SDR content (resolutions tested in this article are highlighted)

Resolution and framerate	YouTube	Facebook	Instagram	Vimeo	Dailymotion
7680 × 4320@60	AV1				
7680 × 4320@30	AV1				
3840 × 2160@60	AV1, VP9			H.264	H.264
3840 × 2160@30	AV1, VP9			H.264	H.264
2560 × 1440@60	AV1, VP9			H.264	H.264
2560 × 1440@30	AV1, VP9			H.264	H.264
1920 × 1080@60	AV1, VP9, H.264			H.264	H.264
1920 × 1080@30	AV1, VP9, H.264	AV1, H.264	VP9	H.264	H.264
1280 × 720@60	AV1, VP9, H.264			H.264	H.264
1280 × 720@30	AV1, VP9, H.264	AV1, H.264	VP9	H.264	H.264
960 × 540@30		AV1, H.264		H.264	
848 × 480@30					H.264
640 × 360@30	AV1, VP9, H.264	AV1, H.264	VP9	H.264	H.264
512 × 288@30					H.264
426 × 240@30	AV1, VP9, H.264			H.264	
256 × 144@30	AV1, VP9, H.264				
256 × 144@15	VP9				

3.2 Source Files Preparation, Upload and Download

Three video sequences were selected as source material for testing. Each sequence was converted to three different resolutions and frame rates, as outlined in Table 1, using FFmpeg 7.0.2 and x265 3.6. The following encoding parameters were applied: "-x265-params lossless=1 -an -map_metadata -1 -pix_fmt yuv420p", ensuring the highest possible quality, with 8-bit channel depth, 4:2:0 chroma subsampling, and no

metadata. This approach was chosen to create high-quality reference sequences suitable for accurate visual quality evaluation.

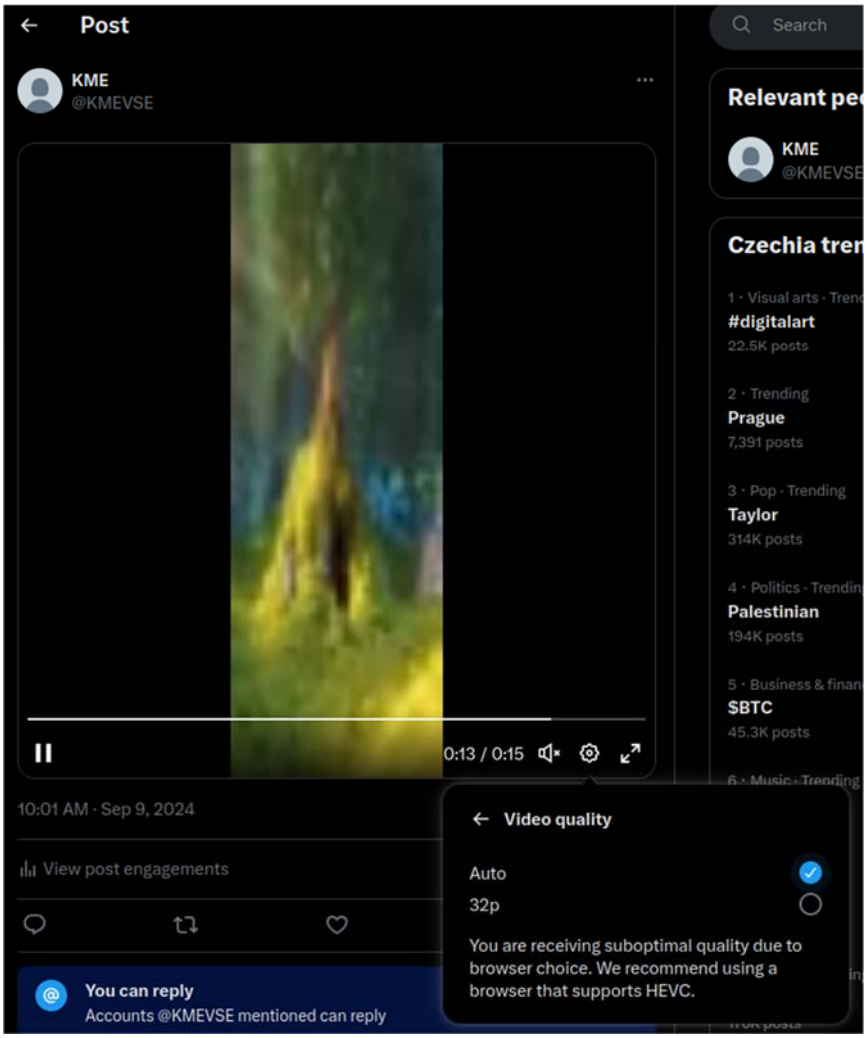


Figure 1: Erroneous video encode of social platform X

The first sequence was taken from the open-source animated film *Big Buck Bunny*. A 15-second clip was extracted from the UHD 30 fps version. The second sequence, *SquareAndTimelapse* (Netflix), is a 10 seconds long live-action clip produced by Netflix, featuring dynamic scenes with a moving crowd and fast-paced motion typical of timelapse videos. To match the supported 16:9 aspect ratio of the selected platforms, the original horizontal resolution of 4096 pixels was cropped to 3840 pixels. The third, 30 seconds long sequence, featured jellyfish footage, showcasing slow-paced motion scenes with tiny particles moving in the water. These sequences were uploaded to each video platform using a web browser, except for Instagram, where the official Android application was required. Since the Instagram app operates as a "black box," there was no control or visibility over any potential local video processing before the upload. The "Upload at highest quality" option was enabled to ensure the best possible quality during the upload process. Once the platforms had encoded the sequences, yt-dlp was used to download the resulting videos. Most platforms provided H.264-encoded versions of the videos, with the exception of Instagram, which used the VP9 codec. A VP9-encoded 360p version was also downloaded from YouTube. Although these platforms support additional video encoding formats, they were not available for the videos uploaded for this study. All downloaded videos maintained the same resolution and frame rate as the original uploads (reference files), with one exception: Instagram's 360 p variant, where the horizontal resolution was altered from 640 pixels to 638 pixels. This discrepancy caused issues during the quality evaluation, which had to be addressed. Additionally, Instagram's videos were converted from the ITU-R BT.709 color space to ITU-R BT.601, a standard originally designed for standard-definition video in the early digital era. This unexpected

color space conversion further complicated the quality evaluation and required additional adjustments to ensure consistency across the tested videos.

3.2 Metrics Used for Objective VQA

Three objective quality metrics were selected for this study: VMAF, PSNR-HVS-M, and MS-SSIM. All of these metrics are full-reference, meaning they require both the distorted video and its corresponding reference video for comparison. The video pairs being compared must have the same resolution, frame rate, subsampling, and bit depth to ensure accurate measurement. However, VMAF provides methods to compare videos even when these parameters do not match, though this feature was not utilized in this paper. For consistency, only the luma channel (Y) of the YC_BC_R color space was used for the quality evaluation. The official VMAF implementation was used for calculating VMAF scores, which involved decoding both the downloaded and reference videos into the YUV4MPEG2 format to obtain uncompressed YCbCr video. For PSNR-HVS-M and MS-SSIM, Python libraries were employed to perform the calculations.

4. RESULTS AND DISCUSSION

4.1 Objective Video Quality

Figures 2, 3 and 4 show results of the selected metrics in all three sequences.

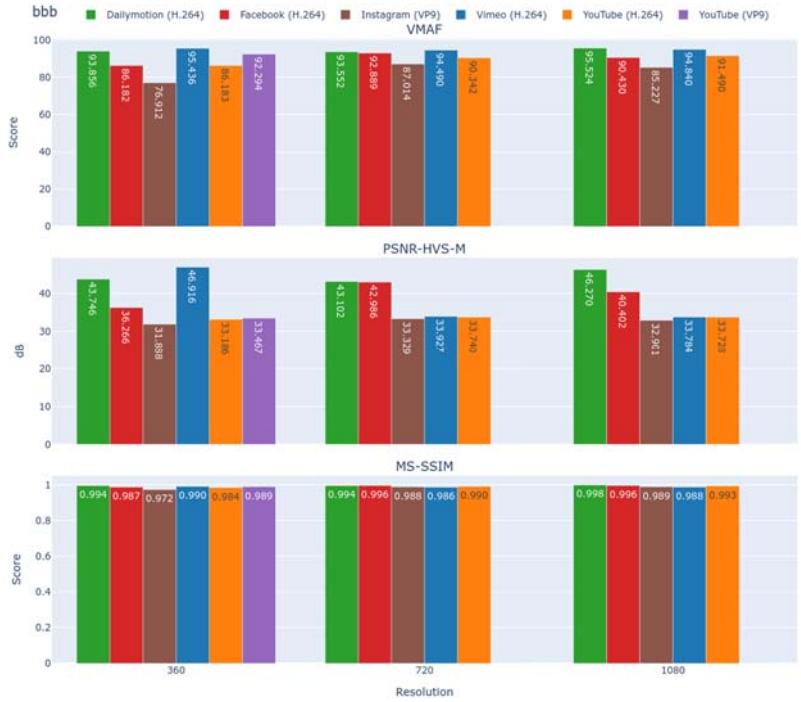


Figure 2: Big Buck Bunny sequence results

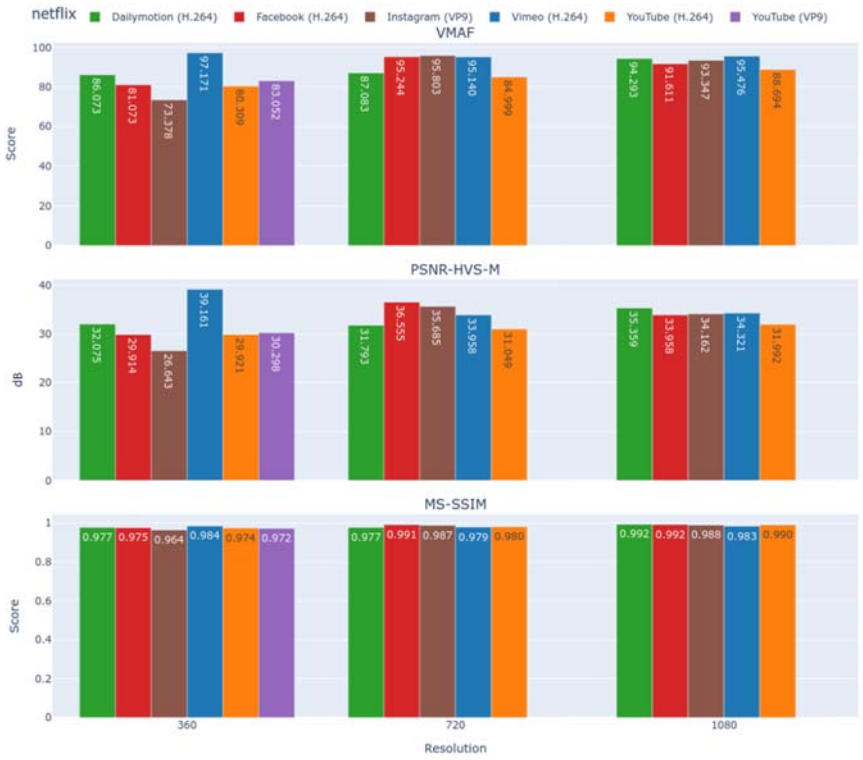


Figure 3: Netflix sequence results

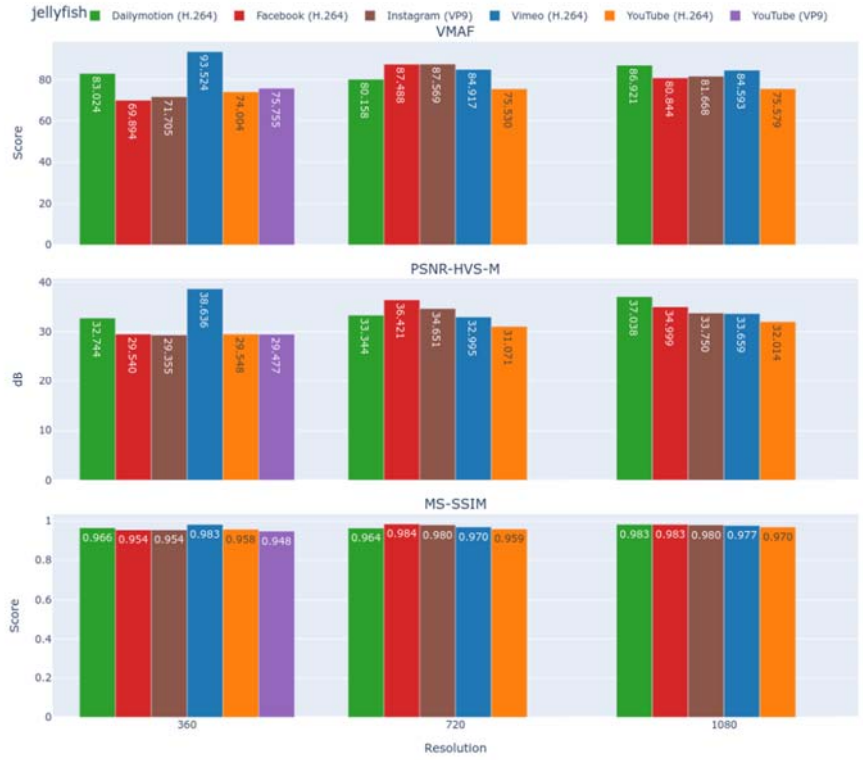


Figure 4: Jellyfish sequence results

The VMAF results indicate consistently high scores across all platforms and resolutions, with Vimeo and Dailymotion generally performing the best, except at 720 p, where Instagram surprisingly excels. In contrast, Instagram typically ranks last in other resolutions, and YouTube's H.264 performance is also

relatively low. PSNR-HVS-M shows greater variation between platforms. For *Big Buck Bunny*, Dailymotion achieves the highest scores, while Instagram performs the worst. In the *Jellyfish* and *Netflix* sequences, Vimeo leads at 360 p with scores of 38.636 dB and 39.161 dB, respectively. However, at higher resolutions, Vimeo's performance declines, with Dailymotion or Facebook often taking the lead. MS-SSIM results show minimal differences across platforms, with near-perfect scores for most resolutions. For *Big Buck Bunny*, the majority of platforms achieve scores above 0.980, although Instagram consistently scores the lowest. Overall, Vimeo and Dailymotion outperform other platforms in most metrics, while Instagram lags behind, particularly in VMAF and PSNR-HVS-M, and struggles at the 360p resolution. MS-SSIM results suggest that the perceptual visual differences between platforms are small. YouTube's VP9 codec generally performs as well or slightly better than the older H.264 variant.

4.2 Bitrate variance

Figures 5, 6, and 7 illustrate the bitrate variations for each resolution across all tested video platforms. For 360p resolution, video platforms generally use bitrates ranging from 0.5 to 1.5 Mbps, 2 to 3 Mbps for 720 p, and 4 to 6 Mbps for 1080 p. Vimeo exhibits the highest bitrate and largest variance at 360p, which likely explains its superior performance across all metrics. At higher resolutions, Instagram shows the most significant variance in bitrate. In contrast, Dailymotion maintains consistent bitrate usage across all resolutions and sequences. Notably, YouTube's VP9 codec achieves the same quality as its H.264 counterpart but at a lower bitrate. Also, both Facebook and Instagram show similar bitrate values and variance while using different video coding standards.

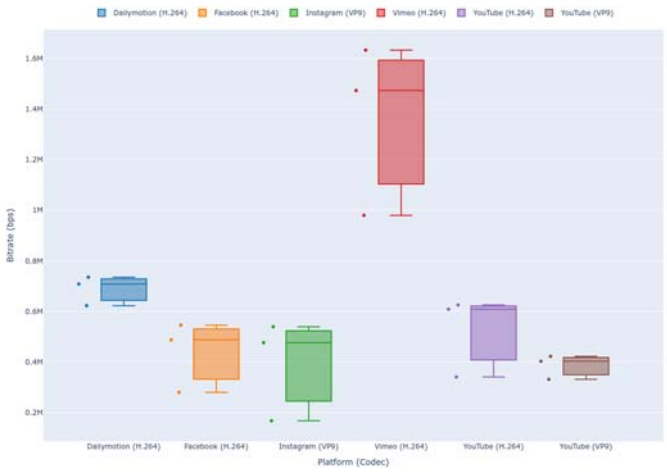


Figure 5: 360 p resolution bitrate variance

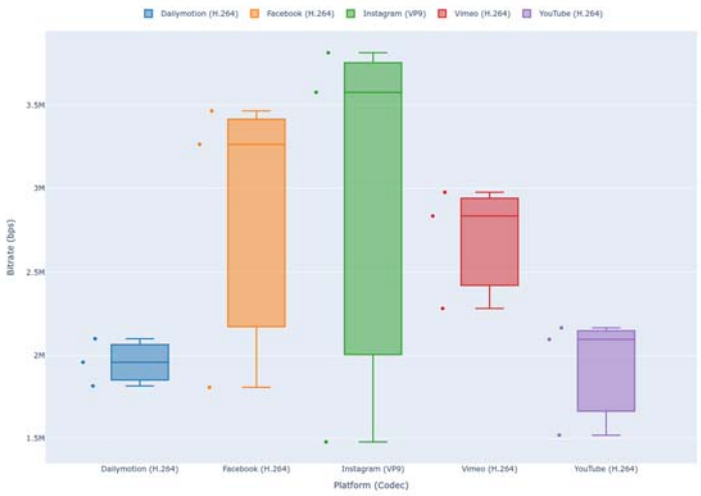


Figure 6: 720 p resolution bitrate variance

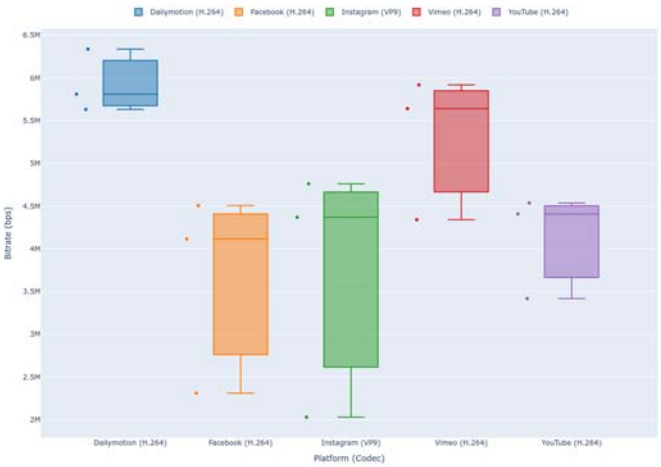


Figure 7: 1080 p resolution bitrate variance

3.3 Future Improvements in Objective VQA for User-Generated Content Platforms

The main goal of this paper is to establish a method for objectively evaluating the video quality of platforms that offer user-generated content and offer initial results. Based on the findings and empirical results, several areas for improvement in the evaluation process have been identified. First, both the variety and quantity of testing sequences can be significantly expanded. To facilitate this, automating the entire process would be highly beneficial. This would involve automating the preparation of reference sequences, video uploads and downloads, objective quality evaluation, and the presentation of results. Such automation would enhance efficiency and ensure consistency in the evaluation process. Further research is needed to explore the impact of clip length on quality evaluation. Currently, the evaluation is constrained by platform-specific limits, with the shortest maximum video length allowed across the selected platforms determining the clip duration. Understanding how the length of a clip affects both perceptual and objective video quality would provide deeper insights. Expanding the evaluation to include additional video platforms could also yield more comprehensive results. This could involve platforms that offer adult content, those requiring premium or affiliate accounts, and subscription-based services. Including such platforms would provide access to a broader range of resolutions and video standards, offering a more complete analysis of video quality across various formats. Partial comparisons could be conducted for resolutions not uniformly supported by all platforms. Additionally, expanding the evaluation to cover more advanced formats, such as HDR content, interlaced video, 360° videos, and stereoscopic (3D) content, would be possible within a subset of platforms. This would allow for a more detailed assessment of how platforms handle cutting-edge video formats, further refining the methodology for objective video quality evaluation.

5. CONCLUSIONS

It is not possible to definitively rank the video platforms from best to worst based on this dataset, but several general conclusions can be drawn. For users who prioritize high visual quality and advanced features, and are not concerned with higher bitrates, Vimeo stands out as a strong choice. YouTube, while not always delivering the highest visual quality, offers a wide range of features and is the most versatile platform. In contrast, Instagram and Facebook do not excel in either visual quality or advanced video features, as video-on-demand (VOD) services are only a small part of their broader social networking offerings. Dailymotion, though a smaller player in the market with limited features (such as the lack of HDR support), still delivers sufficient visual quality for standard use cases.

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DIGITIZATION OF TYPOGRAPHIC CULTURAL HERITAGE AND ITS APPLICATION IN INTERACTIVE WEB PRESENTATION

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Abstract: *Much of the literature on history and cultural heritage is available exclusively in physical (printed) form. The traditional approach towards education still values this type of media more than digital methods of learning and information distribution. This often takes place in communities where people have difficulty accessing this information. Digitization can contribute to solving the problem of accessibility and general interest. This paper discusses the issues of cultural preservation and technical knowledge necessary for the implementation of cultural heritage in modern multimedia. Examples selected for this paper include typical monuments and a writing system from the 14th to 16th century from the area of Bosnia and Herzegovina, specifically the culture of "stećak" (tombstone) and the alphabet called "Bosančica". The paper explores the possibilities of using widely available programs and tools for the promotion of cultural heritage in the digital world integrated in the form of a website. Through several examples, various tools were used to digitize the most prominent characteristics of these monuments: their writing, iconography and relief. The material was used to assemble an interactive educational web platform. Unlike traditional sources, the digital resources reproduced on the website visually complement the textual information and thus complete the learning experience. Fonts and illustrations are presented together with historically relevant contextual information, thus enhancing the learning experience. Together with a special transliterator that was made to directly translate user input text (in Latin alphabet) to "Bosančica" writing, it allows for a personalized and interactive experience.*

Key words: cultural heritage, digitization, fonts, website

1. INTRODUCTION

In today's era of digitization, every branch of human knowledge is gradually moving from the physical form (i.e. paper) to the digital one, where it is being archived and distributed. The digital medium allows for a much faster distribution of knowledge than previous traditional methods. Despite its advantages and existing technology, the effort of existing institutions to digitize their own material was rather lacking, especially in the realm of formal education. The process was sped up during the COVID-19 pandemic as the traditional models of education and knowledge distribution had proven to be inflexible. Chitambo et. al. state that "The value gained from the preservation of human knowledge lies not with the preservation of the past but rather with the way in which this information can be accessed by individuals today." (Chitambo et. al., 2016). Digitization allows better accessibility through easily distributable platforms, and therefore to a wider audience. "Both cultural consumption and production are enhanced and facilitated by new technologies, and digitization of culture brings about better and faster access to and dissemination of the creative output." (Fanea-Ivanovici, 2018). Along with the potential for conservation, the benefits of digitized cultural resources can be seen amongst scientific research, education, the economy, and connecting communities (Tanner, 2010), especially when creatively integrated into the formal school systems (Tzima et. al., 2020).

1.1 Digitization in education and culture

In 2020, the investment in digital education technologies in the world was 227 billion USD, and the figure is predicted to reach 404 billion USD in 2025. Although these are significant amounts, they represent less than 4% of the total investment in education (HolonIQ, 2021). According to a UNICEF report (Vashchenko, 2024) in Bosnia and Herzegovina schools often lack internet connection and an average of 20 students share one computer device, compared to the OECD average of 1.2 students. It is evident that the entire digital education sector still has a lot of room for growth. In the context of sustainable

ORCID numbers are provided at the end of the paper.

development, various international declarations (Unesco Istanbul Declaration, 2016; The Hangzhou Declaration, 2013) and conferences (CoMoCoSEE, 2017) emphasize the importance of widely available cultural education. With its own documents (European Commission, 2021; European Commission, 2011), the European Commission encourages the processes of using new technologies in digitization through financial and legal endeavors, highlighting the value of sustainable tourism and education. The largest undertaking in this field was launched by the European Union through the Europeana platform, which contains digital archives from over 3,000 cultural institutions in Europe (European Commission, 2022).

Companies, institutions, and individuals are all creating different digital cultural platforms through their own initiatives, but there is still no unilateral agreement on the best practices for presenting cultural content. As pointed out by Taylor and Gibson, there is an ethical conflict regarding the digitization of cultural heritage that diminishes its positive effects on the process of democratization of culture (Taylor & Gibson, 2016). The problem originates from the selective approach of displaying cultural content, where often due to limitations only a small part of cultural assets is digitized, while the selection of what is displayed is decided by a small number of people (Gorman, 2003), thus undermining the democratic motive of the entire process. Although the digitization qualities of cultural heritage are highlighted, it is important to structure the presented content in a transparent way that opens the possibilities for users to explore the topic further, beyond the limits of what was originally presented, so that more interpretations of the collective knowledge are considered. Otherwise, the content of the cultural heritage will be an object of the same moral dilemma that scientific publications (Eve, 2013) were in during their own digitization, where distribution was limited by private ventures charging access to information.

The responsibility in the process of digitizing the content belongs mostly to the institutions that own its physical copies. However, given the bureaucratic and financial constraints of the public sector (Adane et. al., 2019), this transformation from physical to digital is taking place quite slowly compared to the great advances in widespread technological literacy and the use of digital resources by consumers. “Individuals with a personal interest in technology can collectively and collaboratively, in a distributed and largely unregulated space, provide useful public resources” (Brady, 2005). Since the mid-2000s, users have been creating their own collections of content from general culture through image-sharing platforms and making them publicly available. It has been shown that such ventures, compared to the projects of traditional institutions, enable better mutual interaction between the interested audience and those who manage the platform, but also greater integration of individual users into the cultural community (Terras, 2011). Terras indicates that such initiatives have the potential to inform institutions about the most efficient ways of compiling online resources and finding relevant audiences in the process (Terras, 2010).

Due to a lack of institutional support for the undertakings of individuals, doubts arise regarding the responsibility for providing accurate information without misinterpretation of content. However, it can be argued that individual endeavors don’t challenge the work of experts in the field, but rather attract public awareness to the culture itself which is necessary for their work to be better recognized in the public discourse. This is especially relevant in cases where the goal is to preserve large numbers of geographically scattered artifacts, requiring widespread public engagement on the issue. This implies a basic level of knowledge about the subject among stakeholders on all levels. It requires educational content that can be easily distributed even though it may be simplified in regard to the expert literature.

Audience participation in content digitization can enrich its contextual background. Thereby, cultural heritage can be shared, promoted, recreated easily, and used to inspire new changes in the field of collective culture. Contrary to the criticism of amateur ventures, Bachi et. al argue that “mass culture is, therefore, quality culture” (Bachi et. al., 2014).

1.2 The cultural heritage of Stećak and Bosančica

The digitization project described in this paper focuses on the cultural heritage of the Middle Ages (14th to 16th centuries) on the territory of Bosnia and Herzegovina. Specifically, the culture of the *Stećak (*pl. *stećci)* and the writing system *Bosančica* (Bosnian Lapidary Cyrillic). *Stećci* are medieval stone monuments that are largely found on the territory of Bosnia and Herzegovina, as well as Croatia (Dalmatia), the north of Montenegro, and southeastern Serbia (Wenzel, 1965). They are most often clustered in necropolises, i.e. medieval cemeteries. The first specimens date from the 12th century, while most were made between the 14th and 15th centuries (Dizdar, 2018). Their exact number is difficult to determine due to their wide spatial distribution, land sedimentation, and human activity over the centuries. According to the source

(Bešlagić, 2020), there are 59,593 *stećak* tombstones in B&H, 4,447 in Croatia, 3,049 in Montenegro, and 2,267 in Serbia. It is believed by some that at their peak they numbered over 100,000 specimens (Imamović, 1995). They first received worldwide attention starting in the 19th century through archeological expeditions in Bosnia and Herzegovina by various international researchers. In 2016, 28 *stećak* necropolises were included in the UNESCO World Heritage List (UNESCO, 2016).

Bosančica is the most widely accepted name for the Cyrillic medieval Bosnian script inscribed on the *stećci* monuments. Some authors claim different names, assigning the script to other regional languages. As Bešlagić explains: "It has not been determined what it was called at the time, nor is there an agreement on how it should be called today, the script used to write medieval Bosnian books, official documents, and epigraphic Cyrillic monuments. From the existing literature, in this regard, there are not only inconsistent but also very different and even controversial viewpoints" (Bešlagić, 2020). Currently, 350 epigraphic monuments have been discovered in Bosnia and Herzegovina that contain the *Bosančica* script. 328 are found on *stećak* monuments and 22 on other stone monuments. Including the region outside of B&H, a total of 386 *stećci* with typographic inscriptions were discovered. Since *stećci* were used as tombstones, their inscriptions are categorized as epitaphs (Bešlagić, 2020).

Most of the scientific research and conservation efforts concerning *Stećci* and *Bosančica* were conducted after the 1950's, because of the aggravating historical circumstances and a lack of institutional interest (Bešlagić, 1971). Although the theory of their origin is more complete today, there is still no agreed explanation for a significant part of their cultural context, leaving much room for further scientific discussion. The best sources related to *stećci* can still be found in print in specialist publications. Although those publications are the most valuable, due to the limited distribution of such literature, it is difficult to include them in traditional teaching, because of the advanced academic language that limits it to a more professional community.

In recent years there have been some educational and artistic initiatives that try to bring the topic closer to a wider audience. There is a digitized collection of old Bosnian texts (DIJAK - *Digitalni jezički anotirani korpus starih bosanskih tekstova*) created by the University of Sarajevo Language Institute (https://www.e-bosanski.ba/dijak/). This project includes a database of all discovered epitaphs on *stećci*, searchable by keywords, and a simple transliterator for calligraphic *Bosančica*. The project under the name "Pišem ti bosančicom" by Amra Zulfikarpašić and Lejla Nakaš in collaboration with other artists, was realized to actively promote the script by developing fonts, organizing exhibitions and workshops, which resulted in a published book (Zulfikarpašić & Nakaš, 2016). Fonts used in both projects were made by artist Miomira Mila Melank. Current online sources on the topic include Stećak.map by the Mak Dizdar Foundation (https://stecakmap.info/) and Nekropola.ba by Edin Bujak (https://www.nekropola.ba/bs), both of which mainly focus on geographically mapping the necropolises, but also provide some background information about the culture itself.

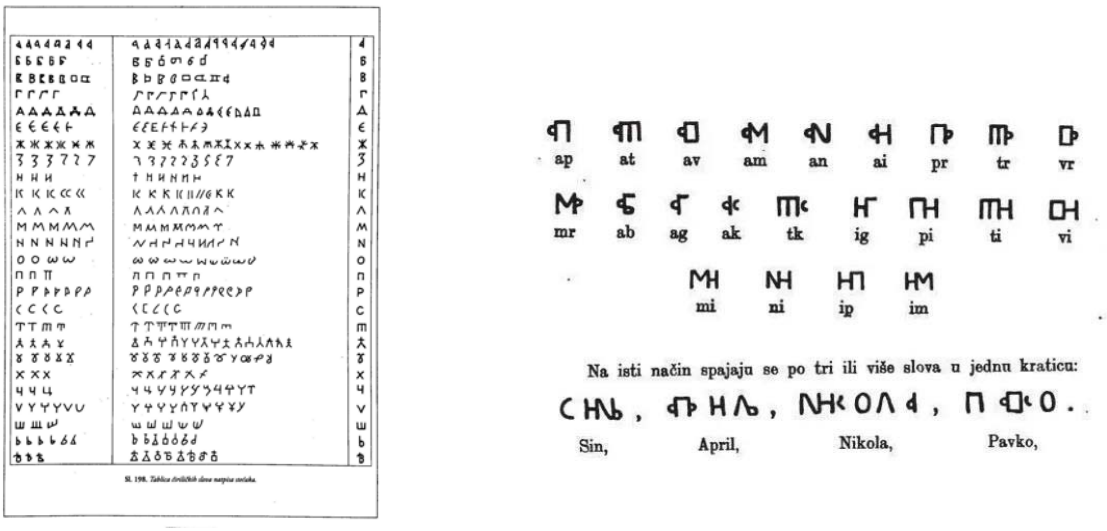
2. METHODS

This project is divided into two main phases:

- digitization of the *Bosančica* script and creation of three stylized fonts with full sets of characters including ligatures and alternative characters, and
- developing a web transliterator with the function of translating Latin text into *Bosančica* with full support for all additional functions of the font.

The digitization process began with the selection of content that would concisely represent the culture and provide a good introduction to its artistic reach. Although there are over 6,000 *stećci* with relief decorations (Dizdar, 2018), many symbols are repeated and can therefore be tentatively categorized. In the *Bosančica* script, there are two distinguished styles based on the way of use: handwritten and lapidary. The definition of lapidary represents all typography found on carved stone medium. Character differences exist between these two categories, but also within them. In this paper, the focus is on the lapidary form of *Bosančica* because of its connection with the *stećak* culture. The sources of typography used in the literature are the works of Marko Vego (Vego, 1964), Amra Zulfikarpašić and Lejla Nakaš (Zulfikarpašić & Nakaš, 2016), Ćiro Truhelka (Truhelka, 1889), Šefik Bešlagić (Bešlagić, 2004; Bešlagić, 2020) (Figure 1a), and Mehmed Kardaš (Kardaš, 2015) (Figure 1b).

The *Bosančica* script was used for several centuries, and in distant localities with their specific linguistic differences. As a result, the glyphs representing the same grapheme can have vastly different styles of writing depending on the region and time period. Taking that into consideration multiple glyph versions of each character were included across all font styles to accommodate these differences, providing separate user choices for each character alternate. *Bosančica* writing also has specific ligature features, where some glyphs unite to form larger symbols representing multiple characters at once. (Figure 1b) Every ligature is assembled from the core identifying shapes of included glyphs, while some elements of the original characters are lost during ligature formation. In reality, these ligatures were used only on certain occasions so their inclusion into the font is purely for education and technical demonstration. Therefore, the goal was to create a font that can automatically assemble the ligatures by itself, while still allowing users control of whether they want to use the ligature feature or not.



a) b)

Figure 1: a) Glyph variations (Bešlagić, 2004.), b) Ligature variations (Truhelka, 1889.)

2.1 Glyph creation

First, vectors were created using Adobe Illustrator according to the lapidary *Bosančica* script. The forms of characters were constructed using curves and were subsequently transformed into vector shapes. By connecting the shapes through the *Pathfinder tool*, final glyphs were formed to be used in the font. To make the complete font more adaptable to the current Latin script keyboard, the letters F and J were subsequently added to the existing list of characters, which originally did not appear on stone monuments but only later in some versions of the calligraphic script. To complement the glyph diversity of this script, three alternates of every character were created where possible, showcasing opportunities for further expansion. These glyphs were then interpreted through three different styles, Lapidary (closest to source) and digitally adapted Regular and Bold versions, which amounted to 297 glyphs in total for this demonstration. To showcase the multi-letter ligature functionality, 25 symbols were chosen from literature (Truhelka, 1889) (Figure 1b) to be used in the fonts. Three separate Latin script-based fonts were created in FontLab 8, one representing each style. The glyphs were then imported from Adobe Illustrator to FontLab, where each *Bosančica* glyph was assigned to a value corresponding to its equivalent in the *Gaj's Latin alphabet,* used today by modern Slavic languages in the countries of localities. After importing the glyphs, the core vectors were optimized through path simplification, and kerning spaces were established for each character.

2.2 Alternates and ligatures

As mentioned, there are three character alternates for each letter in a given font, as well as ligatures combining multiple letters into a singular glyph. Both font features were executed through ligature

functions in the OpenType language (Microsoft Typography, 2024), considering future interactive HTML implementation. Character alternates were defined through the *Standard ligatures* (*liga)* function, where every letter has a set default glyph that forms a ligature with an empty unused value. As these fonts have no glyphs representing numbers, we used code spaces of numbers 1 and 2 for up to two character alternates per letter. Character alternates are output each time either number comes after a letter (e.g. A+1), substituting the original for the new glyph (e.g. A_one). The other type of ligatures that contain multiple letters at once, were assembled through the *Discretionary ligatures* (*dlig)* function (Figure 2) allowing manual control of their use while not impacting chosen alternate characters functioning through *liga*. The final font needed to also retain functionality if both alternate characters and other ligatures were used at the same time. This was done by including each scenario of potential combinations that should result in a certain ligature (e.g. A1+K2=A_K).

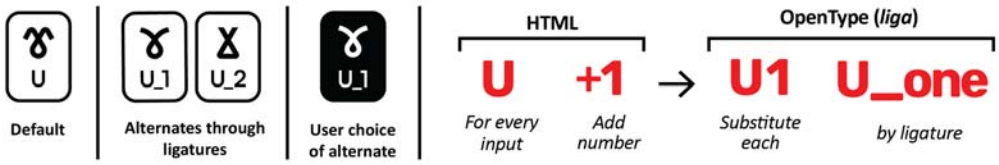


Figure 2: Character alternates expressed through Standard ligatures function

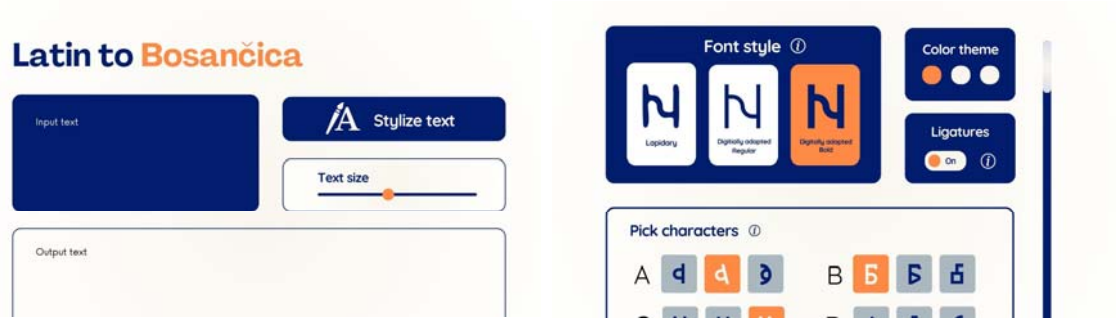
2.3 HTML integration and presentation

A web-based transliterator was created to showcase this digitized heritage in a widely available and interactive medium. It allows Latin to *Bosančica* transliteration with added features for customization of output text. The starting interface (Figure 3a) consists of an input-output box layout with a slider for the sizing of output text and a customization menu option. Upon opening the menu (Figure 3b), the first submenu allows for changing the font style, which switches between three different font files in HTML. There is a ligature On/Off switch for multi-character ligatures that controls if *dlig* features are toggled in CSS. Users can also choose alternate characters for each letter in a table of all glyphs. By selecting a certain alternate, HTML sets a function that types out its corresponding ligature number each time that letter is input. Since it is applied immediately each time, the user just sees their newly chosen glyph as a character alternate and not the ligature itself forming. Because the Discretionary i.e. multi-letter ligatures include all possible combinations of character alternates, the user's unique choices do not influence the regular formation of larger ligatures if their option is activated in the menu.

3. RESULTS

The final website concept opens with a functioning transliterator and adds customization options further through a menu button and output size slider. The menu allows for choosing the font style, color theme, ligature control and choice of alternate characters that stay saved as users' preferences. In terms of visual characteristics, a simplified website structure provides a high-contrast interface that is then adaptable for better visual accessibility by using appropriate color combinations.

Three form styles of glyphs are available, each contained within a separate font while all offer the same ligature functionality regardless of style. The characters and their alternates are presented in the table below (Figure 4), where each row represents one character marked first by its Latin equivalent, followed by groups of alternates categorized through different styles. Using the same order principle, the other table lists all ligatures marked by appropriate letter combinations that comprise them (Figure 5).



a) b)

Figure 3: a) Website interface, b) Customization options menu

Latin	Bosančica								
	Lapidary			Digitized Regular			Digitized Bold		
	A	A_one	A_two	A	A_one	A_two	A	A_one	A_two
A	ⰰ	ⰰ	ⰰ	ⰰ	ⰰ	ⰰ	ⰰ	ⰰ	ⰰ
B	ⰱ	ⰱ	ⰱ	ⰱ	ⰱ	ⰱ	ⰱ	ⰱ	ⰱ
V	ⰲ	ⰲ	ⰲ	ⰲ	ⰲ	ⰲ	ⰲ	ⰲ	ⰲ
G	ⰳ	ⰳ	ⰳ	ⰳ	ⰳ	ⰳ	ⰳ	ⰳ	ⰳ
D	ⰴ	ⰴ	ⰴ	ⰴ	ⰴ	ⰴ	ⰴ	ⰴ	ⰴ
E	ⰵ	ⰵ	ⰵ	ⰵ	ⰵ	ⰵ	ⰵ	ⰵ	ⰵ
Ž	ⰶ	ⰶ	ⰶ	ⰶ	ⰶ	ⰶ	ⰶ	ⰶ	ⰶ
Z	ⰷ	ⰷ	ⰷ	ⰷ	ⰷ	ⰷ	ⰷ	ⰷ	ⰷ
I	ⰸ	ⰸ	ⰸ	ⰸ	ⰸ	ⰸ	ⰸ	ⰸ	ⰸ
J	ⰹ	ⰹ		ⰹ	ⰹ		ⰹ	ⰹ	
K	ⰺ	ⰺ	ⰺ	ⰺ	ⰺ	ⰺ	ⰺ	ⰺ	ⰺ
L	ⰻ	ⰻ	ⰻ	ⰻ	ⰻ	ⰻ	ⰻ	ⰻ	ⰻ

	A	A_one	A_two	A	A_one	A_two	A	A_one	A_two
M	ⰼ	ⰼ	ⰼ	ⰼ	ⰼ	ⰼ	ⰼ	ⰼ	ⰼ
N	ⰽ	ⰽ	ⰽ	ⰽ	ⰽ	ⰽ	ⰽ	ⰽ	ⰽ
O	ⰾ			ⰾ			ⰾ		
P	ⰿ	ⰿ	ⰿ	ⰿ	ⰿ	ⰿ	ⰿ	ⰿ	ⰿ
R	ⱀ	ⱀ	ⱀ	ⱀ	ⱀ	ⱀ	ⱀ	ⱀ	ⱀ
S	ⱁ	ⱁ	ⱁ	ⱁ	ⱁ	ⱁ	ⱁ	ⱁ	ⱁ
T	ⱂ	ⱂ	ⱂ	ⱂ	ⱂ	ⱂ	ⱂ	ⱂ	ⱂ
Ć	ⱃ	ⱃ	ⱃ	ⱃ	ⱃ	ⱃ	ⱃ	ⱃ	ⱃ
U	ⱄ	ⱄ	ⱄ	ⱄ	ⱄ	ⱄ	ⱄ	ⱄ	ⱄ
F	ⱅ	ⱅ		ⱅ	ⱅ		ⱅ	ⱅ	
H	ⱆ	ⱆ	ⱆ	ⱆ	ⱆ	ⱆ	ⱆ	ⱆ	ⱆ
C	ⱇ	ⱇ	ⱇ	ⱇ	ⱇ	ⱇ	ⱇ	ⱇ	ⱇ
Č	ⱈ	ⱈ	ⱈ	ⱈ	ⱈ	ⱈ	ⱈ	ⱈ	ⱈ
Š	ⱉ	ⱉ	ⱉ	ⱉ	ⱉ	ⱉ	ⱉ	ⱉ	ⱉ

Figure 4: Glyphs of characters and character alternates sorted by font values

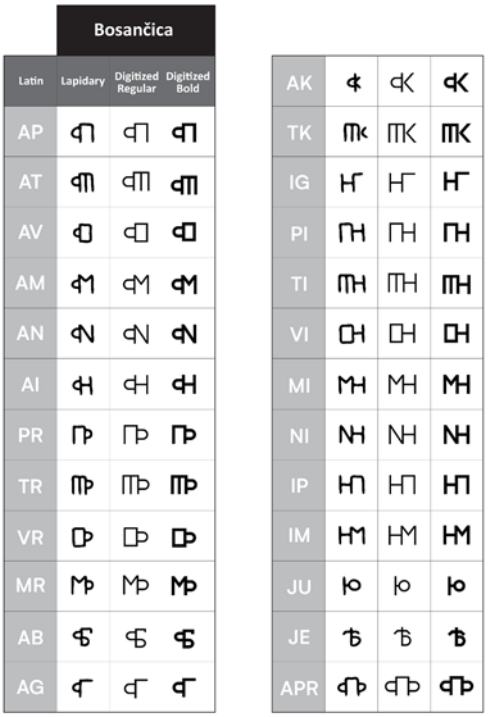


Figure 5: Glyphs of ligatures

4. DISCUSSION

The rich collection of character variations in this script poses a significant challenge in the effort of digitization, especially when making a functioning digital writing system. It is difficult to concisely present this script without compromising on some glyphs and ligature scenarios, undermining historical accuracy. Previous efforts to create digital versions center around two different core principles. The first is for professional editorial purposes of the literature on the subject, whereby some artists attempted to create a full range of all discovered character forms in one font. These have the highest historical accuracy but lack in terms of technical practicality and options for further integration besides professional literature. The other, like the one in this paper, focus on educational and entertainment purposes where compromises are made to balance accuracy with technical adaptability. As we have showcased, through prioritizing HTML integration and creatively using OpenType features, this way of digital interpretation can offer better variety in terms of functionality and adaptiveness. By simplifying the font manipulation process through a user-friendly interface, it allows regular users to further engage with the writing system without the need for prior technical knowledge. A system like the transliterator can easily be integrated with other website sections that offer more detailed cultural information which would allow natural learning progression. This emphasizes its potential for adaptation in educational content and general use as a widespread public digital resource.

5. CONCLUSIONS

In today's digital age, the undisputable next step forward in cultural conservation, participation and education on the matter is the process of digitization of national cultural heritage. Digital platforms allow for broader accessibility of such cultural materials to global masses but hold an obligation to structure the content in a precise and transparent manner while offering the opportunity to its users to further explore said material. The potential interactivity that digital platforms offer with cultural material aids in understanding complex concepts and connecting deeper with the subject at hand.

By using the example of the cultural heritage of Bosnia and Herzegovina, this paper shows an innovative way in which culture, specifically a writing system can be digitized and preserved to appease many of its different variations, adapting it to the environment of today's learners.

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IMPLEMENTATION OF 3D GRAPHICS ON THE WEB – A CASE STUDY OF EXPERIENCE DEVELOPMENT, OPTIMISATION AND QUALITATIVE EVALUATION

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Abstract: *The aim of the study was to develop a website with the main functionality of an interactive three-dimensional (3D) viewer. In the theoretical part, we present a brief overview of content management services (CMS) and their limitations; definition of usability and user experience (UX) with an explanation of the basic components of UX and the theoretical background of the User Experience Questionnaire (UEQ). The experimental part consists of the entire process that was used in the development of the website. We created the concept and design for the graphic identity of the website and developed the information architecture, defined basic and additional functions, created a low-fidelity wireframe and a high-fidelity prototype design. We developed the 3D viewer using open-source software model viewer, prepared and optimised the 3D models for the 3D view (Figure 1), followed by the rendering phase in Blender. We developed the final version of the desktop-first website and designed and developed mobile and tablet versions. Testing included qualitative usability testing using the User Experience Questionnaire (UEQ) and open-ended questions, followed by analysis of the results on three areas of usability (attractiveness, practical quality and hedonic quality). The results of the analysis served as guidelines for improving the current functionalities in terms of UX and technical aspects (with technical limitations). The results showed that creating a modern website that emphasises an interactive 3D model with a CMS platform is an extremely complex project that encompasses many areas. According to the UEQ test criteria, the final online solution scored above average in terms of practicality and attractiveness. The results also show the importance of iterative testing and website upgrades based on the results of the test analyses.*

Key words: 3d viewer, website development, web design, user experience (UX), measuring quality of usability

1. INTRODUCTION

A Content Management System (CMS) is a software platform designed to enable users to create, edit, publish, and store digital content without the need for coding skills. By providing a graphical user interface, CMS platforms simplify content creation, editing, and publication, making them accessible even to those with limited technical expertise. Despite variations in functionality among different CMS platforms, they generally share essential features such as intuitive indexing, search, and retrieval of published data through attributes like dates, keywords, and authors. They also include format management, which involves the organization and control of various content types, and revision tools that facilitate the updating and editing of published content while tracking changes over time. Content publishing is streamlined through the use of predefined or custom templates, enabling efficient and consistent presentation (Godbolt, 2016; Messenlehner, 2019). Additionally, CMS platforms support plugins, which are collections of code that enhance the platform's functionality for specific needs. A notable example is the WooCommerce plugin for WordPress, which extends the platform’s capabilities to support e-commerce activities such as product publication, inventory management, cashless payments, and advertising. The use of plugins allows users to tailor their CMS to suit specific requirements, making it a versatile tool for various digital content needs (Casey, 2023; Sahupala, 2024).

The primary advantages of using a CMS include ease of use, as the graphical interface makes it user-friendly even for those without technical knowledge. Efficient information retrieval is another benefit, with built-in search engines enabling quick access to content. CMS platforms also simplify content management, providing tools for organizing and maintaining digital assets effectively. Being web-based, CMS platforms allow users to access and manage content from any internet-enabled device, offering flexibility and convenience. Moreover, CMS platforms support collaborative workflows, enabling multiple users to work simultaneously on content management tasks with varying permission levels. This capability allows, for example, an editor to update product prices while a customer browses the online catalogue. The ability to

ORCID number is provided at the end of the paper.

quickly update content, add new pages, and implement new functionalities as the site evolves ensures scalability and adaptability for future growth (Godbolt, 2016; Casey, 2023).
Usability and user experience (UX) are crucial considerations in the development and refinement of a CMS. Usability refers to the quality and simplicity of the user interface, which directly impacts how effectively and efficiently users can achieve their goals. It encompasses aspects such as learnability, efficiency, memorability, error management, and satisfaction. Meanwhile, utility addresses whether the design's functionalities meet the user's needs. Together, usability and utility define a product's usefulness, with a successful CMS being both easy to use and capable of fulfilling user requirements (Albert & Tullis, 2022). A CMS is a robust platform for digital content management, and emphasizing usability and user experience is essential for creating an effective and engaging system that meets user needs and facilitates efficient content management.
User experience encompasses all interactions between the user and the design, going beyond basic functionality to include the seamless integration of development, marketing, graphic design, and user interface design. Usability testing is a vital part of the design process, helping identify strengths and weaknesses in the current design, exploring competitive approaches, and refining ideas through iterative testing of prototypes. This process involves observing users in real-world settings, comparing designs against usability guidelines, and continually testing and improving the final product (Garrett, 2010; Albert & Tullis, 2022).
Empirical measurement of UX can be conducted through standardized questionnaires such as AttrakDiff, UEQ, and meCUE, with the User Experience Questionnaire (UEQ) being particularly effective for capturing immediate user feedback. The UEQ assesses aspects like attractiveness, perspicuity, dependability, efficiency, novelty, and stimulation, providing valuable insights for interpreting usability tests and enhancing the overall design experience (UEQ, 2022).
The aim of the work was to design, develop and publish a website that focuses on a three-dimensional object. The special feature of the implementation is the use of the CMS platform and open-source functionalities for viewing the 3D models. This allows the user to view a 3D object from any angle, to zoom in or out and to experience it interactively. The implementation of this type of work is challenging as it requires a multidisciplinary approach and a certain degree of complexity. In practice, this is solved through group work, where each member takes on a specific role based on their expertise. After the creation and publishment of the website, the subjective usability metrics based on the standardized UEQ questionnaire was used to analyse and evaluate the information on possible improvements, shortcomings, additional features and the quality of the user experience.

2. METHODS

The experimental part included following phases, which overlap at certain points: analysing the existing websites to determine the core functionalities and layout of the pages; definition of end users and target groups, determining the basic functionality and information architecture of the website; design wireframes of the website; design of a non-functional website prototype, development of a website for a personal computer (desktop), checking, correcting and finalising elements; development of a website for a smartphone (mobile) and a tablet computer (tablet), usability test with the UEQ questionnaire.
The tools and software used were: Adobe Illustrator (creation of CGP and vector graphic elements); Figma (creation of the information architecture, a rough wireframe of the original and final website and an accurate (high-fidelity) prototype of the website); Blender (editing, rendering, import and export of 3D models); Wordpress.org (website development and publishing models); Elementor and Elementor PRO, Wordpress.org plugin (website template development and creation); WooCommerce, Wordpress.org plugin (management and control of 3D model catalogs); Modelviewer (display and rendering of 3D models on the website); Advanced Custom Fields, Wordpress.org plugin (creation and embedding of dynamic data in an Elementor template); other plugins for Wordpress.org (the functions of this platform were only required for performance-specific tasks without the need to write additional code):

- WP File Manager (for advanced navigation within the website's database),
- Unlimited Elements for Elementor (for a larger number of additional website components),
- Limit Login Attempts Reloaded (to prevent access to the website by brute force when logging in),
- File Upload Types (to extend the permitted file types that can be uploaded to the website),
- Elex WooCommerce Catalog Mode (to extend the Woocommerce catalog tool) and
- Big File Uploads (to increase the maximum size of files that can be uploaded to the website).

Usability was measured using a combined method. i.e. standardised quantitative usability metrics and open-question questionnaire. The actual user experience was measured with a standardized UEQ questionnaire and open-ended questions were used to search for problem areas. The test examined the quality of the user experience in six areas (UEQ, 2022): Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation and Novelty. The questionnaire already contains a tool for analysing the results and a benchmark. Questionnaire with two open questions provided us with information that directly indicated problems with the use of the website, i.e "Comment on your experience of using the website" and "Suggest improvements and/or new functionalities that you think would improve the performance of the website".
The web solution with the integration of 3D viewer was tested on a PC and with browsers: Google Chrome, Safari, Mozilla Firefox, Microsoft Edge; and on mobile devices and with browsers: Google Chrome, Safari, Vivaldi.

3. RESULTS

The website was designed in Wordpress.org platform. The functionalities offered by the website platform were divided into two categories: 1. The main functionalities represent the goal of the website: 3D model that the user can interactively view and zoom from any angle and a gallery with static photos and renderings of the objects. 2. Auxiliary and secondary functionalities that enabled the user to learn and navigate the website or the 3D model, i.e. Presentation and purpose of the website; Selection gallery from which the user can choose any 3D model; Description of the facility.
The object page contained several different components: Address or name of the 3D model, first and last name (or pseudonym) of the author, additional options and the possibility to share on social networks; Functional and interactive window with 3D model; Accompanying text (Slovenian and English description of 3D models created with artificial intelligence); General rendering of the model; Gallery with front, side and roof profile of the model; List of software used to create the final 3D model. Information architecture, basic wireframe and short code with CSS component of the 3D object that displays the website logo are presented in Figure 1.

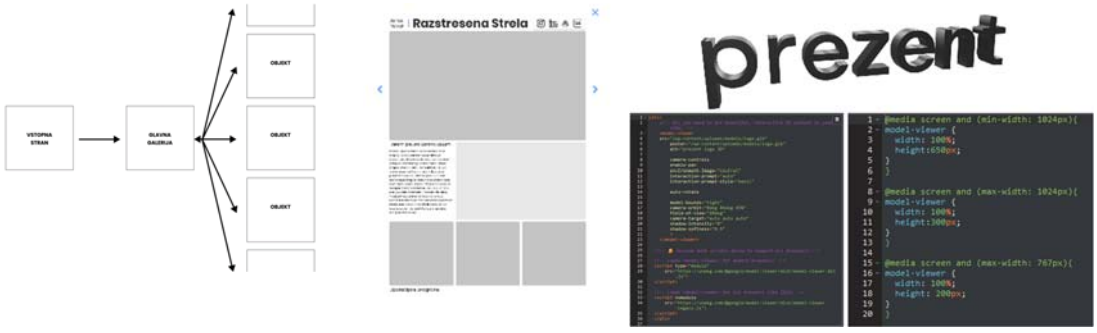


Figure 1: Information architecture, basic wireframe and the short code and CSS component of the 3D object that displays the website logo

The main purpose of the gallery was to support the model viewer and extend the accessibility of the bottom to view objects. Unlike the model viewer, the image gallery was part of the basic set of Elementor components. WooCommerce plugin. Therefore, the component did not have to be subsequently adapted in the program code for the dynamics within the template. Figure 2 shows the appearance of the final form of the rendering gallery on a selected 3D model within the editor in the Elementor plugin.
The creation of a functional version of the website for personal computers was followed by the creation of a format for cell phones and tablets. For all components (with the exception of the model viewer, where responsiveness was defined in the component's CSS field), we created a new, device-specific version of the component that was optimized for a mobile device. Within the template, we then adjusted the appearance of the page according to the screen width of the display device, which can also be filtered in the CSS field. The dimensions of the filtering were defined as follows: Personal computer (screen width at least 1024 px); Tablet computer (screen width between 767 px and 1024 px); Cell phone (screen width maximum 767 px).

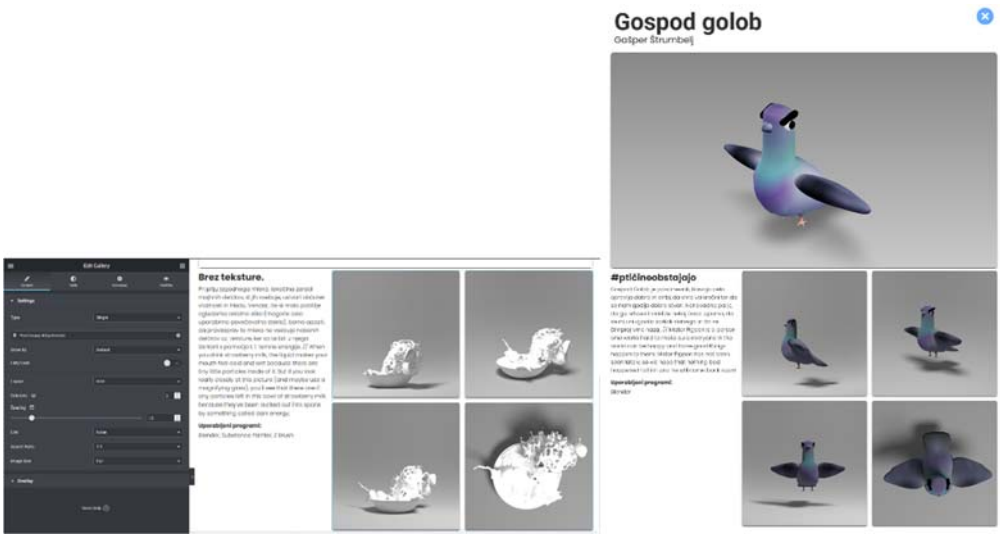


Figure 2: Image gallery layout of the Strawberry model in the Elementor plugin and the final layout of the object page

Table 1 presents summarized results of UEQ testing of the websites with the 3D viewer and Figure 3 the visualisation of the UEQ results.

Table 1: Summarized results of UEQ testing into areas obtained with the UEQ questionnaire data analysis tool (UEQ, 2022)

UEQ parameters	Average	Std. Dev.
Attractiveness	1,464	0,72
Perspicuity	1,286	1,35
Efficiency	1,000	0,77
Dependability	1,250	0,91
Stimulation	0,857	1,22
Novelty	0,786	0,80

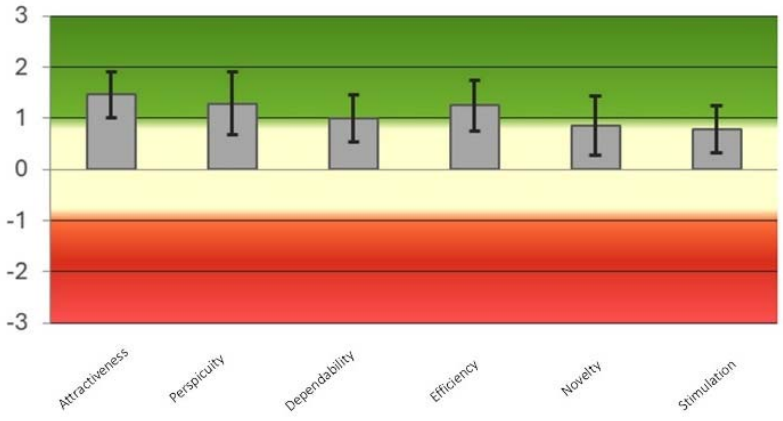


Figure 3: UEQ values of areas with standard deviation obtained with the UEQ questionnaire data analysis tool

The tool for analysing the UEQ results also contains a benchmark. The purpose of this benchmark is to compare the results with other usability tests that have already been completed. It is based on the results of 468 different tests conducted with a total of 21175 people (UEQ, 2022). The UEQ test performance is shown graphically in Figure 4.

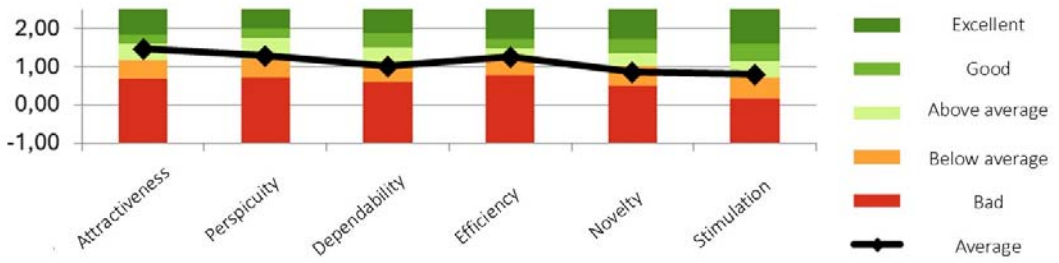


Figure 4: Graphic representation of the UEQ questionnaire test performance measure obtained with the UEQ questionnaire data analysis tool

The Cronbach alpha coefficient is used to measure the reliability or internal consistency of the results. Results greater than 0.7 indicate satisfactory consistency, but with a small sample (less than 50 people) this coefficient should be taken with a grain of salt. This means that we cannot use it independently. In this case, its values are a poor indicator of the consistency or quality of the responses, as the sample is small and very sensitive to changes.
Classification (appeal, practical, hedonic) of comments and suggestions that resulted from the two open questions that were asked the users are presented as follows in Table 2. Table 2 shows that most problems occurred in the category of practical quality, due to problems with individual webpage components, with the overall experience with the website or with a specific limitation of the browser.

Table 2: Classified qualities of the website according to UEQ test and open questions

Positive	Negative comments
Appeal and attractiveness: • engaging interactivity Practical: • intuitive navigation Hedonic quality: • responsiveness of the site Other: • fast loading of the models	Appeal and attractiveness: • visual sophistication • additional features within the viewer Practical quality: • unintuitive navigation • problems with the main gallery • problems with the browser • problems with more sophisticated models • difficult to launch Hedonic quality: • visual sophistication

4. DISCUSSION

Attractiveness. From the results of the questionnaire on comments and suggestions in the attractiveness category, we can conclude that users like the interactive 3D model viewer and that they would like to see additional features in this area, such as: 1. more options within the navigation, such as changing the pivot point and zoom level, 2. opening the viewer in an additional window, 3. technical inspections of installations (e.g. cross-sections of installations), 4. 3D objects with animation.
Practical quality. From the comments and suggestions in the Practical quality category, it can be concluded that users are largely satisfied with the use of the website in terms of transparency and manageability, but somewhat less so in terms of efficiency. This can be seen in both the positive and negative comments and suggestions from users where problems occur throughout the website: 1. problems with the browser, 2. problems with the main gallery, 3. problems with more sophisticated models, 4. problems with loading objects, 5. non-intuitive navigation.
Hedonic quality. From the comments and suggestions in the hedonic quality category, we can conclude that users are not surprised and are on average satisfied with the use of the website in terms of originality and stimulation. This can be seen mainly from the lower test score, as the results are much lower compared to the other two categories. The number of user comments and suggestions in this area, on the other hand, is very low and indicates a lack of both negative and positive reviews.

5. CONCLUSIONS

Creating a modern website that features an interactive 3D model using a CMS platform is a highly complex project, requiring expertise in multiple areas. Although the final website performs above average in terms of practicality and attractiveness based on UEQ testing criteria, adjustments are needed according to feedback received during testing. To improve the user experience, the development team must expand their technical knowledge, which may necessitate adding more members to the team.
The experimental part of the research work the website development with integrated 3D viewer is described. We began by analyzing existing platforms, we created the corporate image (CI), information architecture (IA), and prototype designs. After developing the 3D viewer and rendering models, we built the desktop-first website and its mobile versions, followed by user testing to evaluate UX aspects, which informed future upgrades. For further development, the team should include specialists in web development and technology, product and user experience design, user and market research, user interface and graphic design, 3D model preparation, and website testing for bugs and issues. Further, detailed research and quality measurement of user experience should be conducted through physical testing with a larger sample size. As the most exposed issues were in practical (and hedonic) properties of the webpage, continuous usability testing should be included each stage of development, and the target user group should be clearly defined using simplified user profiles, or personas.

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ANALYSIS OF SELF-REGULATED LEARNING APPLICATIONS BASED ON VISUAL APPEARANCE AND FREQUENCY OF USE

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***Abstract**: The choice of the appropriate visual design for each mobile application has a significant impact on the perception of information. This is also of the utmost importance when acquiring or communicating educational content. In the field of e-learning, there is an increasing number of mobile applications that enable efficient teaching and learning. Our study analyses different applications for e-learning that are frequently used by Slovenian high school students. Based on a literature review, an introduction to the field of application design is given and criteria that influence the selection of appropriate graphical elements when creating an application in general are presented. With the survey, we compared the five most widely used applications for self-directed learning on the basis of their visual design. Our aim was to collect data on the effectiveness of the graphic elements that influence the choice of an application and to identify students' habits in terms of self-regulated learning (type of tool used, learning time, learning circumstances). In addition, the learning habits of students from a suburb were compared with students who live in the city. Based on the data collected, we provide guidelines for selecting the most appropriate graphic elements for designing an effective application as a learning and teaching tool. The research showed differences in the use of applications for learning or entertainment depending on the type of school the students attend (vocational, secondary school and high school students). The study also determined how much time per day students use digital tools for learning or entertainment and, more importantly, which media. Another important finding was that students still mainly rely on traditional learning methods, i.e. textbooks and notebooks, to complete their homework for school. Differences in the popularity of applications between suburban and urban students were found in only two of the five applications analysed.*

Key words: user interface, mobile applications, self-regulated learning, visual appearance, study habits

1. INTRODUCTION

In formal secondary education, new, more modern forms of teaching, including information and communication technologies (Gramma et al., 2020), are being sought to accommodate students as "digital natives" (Prensky, 2001) in a time of rapid technological development. M-learning, i.e. teaching and learning using mobile technologies, enables in addition to the use of teaching materials and applications field learning, the preparation of materials with mobile devices (images, audio recordings, etc.) and communication and collaboration with teachers and other people (Bregar, Zagmajster & Radovan 2021). For learning through the screen, microlearning or learning in smaller content assemblies is very suitable. Giurgiu (2017) states that it is easier for learners to absorb and retain learning content that is divided into smaller learning sections. The most suitable teaching tools for microlearning are mobile tools. With the use of smartphones, m-learning has become learning that is independent of time and space as it enables instant communication and data sharing. Mobile devices with loaded tools or applications allow access to learning content, communication, the use of video camera and sound. Particularly with mobile applications that are intended for learning, great attention should be paid to the design of the user interface. Namely, visualization for effective learning is based on images, infographics and animations. At the same time, visualization is a powerful didactic tool the use of which must be motivated, pedagogically appropriate and methodically supported (Delil, 2017; Alwadei, 2023). A study by Gramma et al. (2020) examined the technical requirements of mobile phones, didactic methods of m-learning, the use of mobile applications and the organization of student education by surveying 79 students over a period of five years. The research results showed, among other things, that it is very important for learning purposes that the user interface is user-friendly (including the visual design, including typography, buttons, and content layout) with clear interaction rules. High-quality interfaces further support learning, expressive aesthetic features of the design stimulate interests to engage in the learning topic, and the aesthetic experience caused by interfaces influences deep perceptual processes such as emotions and cognitive stimulation (Ruf et al., 2022). Planned and well-thought-out graphic visuals contribute to better understanding, ease and simplicity. By graphically

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representing information with symbols, icons, etc., it is easier to understand and manipulate them (Smrdel et al., 2017). Even the name and logo of the application can significantly influence the choice of a particular application for self-study. In a study on digital game advertising involving 293 people, it was found that people generally remember brand logos faster and more strongly than brand names (Ghosh, Sreejesh & Dwivedi, 2022).

The purpose of this study was to examine the frequency of use and the type of digital devices that secondary school students use for learning. In addition, we want to investigate which of the five most frequently used self-regulated learning applications selected among the highest rated international solutions for digital learning is the most visually pleasing to students in three different secondary schools (professional school, vocational school, and gymnasium). All analysed applications had in common the possibility of creating and discovering learning content and sharing learning resources. The focus was to collect data of the likability of the graphic elements of visual design (application name and logo, icons, typography, colour scheme, visibility, and arrangement of graphic elements) that influence the choice of an application and identify students' habits in terms of self-regulated learning (type of tool used, learning time, learning circumstances). Before we began our research, we set five hypotheses: H1: We assume that students use digital media mainly for independent learning at home. H2: We hypothesize that students spend significantly more time using digital media/mobile phones for entertainment than for learning. H3: We assume that there is a difference among students from different schools in terms of preference for applications. H4: We hypothesize that there is a difference between students who are drivers and those who are not in terms of preference for apps. H5: We assume that students find the same independent learning application visually attractive based on individual characteristics (name, colour scheme, typeface colour, visibility, arrangement of graphic elements, icons and logo).

2. METHODS

2.1 Research Instrumentation

An anonymous survey of the target group was conducted using printed copies of the questionnaire, which were given to the students by their teachers. Students completed the online survey voluntarily and after daily school learning obligations from 10th to 20th May 2022. 45 students between the ages of 14 and 18 took part in the study. In the first part of the survey, the students provided their demographic data: gender, age, type of school and whether or not they're drivers. In the second part of the survey, students answered questions about how much time they spend using digital tools for learning and how much time for entertainment and which media they use for independent learning. In the third part of the survey, the students completed the evaluation form for each individual application with the help of a pictorial representation of the respective mobile application. On a 5-point Likert scale (1 - I don't like at all; 2 - I don't like, 3 - I don't like so much; 4 - I like it; 5 - I really like it), the students express their opinion about visual design of the five most used mobile self-regulated learning applications: Khan Academy (2022), GoConqr (2022), Kahoot (2022), Anki (2022) and SoloLearn (2022), presented in Figure 1. The visual graphic elements were: colour scheme, typeface colour, visibility and layout of the graphic elements, icons and logotypes. Beside the graphic elements students evaluated also the name of which application is closest to them. We also determined whether there is a difference in preferring a specific application between students who commute to school from the suburbs of the cities (therefore school locations) and those who live close to schools with no need to take a public transport.

2.2 Statistical Analysis

Transferring the empirical data to the IBM SPSS Statistics program enabled us to carry out a statistical analysis. We analysed the characteristics of the variables (name, colour scheme, typeface colour, visibility, arrangement of graphic elements, icons and logo of the app; type of tool used, learning time, learning circumstances) together with the frequencies (professional school, vocational school, and gymnasium). The statistical results are only given descriptively in the text and numbers in this paper. The Cronbach's alpha test of measurement reliability showed that the internal correlation of the variables of all individual factors is appropriate, as the value of the Cronbach's alpha test is greater than 0.70 for all factors. The measurement characteristics were tested on the entire sample examined (N = 145). Descriptive statistics were calculated for all variables. The Pearson correlation coefficient, the χ^2 test for independent samples and the Mann-Whintey (M-W) test were used to determine differences regarding the liking of individual

applications among types of secondary schools and between drivers and non-drivers. For statistically significant values, we considered differences at the level of 5% and lower risk ($p \leq 0.050$).

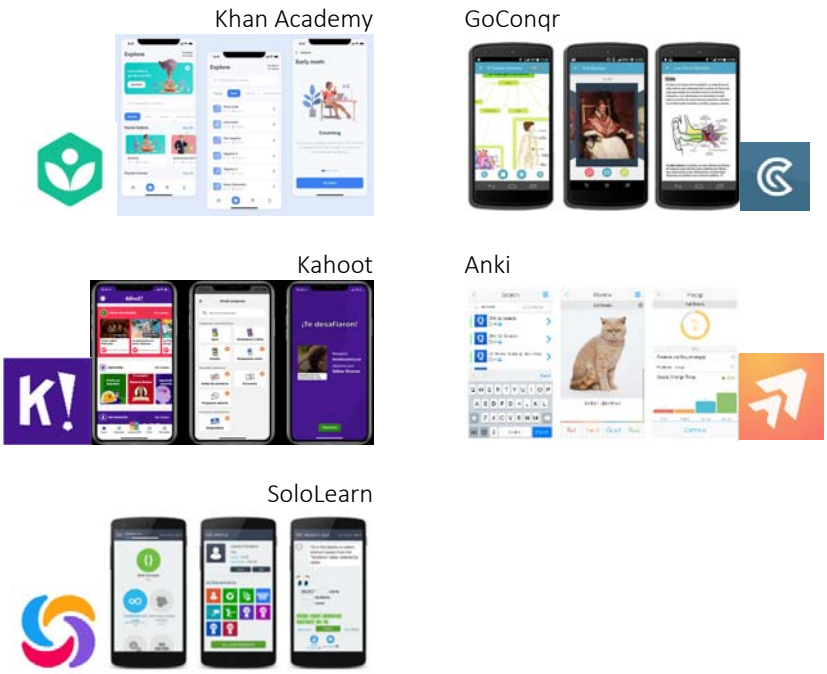


Figure 1: Logo and visual appearance of a self-regulated learning mobile application Khan, GoConqr, Kahoot, Anki and SoloLearn

3. RESULTS

Results showed that 145 students involved in the study could be divided into two groups, i.e. into those who go to school by public transport (spend significantly more time on the way where they can use mobile technologies) - 82%, and those who do not use public transport to access school - 18%. From the questionnaires it was found out that students from gymnasium (48 students), vocational school (49 students) and technical school (48 students) were included in the study. The schools differ in vocational focus, complexity of the general education program and different interests of the students in general. The sample consisted of 18.6% male, 79.3% female students and 2.1% students who described themselves as other.

Figure 2 shows how much time students at different types of secondary school spend each day using digital devices for homework and how much for entertainment, and which media they use at home for homework.

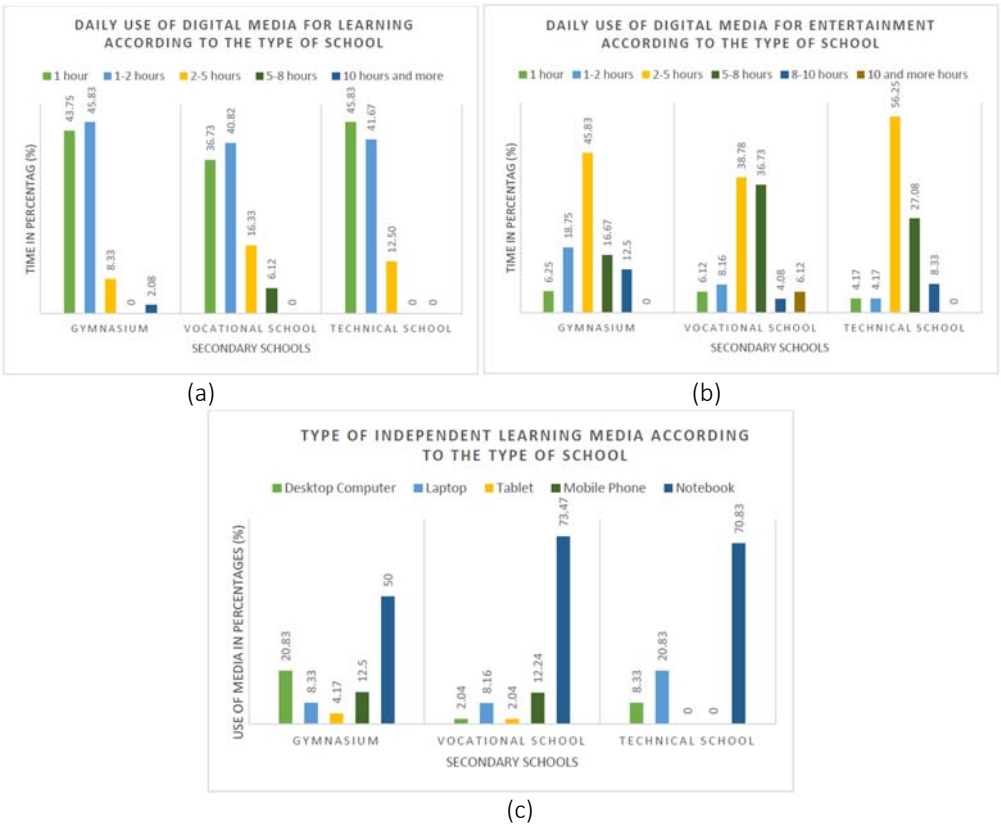


Figure 2: Daily use of digital media for learning (a) and entertainment (b), type of independent learning media (c) according to the type of school (N = 145)

Table 1 presents the results of the percentage of responses of students from all schools (sum) combined regarding the liking of the visual features of Khan, GoConqr, Anki and SoloLearn.

Table 1: The percentage of responses of students from all schools (sum) combined regarding the liking of the visual features of analysed applications

App	Charact.	I don't like it at all (%)	I don't like it (%)	I don't like it so much (%)	I like it (%)	I really like it (%)
Khan	Logo	1	8	17	28	46
	Visibility	6	19	32	30	14
	Name	12	23	38	19	8
GoConqr	Name	17	19	35	2	6
	Colour	7	22	38	23	10
	Visibility	8	19	41	21	10
	Icon	7	25	31	29	8
	Logo	6	16	29	28	21
Anki	Graphics	6	12	36	36	10
	Logo	8	12	34	31	14
	Colour	5	14	41	30	9
	Typeface	4	13	45	27	11
SoloLearn	Colour	5	14	41	30	9
	Typeface	4	13	45	27	11

4. DISCUSSION

Figure 2a and b shows that students at all three types of secondary school use digital media for learning for roughly the same amount of time per day. That is 1 to 2 hours per day. From Figure 2b, we can see that students of vocational school use digital media for entertainment significantly more time than technical school students and students of gymnasium. The results of the χ^2 test for checking the association of factors

type of school and daily time spent studying with digital tools showed that the factors type of secondary school and time spent using digital media for entertainment are statistically associated. Figure 2c shows that most students do their homework using a notebook (50% gymnasium students, 73.47% vocational school students and 70.83% technical school students), followed by laptops and desktop computers. Mobile phones are only used by gymnasium (12.5%) and vocational school (12.24%) students. Tablets are also only used by gymnasium (4.17%) and vocational school (2.04%). For homework and work, students at the technical school only use a notebook (70.83%), a laptop (20.83%) and a desktop computer (8.33%). The results of the χ^2 test to examine the correlation between the factors school type and daily time spent learning with digital tools confirm that the factors school type and type of digital media for learning are statistically related.

We created descriptive statistics of the individual mobile applications for self-learning and compared the results with each other. The results obtained with the Likert scale were added for each group, the arithmetic mean and the statistical deviations were calculated. It was found that the visual characteristics of the Kahoot application achieved the highest value in relation to the group with the same characteristics (colour: M = 3.8, SD = 1.2; typeface: M = 3.9, SD = 2.0; visibility: M = 4.0, SD = 1.0; graphic elements: M = 4.0, SD = 2.0; icons: M = 4.0, SD = 1.1; logo: M = 3.9, SD = 1.1 and name: M = 3.8, SD = 1.2). The GoConqr application achieved the lowest value for visual features (colour: M = 4.0, SD = 2.0; typeface: M = 3.0, SD = 0.9; visibility: M = 4.0, SD = 2.0; graphical elements: M = 3.2, SD = 2.0; icons: M = 4.0, SD = 1.1 and name: M = 40, SD = 2.0) and the Anki app (logo: M = 3.3, SD = 1.1). Only statistically relevant results of the analysis about the students' opinion (for all three types of secondary school) regarding the individual design element of the visual design of tested mobile applications for self-regulated learning are presented in Table 1. The χ^2 test of the association among the responses of students from different secondary schools and the factors of visual appearance of various mobile applications for self-study showed that there are statistically significant differences in the following application variables: Khan, GoConqr, Anki, and SoloLearn.

Statistically significant differences showed that: Secondary school students like the logo and name of the Khan application the most, the visibility of this application is most appealing to vocational students. Gymnasium students like the logo, visibility, icons, and colour scheme of the GoConqr application the most, while these students like the name the least. Technical school students like the logo and graphic elements of the Anki application the most, while vocational school students like the logo the least. Gymnasium students like the colour scheme of the SoloLearn application the most, while the typeface of this application is the most attractive to students from a professional school.

The result of the Mann-Whintey (M-W) test related to students who go to school by public transport and those who do not, in relation to the individual factor of the visual appearance of different mobile applications for independent learning, showed that it is not possible to detect differences between the visual characteristics of each application. A statistically significant difference was seen only in one application and its visual characteristics, the self-study application Khan. The results showed that students who do not use public transport are more likely to approve of the colour scheme of this application (p = 0.026). In terms of visibility (p = 0.060) and logo (p = 0.056), we found a trend difference between the two groups of secondary school students and the visual characteristics of each application. In both cases, this tendency is expressed in favour of the Khan application.

5. CONCLUSIONS

The results of the study showed that the application that students from three schools liked best was also the most visually appealing. According to the Centre for Learning Performance Technologies (2021), the Kahoot application also ranks high on the list of the world's best educational platforms and tools. As part of the research, we also found out how much time per day students use digital tools for learning or entertainment and which media. This is an important starting point for further research. One important piece of information we gained from the study is that they still use the traditional learning method for schoolwork: textbook and notebook. This is probably the result of the way they work at school, as teachers mainly teach with the help of exercise books and textbooks and, in line with this way of working, also give the students instructions for completing the tasks at home. We have refuted hypothesis 1 that secondary school students use the digital medium the most for learning. Students still use the traditional notebook method and textbooks for independent learning at home. We confirmed hypothesis 2, as students of different secondary school types spend significantly more time using digital media/mobile phones for entertainment than for learning. We confirmed hypothesis 3 that there are statistically significant

differences among students from vocational school, professional school and gymnasium in terms of preference for individual visual features of applications. We were able to partially confirm hypothesis 4 that there is a statistical difference between students who take public transport to go to school and those who are not in terms of preference for apps. Differences are only found for 1 out of 4 apps. We partially confirmed hypothesis 5, namely that students find the same self-regulated learning application, i.e. Kahoot, visually attractive based on individual studied characteristics.
In further research, more attention should be paid to the graphic design of digital and analogue learning materials, as the development of learning and teaching should be supported by the design of learning content. Teachers and lesson planners should design and follow the rules of a multimedia approach to learning and encourage students to discuss and critique approaches to learning models found in textbooks, digital learning environments and virtual technology trends in education (Güney, 2019).

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VISUAL DYNAMICS IN DIGITAL CATALOGUES: A COMPREHENSIVE ANALYSIS OF CINEMAGRAPH INTEGRATION THROUGH EYE-TRACKING TECHNOLOGY

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Abstract: *This paper investigates the transformative influence of cinemagraphs, a captivating hybrid of static images and subtle motion, on the overall quality and user experience of digital catalogues. As e-commerce and online browsing continue to shape consumer behaviour, the need for dynamic and visually appealing content is crucial. We delve into the aesthetic and functional enhancements brought about by cinemagraphs, analyzing their ability to capture attention, convey product features, and elevate the overall engagement levels within digital catalogues. Through a comprehensive analysis of user gaze patterns, fixations, and engagement metrics, we explore how cinemagraphs influence attention distribution, enhance product perception, and contribute to the overall quality of the digital shopping experience. Our findings not only underscore the significance of cinemagraphs but also provide valuable insights into designing visually compelling and user-centric digital catalogues.*

Key words: digital catalogues, cinemagraph, eye-tracking, user experience

1. INTRODUCTION

The theoretical framework for this study is based on the concept of visual communication and its role in influencing user behaviour. Visual communication is a powerful tool in digital marketing, as it enables brands to convey messages, evoke emotions, and establish connections with audiences through the use of imagery, colour, motion, and design elements (Lotman, 2016; O'Connor, 2024). In this context, cinemagraphs serve as an innovative form of visual storytelling that combines the best aspects of still photography and video. Unlike animated GIFs, which are often repetitive and low in quality, cinemagraphs employ high-quality visual elements that create a more immersive experience, blurring the line between static and dynamic content (Ramona, 2019; Winter, 2016). The concept of cinemagraphs was first introduced by New York-based photographer Jamie Beck and web designer Kevin Burg in 2011. They created cinemagraphs for New York Fashion Week and posted them on the Tumblr blog "From Me to You," where they received considerable attention (Susanto, 2019). Cinemagraphs are characterized by a subtle movement in one part of the image, while the rest remains static, effectively drawing the viewer's focus and creating a "living photo" effect that sets them apart from both static photography and video content (Ramona, 2019; Flock, 2011). Cinemagraphs are characterized by four main features: an infinite loop, continuity, animated frames, and a hypnotic effect. The infinite loop creates an impression of endless repetition, which is a shared component with forms such as animated GIFs, Vine, Boomerang, and Facebook Live Photo. The second component is pronounced continuity, which distinguishes cinemagraphs from other forms. This creates an illusion of time, making the beginning and end of the video imperceptible. In other formats, the repetition of a series of static frames is evident, whereas in cinemagraphs, individual elements are animated, creating dynamic parts in contrast to the rest that remains static. The visual effect created by the previous three components evokes a sense of hypnosis and emotion in viewers (Fang, 2024). An overview of the components is shown in Figure 1.

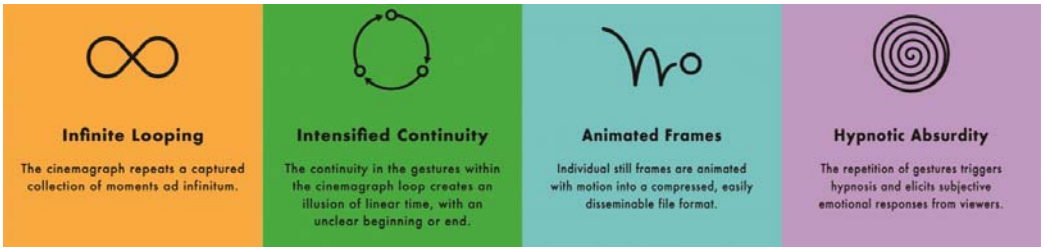


Figure 1: Four main features of cinemagraph

ORCID numbers are provided at the end of the paper.

Due to their visually captivating properties, cinemagraphs are widely used in various fields, including fashion, travel, advertising, and online marketing (King, 2024). Their ability to attract and retain viewers' attention makes them a powerful tool for enhancing visual communication in digital catalogues, where engagement is crucial. Digital catalogues have become a key component in modern marketing, providing businesses with the ability to showcase products and services to consumers in an interactive and visually engaging way. Traditional catalogues, whether in print or basic digital formats, often struggle to capture and hold the attention of viewers in a highly competitive visual landscape. This challenge has led to the adoption of new visual elements such as cinemagraphs, which blend photography and video, to create a more dynamic and appealing viewer experience. Cinemagraphs are defined as a hybrid between a still image and a looping video element, creating an illusion of animation while maintaining the elegance and simplicity of a photograph (Ramona, 2019). Cinemagraphs have been shown to have several distinct advantages over both static images and traditional video in terms of engagement. Research conducted by Flixel, a tool used for creating cinemagraphs, found that dynamic content, such as cinemagraphs, achieved a click-through rate (CTR) 5-6 times higher than that of static images (Rose, 2024). This significant increase in engagement suggests that the subtle movement provided by cinemagraphs can be a highly effective method for capturing and retaining viewer attention in digital catalogues. Furthermore, the emotional response evoked by the motion in cinemagraphs plays a crucial role in influencing consumer behaviour, encouraging interaction, and driving conversions (Flicker, 2016).

The concept of visual hierarchy is central to understanding how viewers interact with digital catalogues. Visual hierarchy refers to the arrangement of elements in a way that guides the viewer's eye through the content in a particular order of importance (Fang, 2024). By integrating cinemagraphs strategically, designers can create focal points that direct attention to key products or messages, enhancing the overall effectiveness of the catalogue. The use of subtle motion in cinemagraphs naturally draws the viewer's gaze, making them an effective tool for establishing a visual hierarchy and improving the usability of digital catalogues (Fang, 2024). Eye-tracking technology provides a practical approach to studying visual hierarchy and understanding how different visual elements contribute to user engagement (Płużyczka, 2018). By tracking the movement of the viewer's eyes, it is possible to determine which elements capture attention first, how long the viewer remains engaged, and whether specific visual elements, such as cinemagraphs, have a greater impact on maintaining interest compared to static images (Eyeware, 2022). Metrics such as time to first fixation (TTFF), gaze duration, and heat maps are essential for evaluating the effectiveness of visual elements in capturing attention and facilitating navigation through the digital catalogue (Eyeware, 2022; Farnsworth, 2024).

This paper aims to provide a comprehensive analysis of the integration of cinemagraphs in digital catalogues through the use of eye-tracking technology. The focus is on understanding how cinemagraphs contribute to visual dynamics, enhance user experience, and drive engagement, compared to traditional static images and video content. By studying eye movement patterns, fixation times, and areas of interest, this research seeks to reveal the impact of visual dynamics on user behaviour and inform best practices for designing digital catalogues.

2. METHODS

Following the same principle, three cinemagraph examples were created in Adobe Photoshop (Figure 2). The videos used were sourced from the internet in the best possible resolution, and the cinemagraphs were saved in MP4 format. After creating the cinemagraphs, the next step is designing and creating the digital catalogue (Figure 3). The first version is a catalogue with all static elements, while the second version is an interactive catalogue featuring three dynamic elements, namely three cinemagraphs.

For the purposes of the research, a visual test was conducted. The experiment involved 30 participants, 20 women and 10 men, with an average age of 22.6 years. For conducting the experiment, a monitor was used to present both versions of the catalogue to the participants. Additionally, the Gazepoint GP3 eye-tracking device was used along with the software tools Gazepoint Control and Gazepoint Analysis. The Gazepoint GP3 is a research eye-tracking device that uses a 60 Hz machine vision camera at the core of its image capture and processing system. The device was calibrated before each participant.

For the analysis of the obtained data, the following research questions were formulated:

- Which element (Area of Interestes - AOI) did the participants notice first, and at which second?
- Does the cinemagraph attract participants' attention faster compared to a static image?
- Do participants spend more time on the cinemagraph compared to a static image?
- Do participants return to the cinemagraph?

To analyze the data, it is necessary to create AOIs in the Gazepoint Analysis software. Defining these areas facilitates and shortens the time required for data analysis. Twelve areas were defined: image/cinemagraph in the upper left corner (S1), image/cinemagraph in the centre (S2), image/cinemagraph in the upper right corner (S3), product prices (Price 1/2/3), device, as well as product names and descriptions. Figure 4 shows the AOIs on a sample.



Figure 2: Samples for the experiment



Figure 3: Catalogue used for the experiment



Figure 4: Areas of Interestes - AOIs

3. RESULTS AND DISCUSSION

Based on the analysis of the results for the elements (AOI) that participants first noticed on the static stimulus, seven elements were identified as being initially observed, with ten participants first noticing the element (AOI) "Coffee machine name." The average time to first fixation was 0.095 seconds, while the average duration of the first fixation was 0.99 seconds. The shortest first fixation duration was 0.02 seconds, and the longest was 2.27 seconds. Figure 5 graphically shows the number of participants who noticed each element during the first fixation on the static stimulus.

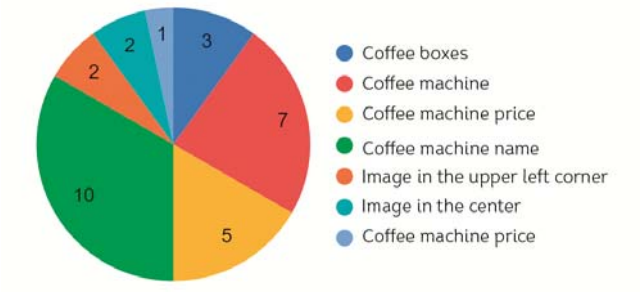


Figure 5: Graphical representation of the elements (AOI) that participants first noticed on the static stimulus

Based on the analysis of the results for the elements (AOI) that participants first noticed on the dynamic stimulus, eight elements were identified as being initially observed, with eight participants first noticing the element (AOI) "Coffee machine name" and one less (seven) noticing the cinemagraph in the upper left corner (S3). The average time to first fixation was 0.095 seconds, while the average duration of the first fixation was 1.25 seconds. The shortest first fixation duration was 0.16 seconds, and the longest was 3.47 seconds. Figure 6 graphically shows the number of participants who noticed each element during the first fixation on the dynamic stimulus.

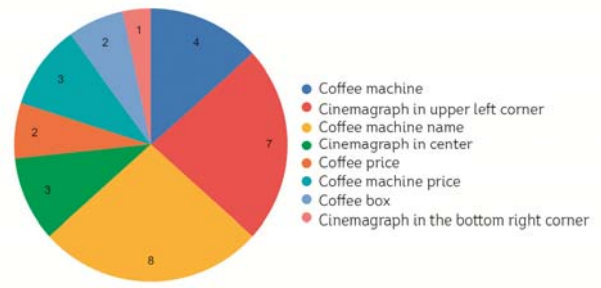


Figure 6: Graphical representation of the elements (AOI) that participants first noticed on the dynamic stimulus

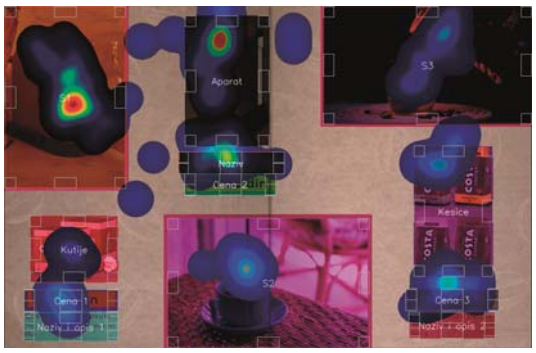
Based on the analysis of how long it took participants to notice images on the static stimulus and cinemagraphs on the dynamic stimulus, which were identically positioned, the following observations can be made. All participants noticed the cinemagraph in the upper left corner, while one participant did not notice the image in the upper left corner. One participant did not notice the cinemagraph in the centre, while five participants did not notice the image in the centre. All participants noticed the cinemagraph in the upper right corner, whereas five participants did not notice the image in the upper right corner.

The average time to first fixation for the image in the upper left corner was 1.68 seconds, while for the cinemagraph in the upper left corner, the average time to first fixation was 2.67 seconds. The average time to first fixation for the image in the centre was 3.77 seconds, while for the cinemagraph in the centre, it was 3.15 seconds. The average time to first fixation for the image in the upper right corner was 3.37 seconds, while for the cinemagraph in the upper right corner, it was 2.4 seconds. Based on this, it can be concluded that participants took less time to look at the cinemagraph compared to the image in two out of three positions, as the movement attracted their attention.

An analysis was also conducted on how long participants kept their gaze fixed on images on the static stimulus and on cinemagraphs on the dynamic stimulus, which were identically positioned. The average duration of the first fixation for the image in the upper left corner was 0.7 seconds, while for the cinemagraph in the upper left corner, it was 1.5 seconds. The average duration of the first fixation for the image in the center was 0.59 seconds, while for the cinemagraph in the centre, it was 1.14 seconds. The average duration of the first fixation for the image in the upper right corner was 0.8 seconds, while for the cinemagraph in the upper right corner, it was 1.38 seconds. Based on this, it can be concluded that participants spent more time on the cinemagraphs compared to the images in all three positions. The time spent on the cinemagraph in the upper left corner was 2.1 times longer compared to the image, in the centre it was 1.93 times longer, while in the upper right corner it was 1.72 times longer.

An analysis was conducted on how many times participants returned their gaze to the image on the static stimulus and to the cinemagraph on the dynamic stimulus, which were identically positioned. For the image in the upper left corner, the total number of revisits was 12, while for the cinemagraph in the upper left corner, the total number of revisits was 32. For the image in the centre, the total number of revisits was 11, while for the cinemagraph in the centre, it was 26. For the image in the upper right corner, the total number of revisits was 14, while for the cinemagraph in the upper right corner, it was 26. The participant with the highest number of revisits was participant 10, with a total of ten revisits, while participant 13 had zero revisits. Based on this, it can be concluded that the movement resulted in more revisits to the element.

The best way to visualize the most frequently observed parts of the stimulus is through heat maps. Warm colours indicate the most visited parts of the stimulus, suggesting that participants primarily observed the dynamic elements-cinemagraphs-during testing on the dynamic version of the prototype. Figure 7 shows the heat map of one participant and all participants on the static stimulus, while Figure 8 shows the heat map of one participant and all participants on the dynamic stimulus.

a) 

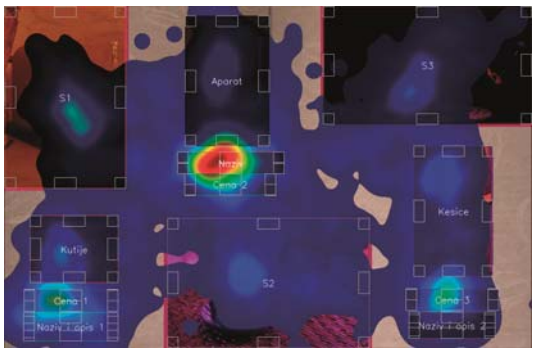
b) 

Figure 7 (part 1): Heatmap of a) single participant and b) all participants on the static stimulus

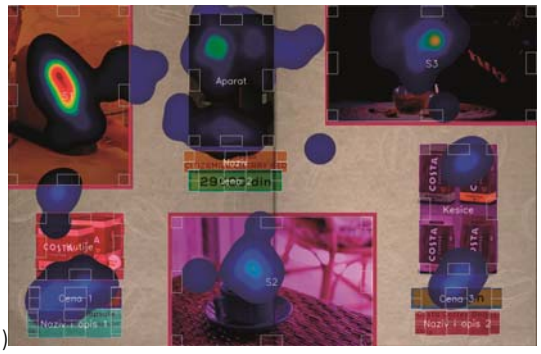
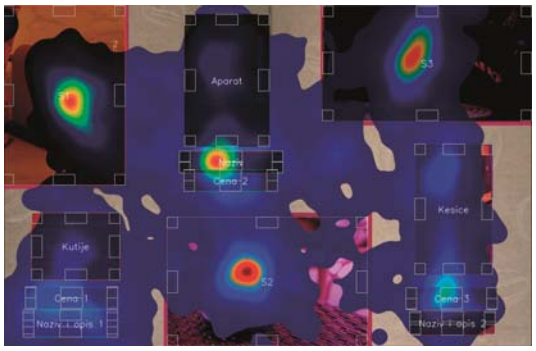
a)  b) 

Figure 7 (part 2): Heatmap of a) single participant and b) all participants on the dynamic stimulus

4. CONCLUSIONS

The combination of dynamic and static elements creates an ideal form that captures attention, intrigues, astonishes, and ultimately leaves a lasting impression on users. A significant advantage of cinemagraphs is their versatility across various fields, as the subject matter can be anything. In today's competitive market, the abundance of advertisements in various forms often leads to people forgetting what they have seen. Therefore, it is essential to capture attention and ensure that users remember their experiences. This can be achieved by incorporating interactive elements into catalogues.
The analysis of the obtained results leads to the following conclusions:

- Dynamic elements attract viewers' attention more quickly than static ones.
- Viewers tend to focus for longer durations on dynamic elements.
- Viewers return to dynamic elements more frequently.
- More attention is directed toward moving elements.
- Dynamic elements achieve greater appeal and interactivity.

Psychology and perception play crucial roles; for instance, individuals in this region tend to read from left to right, which is reflected in heat maps and gaze maps, as attention was observed to linger more on the left side compared to the right. The focus of the participants was predominantly on the centre of the display; this was evidenced by the fact that 24 out of 30 participants first looked at the central elements (product name, product price, appliance, image in the centre) in the static version, while 18 out of 30 did so in the dynamic version. Creating interactive dynamic content does not require significantly more time than developing static content. However, the differences in user engagement that dynamic content creates compared to static content are substantial. A potential drawback of using cinemagraphs in interactive catalogues is the choice of format. Nevertheless, formats such as high-quality GIFs or video formats (e.g., MP4) with autoplay and infinite looping are excellent options for digital catalogues.

5. ACKNOWLEDGMENTS

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EXPLORING THE IMPACT OF STEREOTYPE THREAT AND IDENTIFICATION ON GAMING PERFORMANCE: A PILOT STUDY USING CUSTOM AVATARS

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Abstract: *Stereotype threat, the fear of conforming to negative stereotypes associated with one's group, can significantly impact individuals in various contexts, including education, professional settings, and even entertainment, such as video games. In this study, a pilot experiment is conducted to examine the effects of stereotype threat on players' performance within a gaming environment. The methodology follows existing literature and employs a 2x2 matrix design. The participants play a simple 3D platform game and are divided into two groups: Custom Avatar Group - Participants in this group use avatars created from their own images; and Premade Avatar Group - Participants in this group use preexisting avatars that correspond to their gender while playing the game. Additionally, the presence of stereotype threat is manipulated by exposing half of each group to a fictitious article specifically designed to induce gender-related stereotype threat. This paper aims to address the following questions: (i) Can the recently available technology that enables players to create custom avatars based on their own images be successfully utilized for this type of experiment? (ii) How does stereotype threat impact players' in-game performance? (iii) Is there a correlation between the higher impact of stereotype threat and gender?*
The results of this paper will check for the impact on in-game performance of the new technology allowing players to play as themselves in video games.

Key words: Avatar creation, Identification effects, Computer Games, Digital Character

1. INTRODUCTION

Digital characters and avatars can have an impact on the user's attention, engagement, and thinking. The impact stems from the idea that users tend to identify with digital characters (Cohen, 2001), and as a result, the identification effects such as the Proteus effect (Van Looy, Courtois & De Vocht, 2010) or stereotype threat (Kaye & Pennington, 2016) may take place. In the context of this particular paper, the focus is put on the stereotype threat. Stereotype thereat can occur in everyday situations, professional or educational setting (Brooks, 2023) as well as in entertainment settings (Kaye & Pennington, 2016). As such, it is important to define it. It was first defined by dr Claude Steele as a threat that may occur when one does something or is in a situation or belongs to the group to which a negative stereotype applies (Brooks, 2023). This paper is a pilot study that checks for identification effects, specifically stereotype threat in players, depending on their gender and avatar type. In accordance with existing literature (Li, Lwin, & Jung, 2014; Ratan & Sah, 2015), this paper utilizes a 2 x 2 matrix. Participants are divided into groups based on whether they play with a generic character or a lookalike avatar. Additionally, they are further divided into two subgroups: one exposed to a fake article claiming men are generally better than women in video games, and the other to a real article stating that women progress at least equally well compared to men when given the same amount of time (Shen et al, 2016; UC Davis Department of Communication, 2017).
The purpose of this pilot study arises from the possibility that individuals in various regions may react differently to typical stereotype threat triggers. Additionally, the study aims to investigate whether participants with diverse video game skill levels are suitable for participating in this kind of experiment. This paper aims to address the following questions:

1. Can the recently available technology that enables players to create custom avatars based on their own images be successfully utilized for this type of experiment?
2. How does stereotype threat impact players' in-game performance?
3. Is there a correlation between the higher impact of stereotype threat and gender?

This research paper consists of three main sections in addition to the introduction and conclusion. The second section introduces the methods, participants and materials. The third section showcases the results of the experiment, including significant correlations. Finally the forth section discusses the results and answers the research questions.

ORCID numbers are provided at the end of the paper.

2. METHODS

This section introduces the participants and experimental design, followed by procedure and materials. One of the key elements of the experiment is the game made specifically for the experiment by the authors. The game followed a simple mechanic explained in (Doran, 2023) with the addition of importing the Ready Player Me Unity software development kit (SDK) (Ready Player Me, 2024) in order to allow the participants to make and play with their lookalike avatars.

2.1 Participants and Experimental Design

This pilot study involved 33 participants who spoke the Serbian language, including participants who identified as men (*N=12*) and women (*N=21*). Women who participated in the experiment were between the ages 18 and 50, with the average age range being 18–24 with a standard deviation (SD) of 0.995 and the average education level being a bachelor's degree (*SD=0.653*). Similarly to women, men who participated were between the ages 18 and 50, with the average age range being 18–24 (SD=0.669) and the average education level being a current university student (*SD=1.603*). Looking at both groups combined, they have reported that, on average, they play video games less than once a month (*SD=1.889*), and the average self-reported general in-game skill level was at 1.79 (*SD=1.244*) on a 5-point Likert scale from 0 to 4, where 0 represented "not skilled at all," and 4 represented "extremely skilful."
Disregarding gender, the experiment employed a 2 (stereotype threat present vs. no stereotype present) x 2 (played with the character that looks like a participant vs. played with a generic character) matrix design.

2.2 Procedure and Materials

All participants played a game made by the author. The game was made in Unity engine 2021.3.11f1 (Unity, 2024) and consists of an endless platform environment with obstacles that players had to avoid appearing randomly as the game progresses. The environment is simple, utilizing only white colour, while obstacles are noticeable and in dark red. Upon hitting the obstacle, it would turn bright red, as depicted in Figure 1, indicating to the player that they have lost a life. Players had five lives (were allowed to hit the obstacle five times before game-over) or were limited to 240 seconds of playtime in case they did not lose all five lives. Player movement was done using the keyboard and the following keys:
W - forward, *S* - backward, *A* - left, and *D* - right, or corresponding arrow keys. The perspective of the game was third person, with camera control using a mouse.

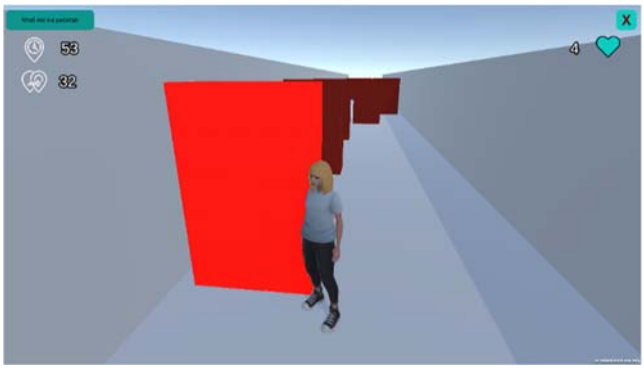


Figure 1: Overview of the game if a player hits an obstacle

Participants were invited to participate via a Google Form, where they got privacy notice in advance and were able to select which day and time was the most suitable for them to participate. The experiment spanned five working days, and the testing hours were divided into two intervals: 9:00 am – 12:5 pm and 16:00 pm – 20:00 pm in order to accommodate participants who are employed. The experiment took place in one of the classrooms of the Department of Graphic Engineering and Design, allowing for a maximum of 8 participants at the same time. Four computer workstations were labelled as "white group" and the other four as "blue group." Since the experiment took place at the end of August, the air condition was set to the same temperature for the duration of the experiment, and all participants had a water bottle and a granola bar prepared for them on the workstation (Figure 2, detail d). On the workstation, there were two sheets of paper stacked, one on top of the other. The top paper explained the privacy policy, what happens with

the collected data, and how it is stored. Under the privacy policy paper, there was a paper that had an online article printed out and translated into Serbian describing a research paper regarding the topic of skill progression between men and women. One-half of the participants got the correct version of the article that stated: "... they found that women advance at least as fast as men do in both games," while the other half of the participants got the fabricated article that stated: "... they found that women progressed much more slowly than men in both games." The second article was used to enforce the stereotype threat among participants identifying as women. Figure 2 depicts the workstation in the classroom.

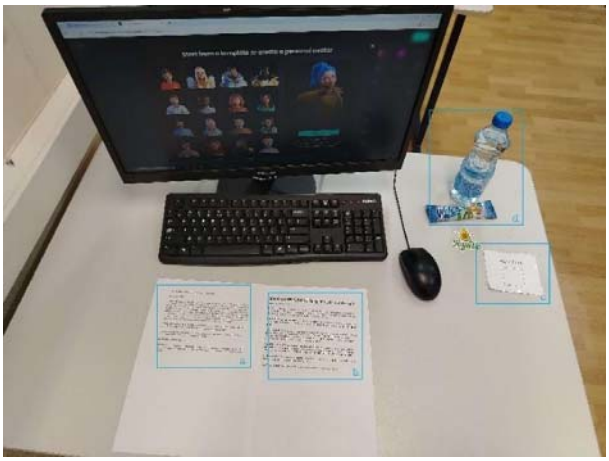


Figure 2: Workstation setup for participants. a) Policy privacy and information; b) Article that was used to trigger stereotype threat; c) White/Blue group indicator for participants playing with generic/custom characters; d) Snack

2.2.1 Introducing the participants to the experiment

Participants entered the classroom and were instructed to sit at the labelled workstations (Figure 2 detail c). In front of them were two papers stacked one on top of the other. They were informed to read the top paper first, which explained the privacy policy, which included a sentence stating that at any point in the experiment, participants can decide that they do not want to participate anymore (Figure 2, detail a) detail a, while the examiner provided any additional explanations. The examiner further informed participants about all the steps of the experiment and instructed them to read the second sheet of paper (Figure 2, detail b) without asking any additional questions about it.

2.2.2 Character creation

When participants were done reading, all of them were instructed to move their attention to computer monitors, where they were presented with a web page by Ready Player Me, which allowed them to take a picture of themselves using a web camera. Figure 3 showcases the step using an image created with the platform "Random Face Generator (This Person Does Not Exist)" instead of using a webcam in order to protect privacy.

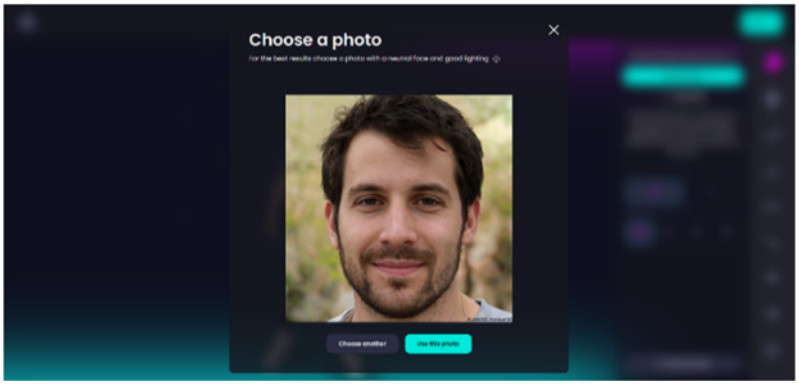


Figure 3: The first step in creating a custom avatar using an image of a participants (the face on this figure was generated using "This Person Does Not Exist")

The platform created the avatars resembling them, and the participants were further instructed to edit and dress the avatars so that they best represent themselves, depicted in Figure 4.

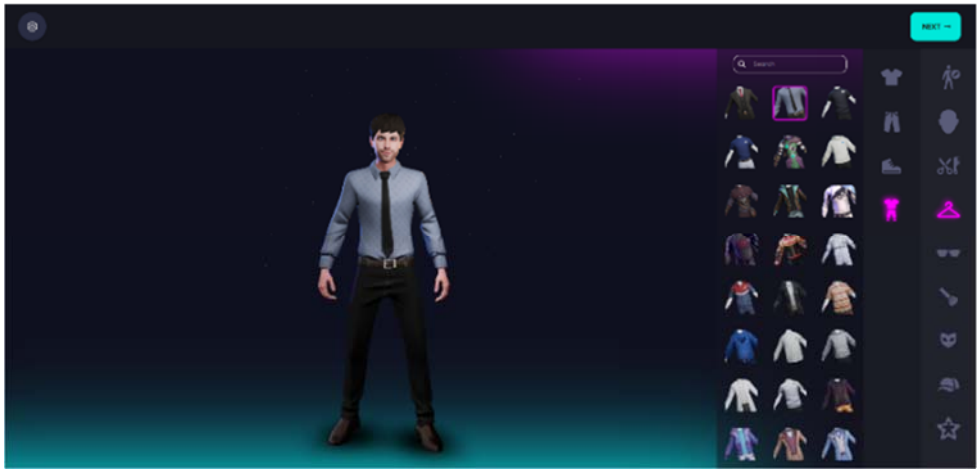


Figure 4: Customized character

When the participants were satisfied with the result, all participants were told to copy the avatar link, which is illustrated in Figure 5.

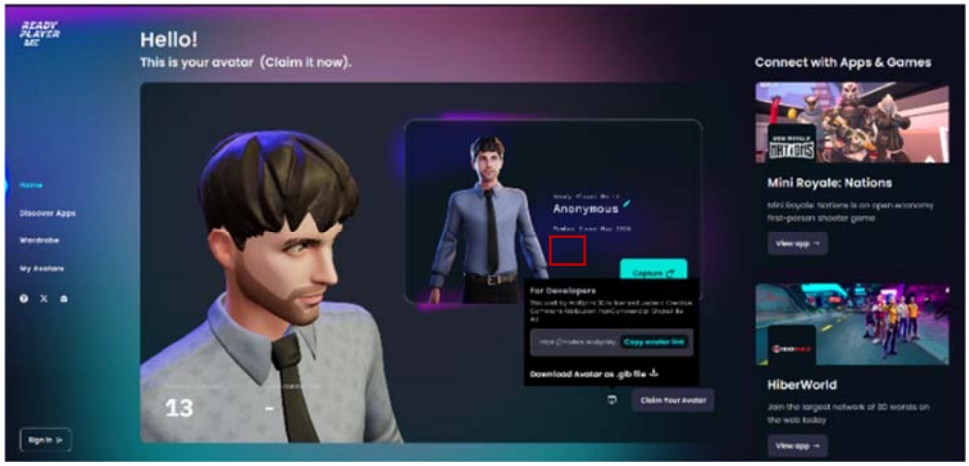


Figure 5: Copy the avatar link button

2.2.3 Game session

Finished with the avatar creation stage, participants were instructed to open up the game, where they were presented with the screen welcoming them and thanking them for participation (Figure 6, detail 1). Pressing the button "NEXT," participants entered the tutorial that explained the mechanics, movement, and metrics of the game (Figures 6, details 2 and 3) and allowed them to try and practice the game until they felt comfortable with the controls. Participants could see two scores, one representing the time played and one distance crossed in the game. The only way to successfully finish the tutorial was to lose all five lives. Figure 6, detail 4 shows the screen with the message that reads: "This is the end of the tutorial. If you want to try again, press the button in the top left corner. If you are ready, press the NEXT button." Following the tutorial, all participants got to the screen, which asked them whether they were in the white group or the blue group (Figure 6, detail 5). Participants that were part of the white group could only choose between two generic characters, one male and one female (Figure 6, detail 6.a), while the blue group was instructed to paste the previously created avatar link in the field (Figures 6, detail 6.b and detail 6.b.1), which then loaded their custom character (Figure 6, detail 6.b.2). The game session was finished after 240 seconds, or after participants lost all five lives. Losing all five lives triggered a screen that instructed the participants to

wait for the examiner to give further instructions, as depicted in Figure 6, detail 7. Following the game session, all participants began the next stage at the same time.



Figure 6: The main screens that participants were interacting with while playing the game. Screen 6. a was the screen the White group saw, while screens 6. b to 6.b.2 were the screens that the Blue group saw

2.2.4 Questionnaire

The final stage of the experiment process presented participants with a questionnaire consisting of the following sections, which were later translated to variables used in result analysis:

1. Game result questions:
    a. Selecting the group that they played as (white/blue),
    b. For how many seconds they have played the game, and
    What distance did they cross;
2. Game experience questionnaire:
    a. In-game questionnaire, and
    b. Post-game questionnaire;
3. General questions:
    a. Gender/age/Education,
    b. Previous experience in playing video games,
    c. Self-reported general in-game skill level, and
    d. Feelings towards the character creation platform used during the experiment:
        i. If the in-game character looked like them,
        ii. If they liked this way of character creation,
        iii. Whether other platforms should implement it and
        iv. Whether they are worried about the privacy policies and actions regarding these platforms;
    e. Feelings towards men and women in video games:
        i. Whether they believe that men are inherently better in games compared to women,
        ii. Whether both genders have equal chances to be good at video games and
        iii. If they believe that women are more often exposed to uncomfortable situations while playing video games and

4. Participants were asked to check either STDA or STNE, as a control question (participants reading the article that was inducing stereotype threat had to press STDA and participants that got neutral/real article had to press STNE).

It is important to note that some questions of this questionnaire were not directly used as variables in the results section of this paper, most notably questions 3.d.ii, 3.d.iii, and 3.d.iv.
After finishing the questionnaire, the participants were offered more water and granola and were on their way.

3. RESULTS

In the context of this particular paper, the following variables are of importance:

1. From section: Game result questions:
    a. *Was the group that had a Stereotype Threat trigger or not (1 = no stereotype threat, 2 = stereotype threat)* – ST,
    b. *White or Blue Group (1 = played with generic character, 2 = played with custom character)* – WB,
    c. *How long did they stay alive in seconds* – T,
    d. *What was the distance crossed during the playing time* – D,
    e. *Weighted Speed* – WS,

2. From section: General questions
    a. *Previous Gaming Experience (choice between 7 levels of experience, from none to playing multiple times a week)* – PGE,
    b. *What is your general skill level (5 point Likert scale, 0 = none, 4 = extremely skilled)* – GSL,
    c. *My character in-game looked like me (5 point Likert scale, 0 = completely disagree, 4 = fully agree)* – LLM,
    d. *Men are generally better in video games, compared to women (5 point Likert scale, 0 = completely disagree, 4 = fully agree)* – MBW,
    e. *Both genders have equal chances to become good at games (5 point Likert scale, 0 = completely disagree, 4 = fully agree)* – MEW,
    f. *I think that women are more often exposed to uncomfortable situations compared to men while playing video games (5 point Likert scale, 0 = completely disagree, 4 = fully agree)* – WUS,

3. From section: Game experience questionnaire,
    a. *In Game Competence* – IGC,
    b. *In Game Sensory and Imaginative Immersion* – IGSI,
    c. *In Game Flow* – IGF,
    d. *In-Game Tension or Annoyance* – IGTA,
    e. *In Game Challenge* - IGCH,
    f. *In Game Negative Affect* – IGNA,
    g. *In Game Positive Effect* – IGPA,
    h. *Post-Game Positive Experience* – PGPE,
    i. *Post Game Negative Experience* – PGNE,
    j. *Post Game Tiredness* – PGT, *and*
    k. *Post Game Returning to Reality* – PGR.

The variables with the prefixes "In Game" and "Post Game" are made according to scoring guidelines in the Game Experience Questionnaire (GEQ): Scoring guidelines – GEQ Core Module, and Scoring guidelines – GEQ Post-game Module (IJsselsteijn, de Kort & Poels, 2013).
The variable "Weighted Speed" is calculated using the following Equation(1):

$$WS = \frac{\sum PGE}{PGE} * \frac{D}{T} \quad (1)$$

The experiment design is a 2 x 2 matrix; however, since participants were both identified as men and women, it is necessary to look at the results separately.
In order to check for correlations, using IBM SPSS, Pearson's correlation was calculated.

Generally, for the sake of this experiment, the important correlation, regardless of gender, occurred between *WB* and *LLM* with [*r=.688, n=33, p<.001*]. Other sets of important correlations are WS and GSL, WS and IGC with [r=.717, n=33, r<.001] and [r=.539, n=33, r=.001], respectively. Finally, an interesting correlation in the context of this paper occurred between *ST* and *IGC* [*r=-.352, n=33, r=.044*]

3.1 Results for Men

Following the previous literature in the field in regards to whether there was an impact of stereotype threat, there were no significant correlations. Another expected correlation is between *WB* and *LLM* with [*r=.607, n=12, p=.036*]. Interestingly, there was a strong correlation between *WB* and *WS* [*r=.607, n=12, p=.036*].

In regards to the translated version of the Game Experience Questionnaire, there were some reaffirming correlations showcased in Table 1. *GSL* and *IGCH*, as well as GSL and PGNE, have strong negative correlations [r=-.619, n=12, p=.032] and *[r=-.678, n=12, p=.015*] respectively. Other significant correlations happened in regards to *IGC* and *IGF, IGC* and *IGTA, IGC* and *PGPE*, and *IGC* and *PGNE* [*r=.641, n=12, p=.025*], [*r=-.735, n=12, p=.006*], [*r=.702, n=12, p=.011*], [*r=-.763, n=12, p=.004*] respectively. *IGSI* and *IGCH, IGSI* and *IGPA* with [*r=.606, n=12, p=.037*], and [*r=.728, n=12, p=.007*] respectively. Another correlation following the logic of GEQ is between *IGF* and *IGPA* and IGF and PGPE with [r=.826, n=12, p=.001], [r=.761, n=12, p=.004], respectively. *IGCH* and *PGNE* have a positive correlation [*r=.635, n=12, p=.026*]. *IGNA* is, as expected, in a negative (albeit not very strong) correlation with *IGPA* with [*r=-.594, n=12, p=.042*], and *IGNA* is in a positive correlation with *PGT* [*r=.631, n=12, p=.028*]. *IGPA* and *PGPE* are in yet another expected correlation [*r=.681, n=12, p=.015*]. Following the previous correlation, *IGPA* and *PGR* are in correlation as well [*r=.709, n=12, p=.010*]. *PGPE* and *PGR* are in a positive correlation with [*r=.634, n=12, p=.027*]. Finally, an interesting negative correlation appeared between *WUS* and *IGNA* [*r=.-728, n=12, p=.007*].

Table 1: Pearson correlations regarding GEQ for male-identifying participants

		In Game Flow	In Game Tension Annoyance	In Game Challenge	In Game Negative Affect	In Game Positive Affect	Post Game Positive Experience	Post Game Negative Experience	Post Game Tiredness	Post Game Returning to Reality
What is your general skill level	Pearson Correlation			-.619*				-.678*		
	Sig. (2-tailed)			.032				.015		
	N			12				12		
I think that women are more often exposed to uncomfortable situations compared to men while playing video games.	Pearson Correlation				-.728**					
	Sig. (2-tailed)				.007					
	N				12					
In Game Competence	Pearson Correlation	.641*	-.735**				.702*	-.763**		
	Sig. (2-tailed)	.025	.006				.011	.004		
	N	12	12				12	12		
In Game Sensory and Imaginative Immersion	Pearson Correlation			.606*		.728**				
	Sig. (2-tailed)			.037		.007				
	N			12		12				
In Game Flow	Pearson Correlation					.826**	.761**			
	Sig. (2-tailed)					.001	.004			
	N					12	12			
In Game Tension Annoyance	Pearson Correlation			.578*				.802**		
	Sig. (2-tailed)			.049				.002		
	N			12				12		
In Game Challenge	Pearson Correlation		.578*					.635*		
	Sig. (2-tailed)		.049					.026		
	N		12					12		
In Game Negative Affect	Pearson Correlation					-.594*			.631*	
	Sig. (2-tailed)					.042			.028	
	N					12			12	
In Game Positive Affect	Pearson Correlation	.826**			-.594*		.681*			.709**
	Sig. (2-tailed)	.001			.042		.015			.010
	N	12			12		12			12
Post Game Positive Experience	Pearson Correlation	.761**				.681*				.634*
	Sig. (2-tailed)	.004				.015				.027
	N	12				12				12

3.2 Results for Women

Unlike men, there are some correlations that align with the literature regarding women. Most notably, there is a negative correlation between *ST* and *WS* [*r=-.524, n=21, p=.015*]. Moreover, women who played the game under stereotype threat gave a higher rate of agreement with the statement “Men are generally better in video games, compared to women,” with the correlation between *ST* and *MBW* [*r=.617, n=21, p=.003*]. However, there are no significant correlations between WB and WS in this case, but it is necessary to check for that correlation in the context of stereotype threat trigger, and not cumulative for all women.

WS had multiple positive and negative correlations with GSL, MBW, MEW, WUS, *and IGC,* with correlations [r=.674, n=21, p=.001], [*r=-.493, n=21, p=.023*], [*r=-.709, n=21, p<.001*], [*r=.525, n=21, p=.015*], [*r=.527, n=21, p=.014*].
GSL is in correlation with MEW, WUS, IGC, and *IGNA*, [*r=-.749, n=21, p<.001*], [*r=.666, n=21, p=.001*], [*r=.619, n=21, p=.003*], [*r=-.445, n=21, p=.043*]. *MBW* and *LLM* and *IGCH* are in the following correlations: [*r=-.564, n=21, p=.008*] and [*r=.445, n=21, p=.043*] respectively. There is a somewhat strong negative correlation between *MEW* and *IGC* [*r=-.522, n=21, p=.015*]. Furthermore, there is another somewhat strong correlation between *WUS* and *IGNA* [*r=-.446, n=21, p=.043*]. Table 2 showcases all previously mentioned correlations regarding female-identifying participants.

Table 2: Pearson correlations regarding female-identifying participants

		Weighted Speed	What is your general skill level	My character in game looked like me	Men are generally better in video games, compared to women	Both genders have equal chances to become good at games.	I think that women are more often exposed to uncomfortable situations compared to men while playing video games.	In Game Competence	In Game Challenge	In Game Negative Affect
Was the group that had Stereotype Threat trigger or not	Pearson Correlation	-.524*			.617**					
	Sig. (2-tailed)	.015			.003					
	N	21			21					
Weighted Speed	Pearson Correlation		.674**		-.493*	-.709**	.525*	.527*		
	Sig. (2-tailed)		.001		.023	.000	.015	.014		
	N		21		21	21	21	21		
What is your general skill level	Pearson Correlation	.674**				-.749**	.666**	.619**		-.445*
	Sig. (2-tailed)	.001				.000	.001	.003		.043
	N	21				21	21	21		21
Men are generally better in video games, compared to women	Pearson Correlation	-.493*		-.564**					.445*	
	Sig. (2-tailed)	.023		.008					.043	
	N	21		21					21	
Both genders have equal chances to become good at games.	Pearson Correlation	-.709**	-.749**					-.522*		
	Sig. (2-tailed)	.000	.000					.015		
	N	21	21					21		
I think that women are more often exposed to uncomfortable situations compared to men while playing video games.	Pearson Correlation	.525*	.666**							-.446*
	Sig. (2-tailed)	.015	.001							.043
	N	21	21							21

In regards to correlations dealing with GEQ, similarly to men, multiple correlations reaffirm the efficiency and accuracy of GEQ Serbian translation.
Finally, as already stated in this section, it is necessary to look at the results solely in case a stereotype threat is present. *WB* has no significant correlations with *WS*. However, there is an interesting negative correlation between *WB* and *MBW* [*r=-.603, n=12, p=.038*].

4. DISCUSSION

In this paper, the methodology and results of the pilot study are presented. The method employed a 2 x 2 matrix, where participants are divided into groups based on whether they play with a generic character or a lookalike avatar. Additionally, they are further divided into two subgroups: one exposed to a fake article claiming men are generally better than women in video games, and the other to a real article stating that women progress at least equally well compared to men when given the same amount. All 33 participants created a lookalike avatar. However, 17 participants played the game with the created lookalike avatar, and 16 played with a generic character, which aligned with their gender. The game itself is a simple infinite runner game that allows its players to go through the tutorial and choose their character, depending on the group.

4.1 Can the recently available technology that enables players to create custom avatars based on their own images be successfully utilized for this type of experiment?

There is a significant positive correlation between the players that belonged to the group that was supposed to play with a lookalike avatar and participants' grades on the level of similarity between them and the lookalike avatar, indicating that the platform Ready Player Me outputted a satisfactory result. Thus, the answer to the first research question is positive.

4.2 How does stereotype threat impact players' in-game performance?

When looking at all participants, there is no significant correlation between the condition of stereotype threat and weighted speed of the participants; there is a somewhat significant negative correlation between the results of the Game Experience Questionnaire in the section of In-Game Competence and the

condition of stereotype threat, when there is stereotype threat present. These results may indicate that stereotype threat has some negative impact on participants' perceived performance. Finally, the answer to the second research question cannot be answered confidently from this pilot experiment.

4.3 Is there a correlation between the higher impact of stereotype threat and gender?

The trend of no significant correlations between the stereotype threat condition and in-game performance, measured through the weighted speed, continues when looking at the results for male participants. However, the opposite is true for women. The negative correlation between the weighted speed and stereotype threat condition means that if the women were in the group that had stereotype threat triggered through the fake article, they performed worse. In order to further support this correlation, there is a positive correlation between the weighted speed and self-reported general in-game skill.
Since self-reported general in-game skills did not go into the equation while calculating weighted speed, this is a good indicator of the participant's ability to judge their gaming skills. Moreover, there was no significant correlation between the self-reported general in-game skill and stereotype threat condition. These results indicate that stereotype threat has the potential to impact performance for women, which is not the case for men, providing the answer to the third research question. Finally, it is important to mention that there was a positive correlation that occurred between stereotype threat conditions and whether women think that men are generally better at video games than them. This result could indicate the following:

1. women believed the article and/or
2. women's confidence in their gaming performance was influenced by the article.

From this pilot study, it is not possible to conclude which one of these two statements is correct.

5. CONCLUSIONS

Following the existing literature on stereotype threat impact to users of interactive media, this paper presents the methodology and results of a pilot study which included 33 participants, from diverse background when it comes to gaming experience.
The methodology followed the 2 x 2 matrix design, differing from other research by adding a 3rd dimension, gender. In order to conduct the experiment, a simple game was developed that employed a mechanic of infinite runner with obstacles and in order to implement custom character creation, a Ready Player Me SDK was used.
Results indicate that the Ready Player Me platform was performing well enough for this kind of study despite it offering highly stylized characters instead of realistic ones, answering the first research question. Furthermore, the diversity of the participants when it comes to previous gaming experience was mitigated using formula (1) and further presented a non-issue.
This pilot study was able to answer two out of the three research questions. Looking at the answer to the third research question, it can be concluded that this experiment design is able to induce some level of stereotype threat in participants identifying as women, while the same cannot be said in regards to ones identifying as men. Another positive conclusion is that this type of experiment can be conducted in regions outside the English-speaking ones if the materials used in the experiment are adequately translated.
In future work, this pilot study should be expanded to a larger number of participants since the current participant pool represents around 15% of the ideal participant number. Furthermore, due to the results of this pilot experiment indicating that there were no significant impacts from stereotype threat on male participants, future studies should focus on working with participants who identify as women. Finally, the results discussed as a part of the third research question can act as a green light for future studies on the topic of lookalike avatars and their impact on users of interactive media.

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FROM SKETCH TO ANIMATED 3D MODEL: THEATRICAL COSTUME DESIGN

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Abstract: *Theatre costume design is a demanding process that requires the collaboration of the play's creative team, including the director and performers. Traditionally, the process involved phases such as sketching, tailoring, sewing, and fitting. Nowadays, these phases have been transformed through digital reconstruction, clothing simulation, and motion-tracking tools. This paper aims to illustrate the theatrical costume design process using Tibor Vajda's play Pygmalion as a case study and to explore how modern technology can breathe new life into the process. The study examines the costume design workflow, from the initial sketching to crafting costumes that meet the play's specifications. The characters' costumes were redesigned using Marvelous Designer, and the movement of Miljana Kravić's character Eliza Doolittle was recreated using motion-tracking achieved with Wonder Dynamics. The result of this approach was a Blender animation that could serve as a costume-fitting preview for the creative team. This study provides insights for future projects, including the potential for three-dimensional theatrical productions emphasizing performers and scenography along with costumes, especially for plays that have been withdrawn from the repertoire.*

Key words: Theatrical Costume Design, Eliza Doolittle, Marvelous Designer, Wonder Dynamics, Blender

1. INTRODUCTION

This paper explores different points of view on theatrical costumes, explores the process of gathering and digitizing costume sketches and emphasizes a successful collaboration with the Theatre Museum of Vojvodina and its curator and former director Zoran Maksimović. Furthermore, it discusses the digitalization of the costume and its subsequent reconstruction using Marvelous Designer, a 3D garment simulator. Following the costume recreation, an authentic video clip featuring the costume was obtained and utilized to track the movements of the actress Miljana Kravić wearing the costume. Tracked movement was then remapped to the 3D costume recreation. The outcome of this process is an animated portrayal of the costume. The paper concludes by outlining the motion tracking and retargeting results and provides suggestions for future research.

We were wondering about the effectiveness of using low-quality video material for motion detection. Additionally, we were curious about Eliza Doolittle and how their character development impacted the costumes they wore. Specifically, the character of Eliza Doolittle in the play Pygmalion endures a transformation upon meeting the phonetics professor, Henry Higgins. They embark on an experiment where the professor teaches Eliza the proper accent and posture to present them as a 'lady'. During the first act, Eliza is attired in a more modest yet dynamic costume, which gradually transforms into a more refined one throughout the play. The literary piece was written by George Bernard Shaw and has undergone theatre and film adaptations, the most famous being *My Fair Lady* starring Julie Andrews as Eliza Doolittle and Rex Harrison as Henry Higgins, featuring costumes designed by Cecil Beaton. Andrews once expressed: '*It wasn't until I had Eliza's shawl on my shoulders and her silly broken hat on my head that I knew how I was supposed to act'.* Their statement accentuates the significance and influence of Eliza's costumes.

2. LITERATURE REVIEW

Costumes have attracted academic interest over the years (Barbieri & Pantouvaki, 2016). However, authors noted that the field is still in the early stages of development compared to the established ones. Moreover, authors pointed out that Elizabeth Goepp brought up the issue as early as in 1928, particularly emphasizing the ambiguity surrounding the field's terminology. In their research, Barbieri and Pantouvaki separated costuming from the practice of everyday dressing, reclaiming costuming as a preparation of the performer specifically for performance, echoing Goepp's view of costume as 'the stuff of which drama is made'.

ORCID numbers are provided at the end of the paper.

Costume is described as a performance articulation tool and a challenge to assumptions (Petranović, 2022), its 'critical' role was emphasized in questioning the relationships between body, design, and performance (Hann & Bech, 2014). Authors further explored this idea, viewing costume as an 'act of revelation and concealment' and agreeing with Aoife Monks that 'the costume is a body that can be taken off' (Monks, 2010). The costumes of the main characters are considered an important element of the stage performance (Bezruchko et al., 2024), they manifest the characters' personalities and backgrounds. In addition, costumes affect the portrayal of the characters and establish the tone of the play. Along with integrating the performer into the scenography (McKinney & Butterworth, 2015), the costume distinguishes between the performer and their environment. Furthermore, costumes are described as visual narrators shaping characters to serve the narrative (Academy of Motion Picture Arts and Sciences, 2004). Moreover, the interaction with lighting and scenography is highlighted (Macintosh et al., 2018), which contributes to the creation of the character's image. It is pointed out that the costume designer should work closely with the director, actors, and creative teams to achieve effectiveness. The imperative of 'performativity' is imposed on the costume in every production phase, from the rehearsal to the performance and even after (Barbieri, 2013). Opulence should not come at the expense of the performance. Furthermore, costume is considered a cultural phenomenon (Dembich, Zyrina & Fatkullina, 2021) that conveys and reinforces ideas and concepts. Value-communicating aspect of costume is highlighted (Wilson, 2003), arguing that when we dress, we carry an inscribed combination of art, social order, and personal statements on our bodies.
The progress of three-dimensional simulation technology for conducting garment simulations has been made (Porterfield & Lamar, 2017). The five main procedures typically involved in clothing CAD systems are: 2D pattern design, pattern prepositioning, virtual sewing, simulation, and 2D or 3D design modification. When the film industry started to show interest in 3D computer-generated imagery in the 1980s, research on virtual clothing 'began to gain momentum' (Spahiu, Shehi & Piperi, 2014). Currently, one of the most important examples of collaboration between IT and the fashion industry is the three-dimensional garment simulation (Kim, Kim & Park, 2017). The technique involves creating a 3D garment shape by applying different sewing conditions to flat pattern pieces. Additionally, the use of software to simulate three-dimensional clothing can accelerate the development of new garment pieces. Designers can visualize how a garment will look like on an avatar by digitally 'sewing' together 2D patterns, to reduce the need for prototyping and enhance team communication (Porterfield & Lamar, 2021). Motion capture is described as a process of recording the motion, processing it, and mapping it onto a virtual character (Reuter & Schindler, 2023). In this paper, a video clip of a play provided motion information, the task was to detect the main character and track their motion. Motion detection and tracking are often based on background estimation and subtraction (Uke & Thool, 2014). It is necessary to separate the moving objects from the background in each frame and consider variables involving object textures (Wang, Doherty & Van Dyck, 2000). The concept of digital theatre has been adopted, symbolizing the coexistence of performers and digital media (Andreadis et al., 2010).

3. METHODOLOGY

3.1 Phase One: Costume design sketches

During the first visit to the Theatre Museum of Vojvodina, several theatre costumes were discovered, including a collection donated by theatre director Tibor Vajda and costume sketches drawn by Tibor's associate, Anamarija Mihajlović. In 1976, they worked together on Tibor's play 'Who's Afraid of Virginia Woolf?' for the first time. Pygmalion was their final production together since Anamarija passed away in 2003. This was Anamarija's final engagement of this type, while for the then-young actress Miljana Kravić, who portrays the play's lead female character, Eliza Doollitle, it was their first role in the Kikinda theatre.
Anamarija Mihajlović is considered one of the first professional clothing designers in Yugoslavia. Mihajlović has designed fashion and stage wear since the 1970s. Anamarija was a member of the Association of Artists of Applied Arts and Designers of Vojvodina, which stated the following:

'*Anamarija Mihajlović always had a tendency to experiment, beginning each new project in their creative endeavors by reimagining the social purpose of clothing. The aesthetic never aspired to surpass the function of clothes. Because of these lasting qualities, their work is still highly valued*'. (UPIDIV, 2014)

During the second visit, photographs shown in Figure 1 of the costumes and costume design sketches were taken under the supervision of Milisanda Milović, curator of scenography, costumes, puppets, and art objects, to whom we owe a great debt of gratitude, as well as to Zoran Maksimović, the curator of the Theatre Museum of Vojvodina. Photographs were shot using a Nikon D3500 (18–55 mm) in daylight and without flash.

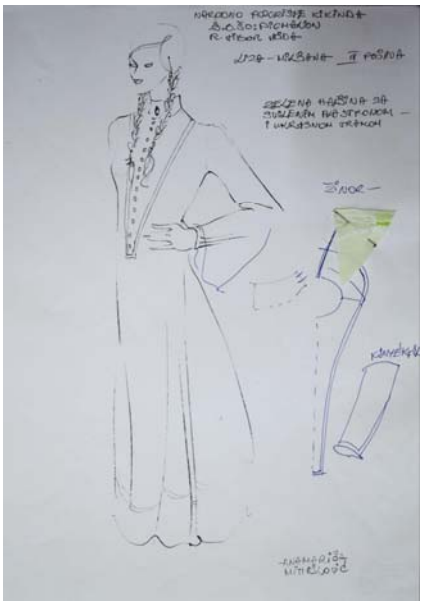
a  b 

Figure 1: Anamarija Mihajlović's a) costume sketch and b) a costume made for Miljana Kravić

3.2 Phase Two: Costume construction and redesign

For costume construction and redesign purposes, the Marvelous Designer 12 software (Marvelous Designer, 2024) was used, which enables the creation of 3D objects based on two-dimensional sketches. First, the contour line of the skirt was digitally drawn to recreate the left part of the costume, and a symmetrical duplicate was generated. Then, the plastron, which was going to be attached to the left and right elements of the outfit, was digitally reconstructed as a separate segment.

Subsequently, three distinct segments were created to function as the left pair of sleeves. To create the illusion of a puff sleeve, the bottom edge of the upper segment of the sleeve is wider than the upper edge of the middle segment. The ratio is the same between the middle and lower segments. The segments were symmetrically duplicated for the matching pair of sleeves. At this stage, the front of the costume was finished, and the back part was made as its modified duplicate. This was followed by the digital segment sewing. There is a counterpart for each selected edge, with which it is joined. Points have been added to divide the lengths into segments adequate for sewing. The detailed construction process and motives for the redesign were published in the thesis (Ilić, 2024), and the results are shown in Figure 2.



Figure 2: Reconstructed costume a) front, b) back, c) worn - front, d) worn - perspective, and e) worn - back

3.3 Phase Three: Theatre play video

A 'Pygmalion' play video clip was found on Miljana Kravić's YouTube channel, so we emailed them with the request to utilize it. Miljana approved our request and directed us to the existence of the entire video owned by Radio Television of Vojvodina, although it couldn't be obtained due to the digitization process. With its quality and the fact that all costumes are presented, such a video would influence the costume choice for redesign and animation. In this case, the costume with the most 'screen time' was picked (Kravić, 2011).

The costume of interest is in the frame from the sixth minute and 37th second to the ninth and 28th second, and in the tenth minute, from the 34th to the 40th second. Among the costumes that have been digitized in the Theatre Museum, this is the longest and provides the most video material to be manipulated with. The total presence of the costume is 177 seconds. The background and the movements of the camera also influenced the choice. The shots of the other costumes mostly involved a broad shot, more actors entering into interactions, and more complex scenography.

In the After Effects 2019 software (After Effects, 2024), it was first necessary to stabilize the video, utilizing the Warp Stabilizer effect, which neutralizes the shaking of the footage that occurs due to the absence of a tripod, handheld video recording, or slight camera movements. This step was taken to bring more stable footage to the platform and to make it easier to detect the actress in each frame and track their movements. The sharpening of the video was done utilizing the Sharpen and Unsharp Mask effects. The video segments were also subjected to colour corrections; to make a better distinction between foreground and background, the dominant tone on the frames was neutralized, and the exposure, contrast, and saturation were adjusted, as shown in Figure 3.

The recording was subjected to a free video upscaling solution, Video2X (Video2X, 2020), to increase the number of pixels available for motion detection.



Figure 3: 'Pygmalion' play video clip a) before and b) after the enhancements

3.4 Phase Four: Motion tracking

The costume was exported from Marvelous Designer along with the avatar wearing it. A generic avatar was utilized, as shown in Figure 2, and its armature was also exported for Blender 3.4 (Blender, 2024). Marvelous Designer allows avatar's measurement modifications. However, asking Miljana for their measurements was deemed inappropriate, particularly since this paper does not focus on that aspect. The costume and the avatar were imported in Blender, to get validated by The Wonder Studio Character Validator.

The Wonder Studio Character Validator add-on is installed in Blender 3.4 for motion tracking purposes. Its main function is to validate and ensure the model is compatible with the Wonder Dynamics platform (Wonder Dynamics, 2024). Selecting the character's skeleton is a mandatory validation step in the Select Body Elements section. The validation process consists of three steps: cleanup, validation, and warning. The Character Validation section manages the validation process and identifies potential problems. After the validation is passed, the add-on creates metadata and saves it in the metadata.json file, located in a folder named 01_wonder_studio_character_data, along with all the textures used to create the model. A validated character is then integrated into the Wonder Dynamics platform, accompanied by a video presenting the costume for motion detection and tracking.

After importing the video into the project, it is required to perform a frame scan in search of actors whose movements will be detected and used later. The platform detects and frames the recognized actors. Upon detection, the imported character is assigned to the actress by simply selecting it from the character list. The project is executed digitally and downloaded for further use. The motion detection results are imported into Blender as an .fbx file type, as shown in Figure 4. Facial expressions were not tracked, as the actress is engaged in a conversation and is facing Colonel Pickering.

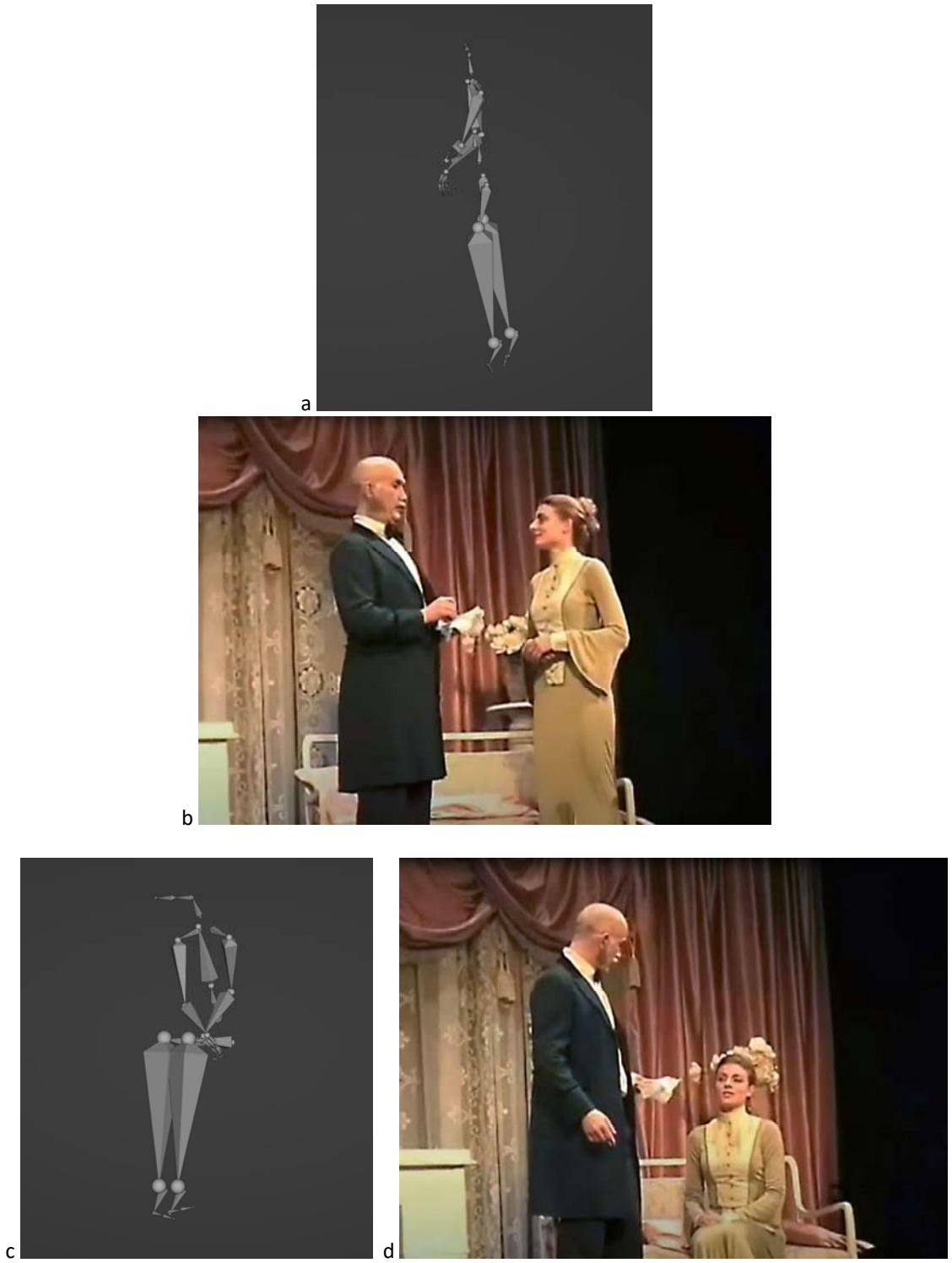


Figure 4: Wonder Dynamics results and references while a) and b) walking and c) and d) sitting

3.5 Phase Five: Animation

The movement redirection was done in Blender using the Auto-Rig Pro add-on that allows rigging and retargeting. It requires the import of a rigged model as the motion-remapping target skeleton and the import of the reference skeleton as the source.
The add-on allows matching them based on size, and within the bones section, it identifies the source and target bones. If the naming conventions don't match or the add-on makes an incorrect assumption, the bones can be manually adjusted. It is possible to exclude certain bones from the procedure, in this case,

fingers and facial bones. The sleeves covered most of the fingers, and facial bone movement wasn't tracked in the first place. The results of the remapping process are shown in Figure 5.

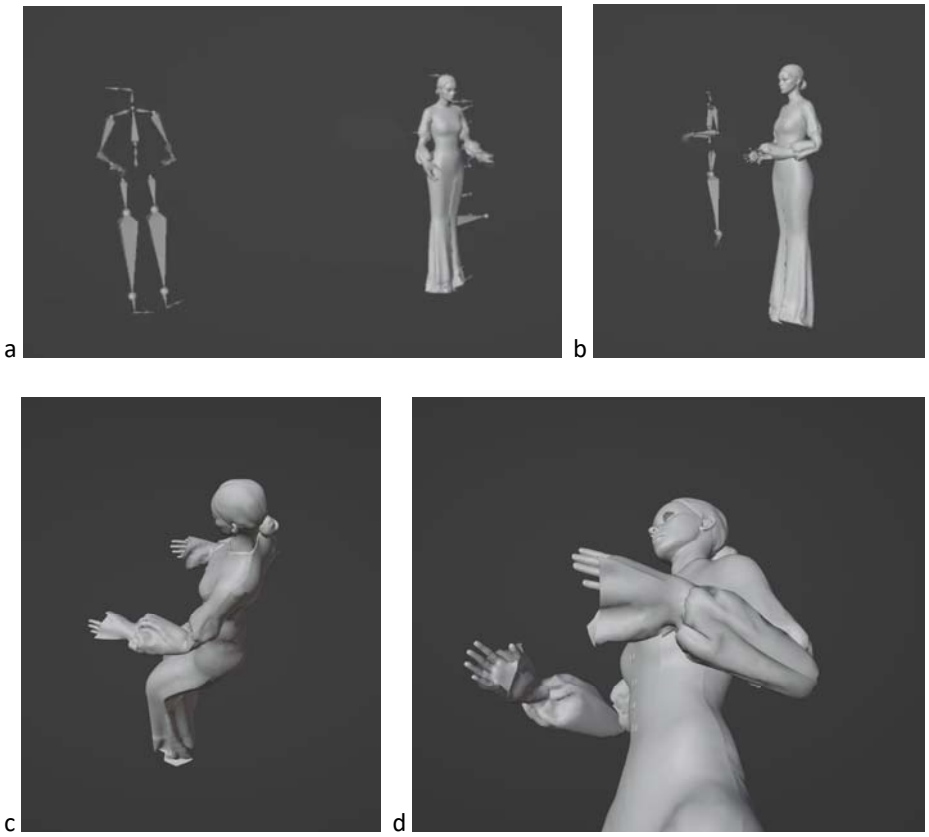


Figure 5: Remapping results a) side by side, b) side by side, c) above, and d) below

4. RESULTS

The final results include 400 frames of animated material in which the actress is continuously in the frame and is shown conducting a conversation in which her hands are the ones that move the most. The moments where Eliza and Colonel Pickering decide to sit down do not make it into the final animation, as the actress sits down holding the actor's hands. The actor's movements were not detected, so their interaction is excluded. The accomplishment of the Wonder Dynamics platform and the Auto-rig Pro add-on is shown in Figure 5. The remapping process went efficiently, considering that the same naming convention and the skeleton were used for tracking motion and then remapping it to the same but static skeleton of the avatar. However, the imperfections in tracking are noticed, shown in Figure 6, particularly on the right hand. These imperfections are assumed to be caused by the actress's position in the frame, shown in Figure 3. The actress is dominant in the frame, with their arms bent, gesturing during the discussion with the actor. The selected costume was chosen for this process because it appeared for the longest in the frame and was part of a simple stage setup. However, the results lack a distinction when the background and foreground of a video have similar colour tones. Additionally, the detection of the fingers was poor due to their distance from the camera and their size relative to the overall video. Stiff and motionless fingers detract from the authenticity. In the conversation between Eliza and Colonel Pickering, the actress's fingers were straightened and tense. In the final results, they are static and do not reflect active discussion. Furthermore, the lack of facial expressions enhance the impression of stiffness.

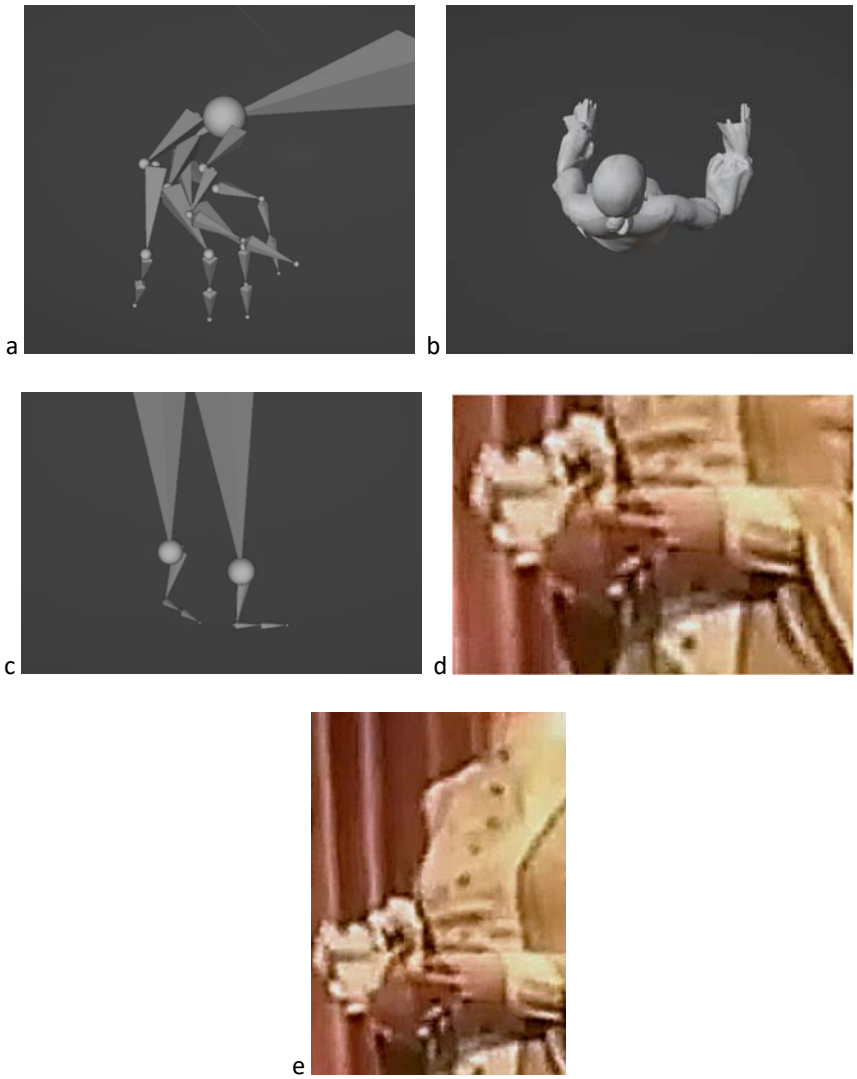


Figure 6: Imperfection shown on the a) fingers, b) right hand, c) feet, d) background and foreground (fingers), and e) background and foreground (right hand)

Since keyframes are remapped onto the costumed avatar, it is possible to manually modify the animation in Blender software to achieve better results. Especially in the case of the right hand shown in Figure 6, for which the platform predicts that it is further away from the body than it actually is. In the case of fingers, it is necessary to use a higher-quality video for motion detection and tracking, and they should be closer to the camera for better distinction. The same applies to the facial bones.

5. CONCLUSION

The lack of exhibition space forced the Theatre Museum of Vojvodina to store costumes in sacks, which was a key motivation for writing this paper. The paper deals with costumes that have already fulfilled their main purpose, aspiring to breathe new life into the play withdrawn from the repertoire. The employees are trying their best to maintain the museum's legacy through various projects and exhibitions, this was just our way to contribute to their cause.

The entire process was driven by the idea that it is possible to detect and track movement in a low-quality video. The results show that the outcomes differ depending on factors such as video quality, character movement, background and foreground, distance between the character and the camera, distance among the characters, etc. There is an opportunity to acquire a high-quality video of the performance from Radio Television Vojvodina in the future and repeat the procedure. It is also anticipated that the actress Miljana Kravić may be invited to provide insights on Eliza’s character.

In the future, examination of the minimal video requirements that can undergo motion detection, the impact of the background on motion detection, and identification of patterns that would optimize detection on smaller bones could be undertaken. The potential to experiment with creating various costume constructions in Marvelous Designer arises, along with the opportunity to use designed models to interact with lighting and cameras to create interactive experiences. Additionally, exploring the parameters for restoring old theatre recordings in After Effects, assessing the background and foreground in terms of contrast and sharpness, and studying the impact of colours on motion detection could be pursued in the future. Testing the parameters of motion detection in Wonder Dynamics and evaluating the platform's success in detecting characters without human skeletons, can be explored. Furthermore, assessing the success of motion detection under varying lighting conditions, and scrutinizing the relationship between characters and their environment, as well as detecting fluid or unconventional shapes, can be considered. This paper opened up technical questions and possibilities for the future and told the story of the costume that once lived.

6. ACKNOWLEDGMENTS

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MODELING OF A VIRTUAL PRINTING MACHINE FOR INTERACTIVE E-LEARNING APPLICATIONS

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Abstract: *The advancement of interactive e-learning platforms requires developing sophisticated simulation tools to enhance the educational experience. This study focuses on modelling a virtual printing machine designed for integration into interactive e-learning applications. The virtual printing machine aims to simulate the functionalities and operations of a real-world printing machine, providing students with a hands-on learning environment. Using advanced software engineering techniques, the virtual model replicates mechanical processes, operational parameters, and troubleshooting scenarios typically encountered in printing technology. This approach not only aids in comprehending complex printing processes but also promotes active learning and critical thinking. The effectiveness of the virtual printing machine is evaluated through user feedback and performance assessments, demonstrating its potential as a valuable tool in technical education. The findings suggest that integrating such virtual simulations in e-learning platforms can significantly enhance the quality of technical training and education.*

Key words: Virtual Printing Machine, Interactive E-Learning, Simulation, Technical Education, Software Engineering

1. INTRODUCTION

Distance learning proved its importance during the 2020 pandemic, but its relevance extends beyond that period. It also highlighted numerous shortcomings, demonstrating the need for continuous improvement to ensure better learning outcomes. Distance learning is a form of education where the main elements involve the physical separation of teachers and students during instruction and various technologies to facilitate communication between them. It has primarily focused on non-traditional students, such as full-time workers, military personnel, and individuals with family obligations, providing them the flexibility to pursue education while balancing other responsibilities. (Berg & Simpson, 2024). It usually emphasizes the lack of personal contact between participants as the greatest shortcoming of this type of learning (Kalamković, Halaši & Kalamković, 2012)

Distance learning also serves as an excellent complement to conventional education, allowing us to define a subgroup involving virtual spaces and machines. Virtual learning, including access to virtual classrooms where students can supplement their theoretical knowledge, provides a significant contribution to a deeper understanding of the material. Also, virtual learning drives students to collaborate among themselves and with professors, which creates a positive correlation between technology-based learning and active learning (Kuh & Nelson, 2005). The use of technology to aid in information processing and communication is not new. In fact, over the past 50 years, numerous technologies have developed exponentially, primarily due to the invention of digital electronics (Bušelić, 2012).

This paper presents a solution for an educational tool designed to provide students with access to a digital printing machine in a virtual space. Students who may or may not be physically present in the classroom can virtually access elements they do not have adequate access to in the real world. Even when a physical machine is available, only a few students can gather around it, meaning others lack a clear view, cannot hear the instructor well, or are unable to approach the machine due to the presence of their peers, leading to a quick loss of interest. Virtual access to the machine allows a large number of students to have unlimited access to the necessary information simultaneously. In education, VR offers significant support for learning. By using such systems, students can visualize abstract concepts, observe events from different perspectives and scales (for example, atomic and giant scales), visit environments, and interact with events remotely (Machado, Costa & Moraes, 2006). Some studies, through informal interviews with students, have shown that most enjoy and appreciate 3D environments (Dickey, 2005).

As emerging technologies, Augmented Reality (AR) and Virtual Reality (VR) have been widely applied in the education of various disciplines. (Huang et al., 2021). VR possesses much potential, and its application in education has seen a lot of research interest lately. It has mostly been a part of experimental and development work rather than being applied regularly in actual teaching (Radianti et al., 2020). Today's VR

ORCID numbers are provided at the end of the paper.

systems can run on a relatively cheap system like a desktop personal computer. Such a VR system is commonly known as a desktop VR, where users can interact with the virtual environment using their keyboard, mouse, joystick, or touch screen (Lee, Wong & Fung, 2010). A key feature of the VR experience is the possibility of actively interacting with the created environment (Mantovani, 2001).

Today's students, often referred to as digital natives, have been using technological devices since infancy. Their brains have adapted to a fast-paced, hypertext-driven, interactive environment, leading to cognitive shifts that influence their learning methods (Prensky, 2001). They don't just seek information and solve problems online; they engage with digital content through exercises, simulations, games, and virtual worlds. Rather than passive observers, they are active participants, taking control of learning materials while managing their own time and pace. This fosters self-agency, autonomy, and problem-solving abilities and helps them stay focused (Alt & Raichel, 2020).

The paper presents the development of an educational tool for the Roland Versa UV LEC540 digital machine, featuring its basic functions, which are animated and integrated into a web application to maximize student access. The key animated actions include loading ink into the machine, printing, die-cutting, and cleaning the print heads. The machine's modelling process was conducted according to a precise schedule and well-defined components, considering the actual machine's operation, including the movements that need to be animated and the parts that would move and be displayed. Following the modelling phase, animation was applied, involving both the camera and the machine's moving parts. To enable interactivity within the application, separate 3D animations are created, which can be activated by the user through the web interface. The user selects which part of the machine to activate or which function to view. After viewing the animation, the user can repeatedly activate specific machine functions to understand the device's operation better. This method provides insights that are not easily achievable through traditional learning and are often difficult to comprehend. Additionally, the virtual machine cannot malfunction, pose any danger to the user, or consume expensive resources such as paper and ink to demonstrate its functionality.

2. DEVELOPMENT OF ANIMATION FOR EDUCATIONAL PURPOSES

The animation is divided into four main parts, which are integrated into a single educational tool, forming a unified whole that simulates the operation of the printing machine. Separate animations are created for loading ink into the machine, printing, die-cutting, and cleaning. Additionally, individual animations are made for the camera, which will provide the best view of the specific part of the machine performing its respective function at any given moment. Each camera for the selected machine operations follows a unique path, as shown in Figure 1.

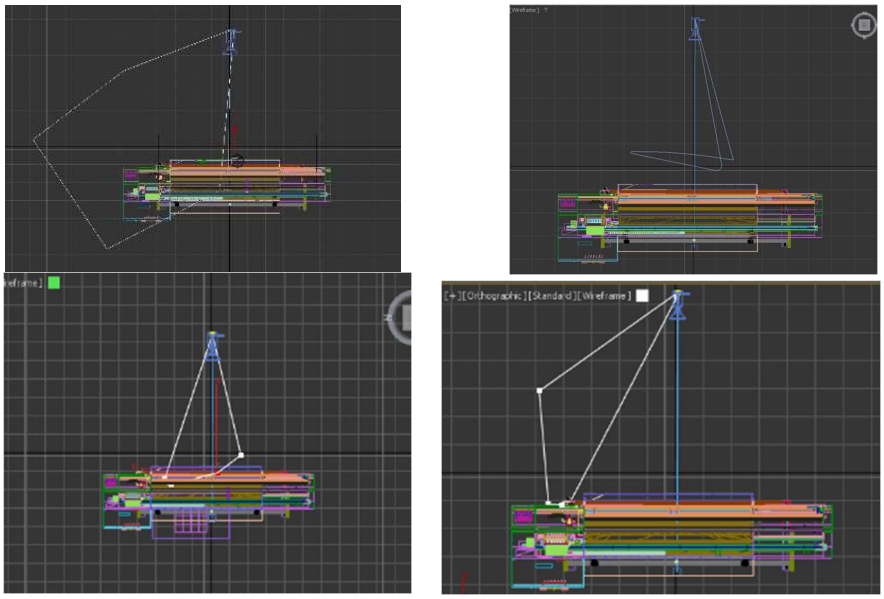


Figure 1: The different camera paths are designed to provide a detailed view of the specific part of the machine performing a given function at the precise moment

Video animations start and end with the same initial/final frame to ensure a smooth transition between animations without interruption (Figure 2). Special attention is paid to each camera path to avoid sudden turns and stops so that the movement does not appear abrupt or unexpected to the viewer.
Before starting each animation, it is necessary to set the appropriate number of frames, i.e., the duration of the animation in seconds. The initial frame count for each animation was set to 1,000 and was adjusted as needed, depending on the length of the machine operation being simulated, which is best assessed during the animation creation process. In addition to the animation duration, the frame rate must be set. Each second must display a minimum of 24 frames to ensure smooth movement. This frame rate is considered optimal for producing a natural and pleasant sense of motion for the viewer. For these animations, the frame rate was set to 30 frames per second. Each animation segment is planned so that none of them are excessively long, maintaining the viewer's concentration at its peak.

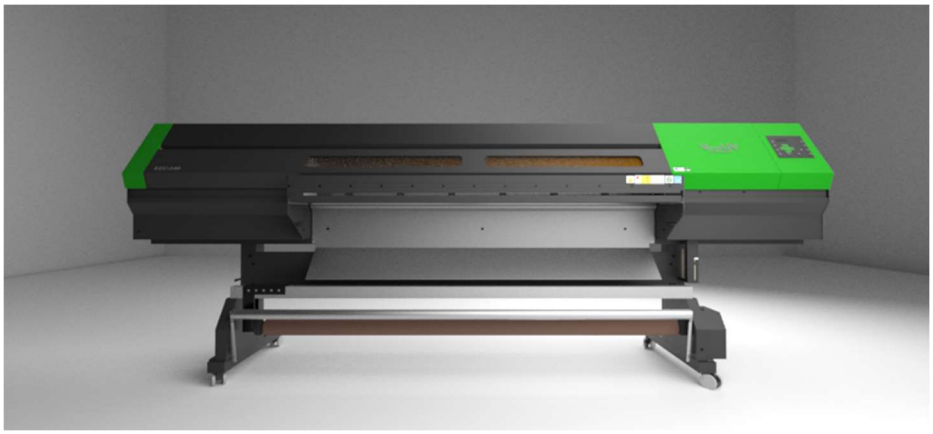


Figure 2: Display of the initial and final frame of each animation

Each animation has something unique that sets it apart from the others, whether the duration or the animation technique used. The first animation is the shortest and relatively simple compared to the others. The camera has only one stop and focus point. It pauses at the rear part of the machine where the ink is loaded, remaining stationary until the ink-loading sequence is complete. The rear doors open, and their rotation is animated around a single axis. Like the camera, they stay open until the ink is inserted. The cartridges are animated to move into the machine, and once the doors close, the camera returns to its initial position.
The second animation is notable for depicting the printing process. To show the printing or the gradual appearance of the image with each pass of the print head over the paper, an additional animation is created to display the image progressively. This is done in a separate program that produces a 2D animation, where the logo appears incrementally every 10 seconds (Figure 3).

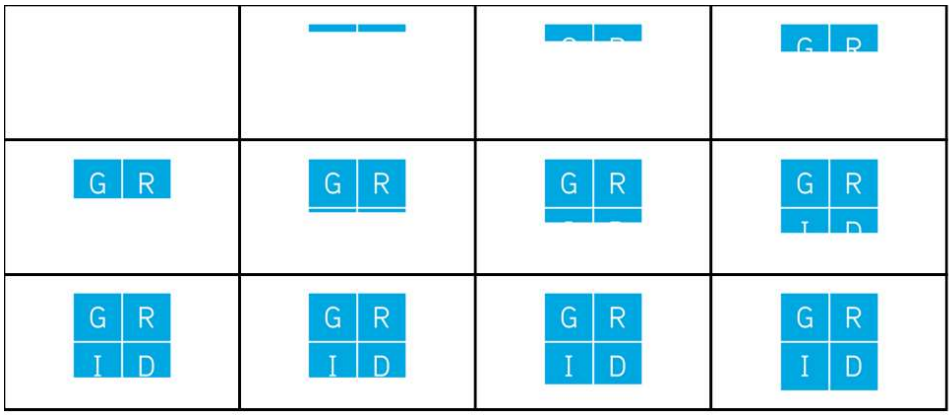


Figure 3: Animation of print appearance on paper

The 2D animation created in this manner is imported into a 3D program as a material. In order to be used as a material, it must be saved as a sequence of images. Once the animation is obtained in the form of a material, it is applied to an object representing paper. Throughout the entire printing animation, the camera focuses on the printing table, where, before displaying the paper itself, the stopper's placement is shown. During the printing animation, care must be taken to position the print head above the paper at the appropriate moment, making it appear that the image is being printed as the head moves across. It should also be noted that once the paper animation is imported into the 3D software, it cannot be modified, meaning the 3D animation must be adapted to the paper animation.
The die-cutting animation is similar to the printing animation, except in this case, the gradual appearance of the image is not animated, it already exists as the bottom layer beneath the printed image. It is essential to demonstrate what is achieved through die-cutting, precisely how the paper is partially cut. In this case, the process is shown through an animation where separate objects, the paper and the sticker, are created. These objects appear connected during the tool's scoring process, after which it becomes easier to show how the two models separate. It is crucial that they maintain the same position and that their movements are synchronized so as not to reveal any difference between the objects.
For the printhead cleaning animation, the right-side door must be opened. Under normal circumstances, this door typically remains closed since the cleaning process can only occur when the machine is sealed. It is important to emphasize that this function cannot be observed live during operation, as it takes place within a closed system. The camera focuses on the printheads, and to demonstrate the cleaning process, the protective barrier over the printheads is also removed.
The cleaning process involves sponges within the machine being raised to absorb excess ink from the heads, after which they must be lowered (Figure 4). Once the sponge has absorbed the excess ink, the printhead moves to the squeege located next to the sponge. The squeege moves back and forth to thoroughly clean the printheads. To adequately represent the motion of the squeege, it is not sufficient to merely adjust the camera's target position; the camera itself must be rotated during the shot. The printheads are cleaned two at a time, so the animation should be structured accordingly.

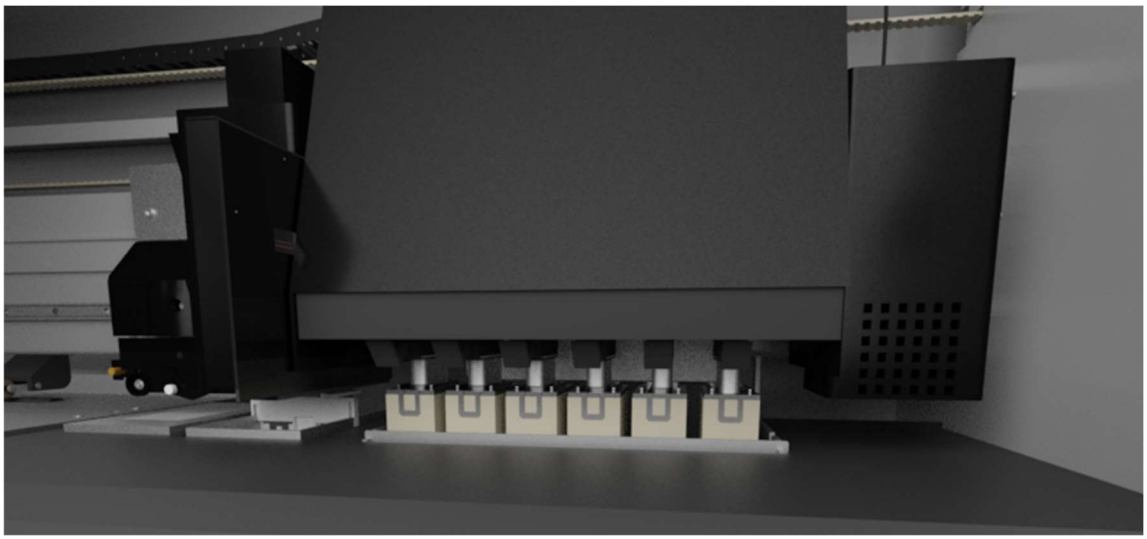


Figure 4: Display of printheads during cleaning

After cleaning, the camera moves down towards the waste container where the excess material is collected, showing the path the ink takes during the cleaning. The camera remains focused on the container for a few seconds before returning to its original position, during which the doors and screws are also returned to their proper places.

3. INTERACTIVITY

The animation is rendered from the 3D program as a sequence of images, which are then combined into a video using Adobe After Effects (Tables 1-3). The individual videos are rendered separately and then

combined in the web application. It is important to ensure that the beginning and end of each animation align perfectly to avoid discontinuities in the video sequence.
In the program, a composition is created with the same dimensions as the animation (800x600), and the frame rate is set to 30 frames per second. The image sequence is imported into the program and placed within the created composition. The resulting video is then added to the render queue to be processed in the appropriate format. The format generated this way is .avi, and additional software or extensions are required to convert it into .mp4 format.
Once each animation has been converted into a video, it must be merged into a single interactive video, which begins in the same way as each animation – with the first frame. The application is formed by defining a reference to a tag in the HTML itself, *initialVideoRef,* and the HTML will always display the initial frame of the animation, as later shown in the code as: *<video ref={initialVideoRef} controls={false}>.*

Table 1: Reference creation for the initial tag

```
const [video, setVideo] = useState<string>('');

const initialVideoRef = useRef<HTMLVideoElement>(null);
const stampaVideoRef = useRef<HTMLVideoElement>(null);
const bojaVideoRef = useRef<HTMLVideoElement>(null);
const ciscenjeVideoRef = useRef<HTMLVideoElement>(null);
const ricovanjeVideoRef = useRef<HTMLVideoElement>(null);

const playVideo = (name: string) => {
  setVideo(name);

  switch (name) {
   case 'stampa':
     stampaVideoRef.current?.play();
     break;
   case 'boja':
     bojaVideoRef.current?.play();
     break;
   case 'ciscenje':
     ciscenjeVideoRef.current?.play();
     break;
   case 'ricovanje':
     ricovanjeVideoRef.current?.play();
     break;
   default:
     break;
  }
 }
```

In addition, four more video tags are defined, one for each animation. The displayed portion of the code also includes a div tag containing buttons necessary for starting the animations. When each button is clicked, the *playVideo* function is called, which receives the name of the animation to be played as a parameter. Upon the completion of each animation, the *endVideo* function is invoked, setting the state so that no animation is active. Based on whether a specific animation is active, the CSS class of the video tag (*className*) is applied to determine whether the animation should be displayed or hidden.

Table 2: Display of the animation code

```
const endVideo = () => {
   setVideo('');
 }
 return (
   <div className='container'>
     <div className='image'>
      <video ref={initialVideoRef} controls={false}>
        <source src='./videos/Stampa-1.m4v'
type='video/mp4' />
      </video>
      <div className='button-container'>
        <button onClick={() =>
playVideo('boja')}>Ink</button>
        <button onClick={() =>
playVideo('stampa')}>Printing</button>
        <button onClick={() =>
playVideo('ricovanje')}>Die-cutting</button>
        <button onClick={() =>
playVideo('ciscenje')}>Cleaning</button>
      </div>
     </div>
     <video ref={stampaVideoRef}
onEnded={endVideo} controls={false}
className={'video ' + (video === 'stampa' ? 'show' :
'hide')}>
      <source src='./videos/Stampa-1.m4v'
type='video/mp4' />
     </video>
     <video ref={bojaVideoRef} onEnded={endVideo}
controls={false} className={'video ' + (video ===
'boja' ? 'show' : 'hide')}>
      <source src='./videos/Boja-1.m4v'
type='video/mp4' />
     </video>
     <video ref={ciscenjeVideoRef}
onEnded={endVideo} controls={false}
className={'video ' + (video === 'ciscenje' ? 'show' :
'hide')}>
      <source src='./videos/Ciscenje-1.m4v'
type='video/mp4' />
     </video>
     <video ref={ricovanjeVideoRef}
onEnded={endVideo} controls={false}
className={'video ' + (video === 'ricovanje' ? 'show' :
'hide')}>
      <source src='./videos/Ricovanje 1-1.m4v'
type='video/mp4' />
     </video>
   </div>
  );
}
```

To achieve the desired appearance of the animation, CSS code is created to define the properties of the HTML elements. The position of the buttons is set relative to the top of the animation, and the animation itself is centred in the window, which is reflected in the code with justify-content: centre and align-items: centre;

Table 3: Display of animation setup in the window and css code

```
.container {
  width: 100%;
  height: 100vh;
  display: flex;
  justify-content: center;
  align-items: center;
}

.container .image {
  width: 800px;
  height: 600px;
  position: relative;
  border: 1px solid black;
  z-index: 0;
}

.container .video {
  width: 800px;
  height: 600px;
  border: 1px solid black;
  z-index: 2;
  position: absolute;
}

.container .show {
  display: flex; }
```

```
.container .hide {
  display:

.container .button-container {
  width: 650px;
  position: absolute;
  top: 95px;
  right: 71px;
  display: flex;
  justify-content: space-evenly;
  align-items: center;
  z-index: 1;
}

.container .button-container button {
  height: 40px;
  width: 140px;
  border: 2px solid white;
  background: transparent;
  color: white;
  font-size: 24px;
  cursor: pointer;
  border-radius: 10px;
}
```

After all the previously described steps, the final appearance of the interactive animation, which runs locally, is obtained. The initial frame of the animation is shown in Figure 5.

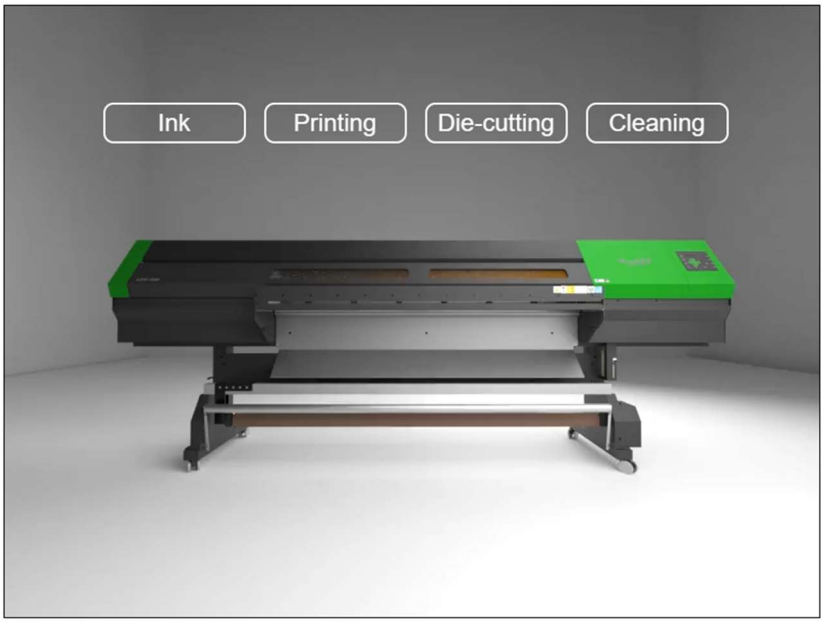


Figure 5: Initial frame of the interactive web application

The previous steps create an interactive web application that can be run locally or on a publicly hosted website with a domain. When the application is launched, the initial screen displays either the first or last frame of the animation. Above the machine, buttons are indicating which animations can be started, and clicking on a button triggers the desired animation. This allows each video to be played unlimited times, making them appear as a cohesive unit within the application.

4. CONCLUSIONS

The animation of various jobs, sciences, and engineering fields provides access to objects that people do not typically have the opportunity to observe in their daily lives. This paper focuses on the principles of digital printing technology and its operation animation. By visualizing the functioning and features of digital inkjet printing machines, the animation offers many individuals the chance to learn and gain a deeper understanding of how such machinery operates.

Through these animations, users are enabled to acquire a clear insight into how different components and processes work together. This enhances users' comprehension and knowledge and contributes to improved training and preparation for working with complex technologies. Moreover, animation enriches the learning process and opens new avenues for exploration and innovation.

This application, as defined, allows for online deployment without requiring installation on personal computers. The number of visitors is limited only by server capabilities, enabling unrestricted use in educational settings and as a supplementary resource for home learning.

Future work will include optimization for mobile platforms, which are expected to become the preferred mode of learning over traditional computers among younger users

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ILLUMINATION WITH ELECTROCHROMATIC WINDOWS IN VIRTUAL REALITY

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Abstract: *Electrochromatic materials are characterized by reversible colour change when placed in an external electric field. One of the possible applications of such electrochromatic films is in the "Smart windows" that are used to modulate the transmitted light in objects. Thin electrochromatic films of copper oxide are obtained by the chemical deposition method of two solutions. The spectral transmission of the resulting films was recorded in a state as obtained, in a coloured and shaded state, in the visible part of the spectrum. From the sum of the intensity of the incident solar spectrum AM 1.5 and the amount of intensity of the spent radiation through the films, the mean values of the transmission coefficient of the films in the three states are determined, in the wave interval from 350 to 820 nm. The obtained results for the mean value of the transmission coefficient are used to simulate the illumination in the virtual reality, to a real object in which the outer illumination is modulated when passing light on the case when the windows would be examined films in the state as the film was obtained, in a coloured and shades condition. The simulation of the process is using Quest3D software for virtual reality.*

Key words: Electrochromic materials, copper oxide, virtual reality, 3d model, illumination

1. INTRODUCTION

Electrochromatic materials are characterized by the change in their optical properties, when small ions and electrons are brought or taken in the presence of an external electric field. The optical properties of electrochromatic materials are reversible, i.e. by changing the polarity of the applied voltage, the material returns to its initial state. Optical changes occur when applying a low-power electric with low voltages from one volt to several volts. A large number of materials, organic and inorganic, in liquid or solid state, that have electrochromic properties (Granqvist, 1995). In recent decades, the properties of these materials have been widely explored for the possibility of their use in different optical devices. The electrochromatic properties of various materials depend on the method of their production, with great influence of the structure, stoichiometry, the presence of water in the film. When describing the electrochromatic properties of a material, a detailed description of the procedure for obtaining it should be given. Electrochemical properties also show thin films from CuO, Cu_2O (Neškovska et al., 2007; Ristova et al., 2007; Ristova et al., 2015). These films can be obtained by different methods: thermal oxidation at lower or higher temperatures, electrode deposition, dispersion, anode and chemical oxidation of a copper plate and others. In order to see the optical changes occurring in electrochromatic films when changing the polarity of the outer field, the films should be deposited on a transparent conductive substrate. Thus, the methods for producing thin copper oxide electrochromic films are limited by the substrate on which they are deposited. In this scientific work, the films were deposited on glass substrates by the chemical deposition method of two solutions (Ristov et al., 1985). After that, an electrochromic test device was constructed to record the transmission coefficients of the films in the visible part of the spectrum in the interval of the wavelength of the fallen radiation from 300 to 850 nm in a state as obtained in a coloured and shaded state (Ristova et al., 2007).
Furthermore, the absorption coefficients of the film were calculated in the three states and the obtained results were used to determine the intensity of the transmitted radiation that passes through the films and the mean value of the transmission coefficients, and for the fallen radiation the solar spectrum of AM 1.5 was taken. The mean value of the transmission coefficient for the three states of the film is taken to simulate the illumination of the interior of a real object, when the existing windows would be the examined electrochromic films in the state as they were obtained in a coloured and shaded state. The simulation is using Quest3D virtual reality software. In this model, a virtual environment of a realistic model of the sports hall in Skopje was made. The hall is 40m x 20m, which includes a panel for 500 spectators. To create virtual environment, the following steps were made: collect data from the real model (appearance, dimensions), creating the same model in 3D Studio Max, importing models in the

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virtual reality software Quest3D and connect the models with the appropriate channels and their programming.

2. EXPERIMENTAL RESEARCH

Films from Cu_2O were deposited on glass substrates over which a transparent film of tin oxide doping with fluor was applied, SnO_2: F, also known as FTO, which also serves to store ions. For this purpose, the clear glass was heated to 400 °C and was sprayed with 300 ml of a 0.05 M aqueous solution of tin (II) chloride dihydrate ($SnCl_2 \cdot 2H_2O$), in which were added 2.4 g crystals of ammonium fluoride, NH4F, to obtain a solution with pH ~ 7 (Ristov et al., 1997). The preparation was sprayed with BOSCH Type 0603 260 403 sprayer. In this way were obtained homogeneous, conductive FTO substrates with a resistance of 18-40 Ω/cm^2, with a white light transmission of about 80% and a thickness of about 2 μm (Ristova et al., 2007).
On them were deposited thin films of copper (I) oxide following the method of chemical deposition (Ristova et al., 2015). In the process of obtaining the films, a cold and warm solution was used. For the deposition of several films with a thickness of less than 1 μm, 200 ml of the cold solution were enough, prepared from 20 ml of a 0.5 M solution of copper sulphate $CuSO_4$, in which gradually added 1 M solution of $Na_2S_2O_3$ (sodium thiosulphate) and getting a colourless solution. Then, a complex solution of $3Cu_2S_2O_3 \cdot 2Na_2S_2O_3$ was obtained. This complex solution was supplemented with distilled water to 200 ml. The hot solution was 200 ml of 2 M sodium hydroxide solution, NaOH, which was heated and maintained at a temperature of 60-80°C. Clean glass tiles with FTO base alternately submerged 1-2 sec. in hot and cold solution, until films with desired thickness were obtained. According to the method of chemical deposition (Ristov et al., 1985), every ten indigenous immersions give a film with a thickness of 100 nm. The films examined in this scientific work were with a thickness of 150 nm.
For research on the electrochromatic properties of thin films from copper(I)oxide, was constructed electrochromic test device with working electrode from glass substrate/FTO/ Cu_2O film and a glass substrate/FTO film as the opposite electrode. The electrodes were immersed in a liquid electrolyte of a 0.1 M aqueous solution of sodium hydroxide, NaOH. There was a small voltage across the electrodes.

3. RESULTS AND DISCUSSION

Transmission, reflection and absorption, as well as emission, are optical characteristics that can be measured experimentally and from the obtained values some conclusions can be done. The coefficient of transmission of electrochromatic films is change with the state of the film, ie it is different in the shaded and coloured state. In this study, the coefficient of transmission of films in the visible part of the spectrum was recorded in the interval of the wavelength of the fallen radiation from 300 to 850 nm, in a coloured and shaded state. The measurements were performed using the Varian Cary 50 Scan UV-Visible Spectrophotometer. The colouring and shading of films was performed with a voltage of -4 V and +4 V, respectively.

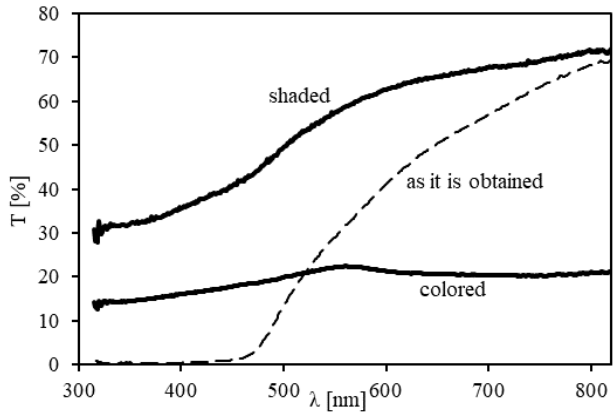


Figure 1: Dependence of the transmission coefficient of the wavelength, in the visible part of the spectrum, for a film of copper(I)oxide, obtained with method of chemical deposition

The intensity I(λ) of radiation passing through a film with thickness d and absorption coefficient α(λ), with the intensity I0(λ) (Figure 2) of the fallen radiation is related to the Equation (1):

$$I(\lambda) = I_0(\lambda) e^{-\alpha(\lambda) d} \tag{1}$$

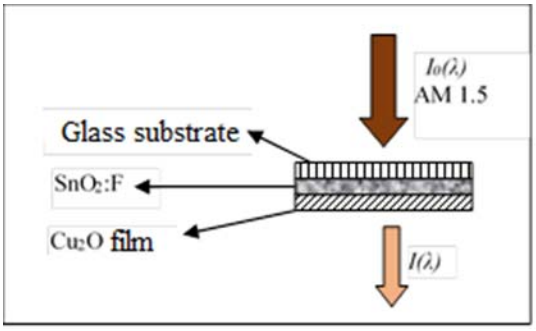


Figure 2: Schematic of modulation of the light

In calculating the intensity of radiation I(λ) through the films of the solar spectrum AM 1.5 was taken for a fallen rays. AM 1.5 gives the distribution of solar spectral irradiance (diffuse and direct) that comes to a surface located at 0m elevation at an angle of 37°, at 14.2 mm water vapor and 3.4 mm ozone (Smith et al., 2016).

Then, from the ratio of the sum of the spectral dependence of the irradiance I(λ) on the modulated radiation and the sum of the spectral dependence of the fallen radiation I0(λ), was defined the mean value of the transmission coefficient according to the Equation (2):

$$\overline{T} = \frac{\sum_{350}^{820} I(\lambda)}{\sum_{350}^{820} I_0(\lambda)} = \frac{\sum_{350}^{820} I(\lambda)}{520\ \mathrm{W/m^2}} \tag{2}$$

The intensity of the spent radiation is in a wave interval of 350 to 820 nm. The film have a value of 182.41 W/m^2, for the coloured state the value is 104.02 W/m^2 and for the shaded state W/m^2. The sum of the intensity of the fallen radiation in the same wave interval is 520 W/m^2. For the mean value of the coefficient of transmission in the same wave interval, for the condition in which the film is obtained, in the coloured and shaded state, the values are 35.08%, 20.0% and 57.60%, respectively. From the presented results it can be concluded that films of copper(I)oxide are suitable for modulating the infrared radiation in the visible part of the spectrum.

A graphic representation of the dependence of the intensity of radiation through the films as a function of the wavelength of the fallen radiation is given in Figures 3, 4 and 5.

The obtained results for the mean value of the transmission coefficient in the three conditions of the film, were used for simulation of the interior illumination of a real object, a sports hall in Skopje, when the existing windows would be examined as electrochromic films in the state as they were obtained, in coloured and shaded condition. The hall is 40 m x 20 m, which includes a panel for 500 spectators. The simulation was made using the virtual reality software Quest3D. Only external lighting was taken and the interior was switched off.

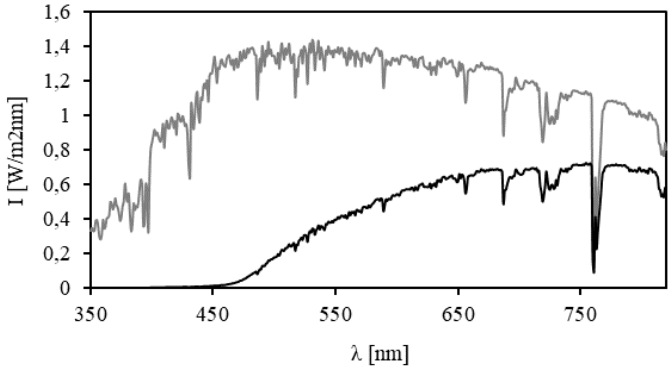


Figure 3: Iradiation I in terms of I0 for chemical deposited film, in a state as it is obtained

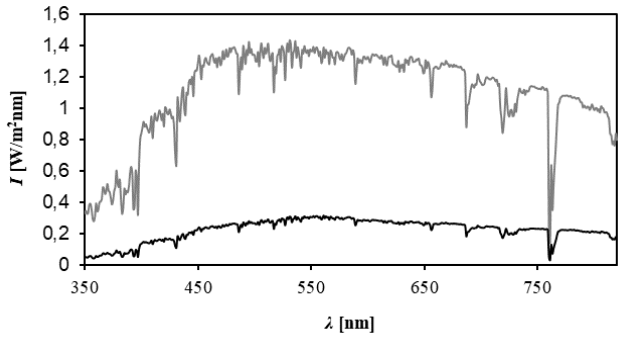


Figure 4: Iradiation I in terms of I0 for chemical deposited film, in coloured state

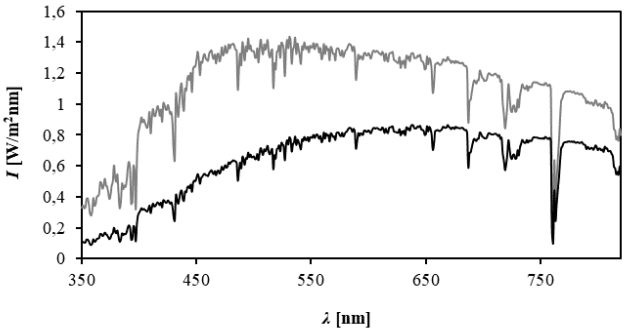


Figure 5: Iradiation I in terms of I0 for chemical deposited film, in shaded state

For creating a virtual world, we need 3D models that are developed in a suitable software package like 3DS Max, Maya, Archicad. These 3D models are exported in some virtual reality software and build virtual environments.

Quest3D is an extensive software package for creating interactive 3D scenes. It is characterized by a unique programming style. Quest3D working environment is in real time. It works directly on the virtual environment and any change in it is available. In Quest3D there are also ready-made schemes. They are predefined channels or group of channels. 3D objects are very important and can be import from external 3D modelling packages, such as 3DS Max or Maya (Popovski et al., 2014). Quest3D runs on Windows operating system. Its requirements are a more core processor, a minimum of 1 GB of RAM and a good graphics card that supports DirectX 10. It supports a large number of 3D formats, 2D formats, video and audio formats.

For the development of the 3D model, first of all was completed the data for the real object according to which the model was prepared. Then all the necessary data, dimensions, colours were completed, which started the creation of textures for the given model. Each of the textures are worked in Autodesk 3D Studio Max and then imported into the virtual reality software Quest3D.

For the needs of this research, was used 3D model developed in 3D Studio Max. The construction of the sports hall is a process in which each separate element is drawn as a separate polygon, so that later all

the polygons can be joined and the 3D look of the hall is done. 1062 special polygons were made and later fit into a single whole. On each of these polygons was applies to get the final look of the sport hall.
After completing the process of modelling objects in 3D Studio Max, there was preparation for import into Quest3D. Before importing each object, it is necessary to make a triangulation. Triangulation is a process of dividing polygons that are determined by four or more points, on three-point polygons. The next step is to export each object separately in Quest3D in a format acceptable to this software. The native format in which files are stored in 3D Studio Max and are exported to Quest3D is (.X) format. This format to be visible in the 3D Studio Max menu, there are exporters called kW x-Port that can export objects. For manipulating with objects in the virtual environment, it is best to keep each object separately. Then each element in the scene is connected separately to the render and virtual environment is visible. Then start the process of shadowing and texturing of objects. The quality of the rendering depends on the type of material used in the scene, visual components such as the colour, glossiness, transparency and surface to which it is applied, which determines how much it absorbs or reflects light. Adding textures to all surfaces provides a highly realistic virtual environment.
Figure 6 shows a comparation of the real and virtual model of the sports hall. Figures from 7 to 10 shows simulations of the interior illumination of the sport hall in daylighting and the same are modulated when passing through the windows of the sports hall, when they have electrochromic film in a state as it is obtained, in a coloured and shaded condition. In the four cases, the interior lighting is off.



Figure 6: Comparison of the real and virtual model of the sports hall

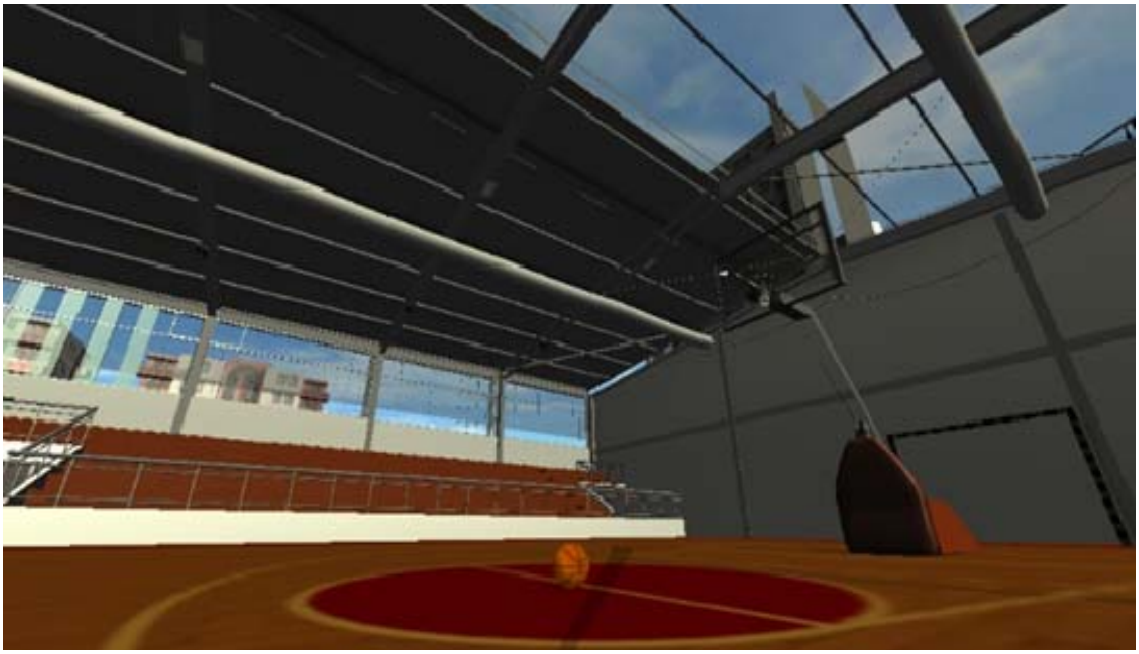


Figure 7: Simulation of the illumination in the interior of the sport hall in daylight. The interior lighting is off

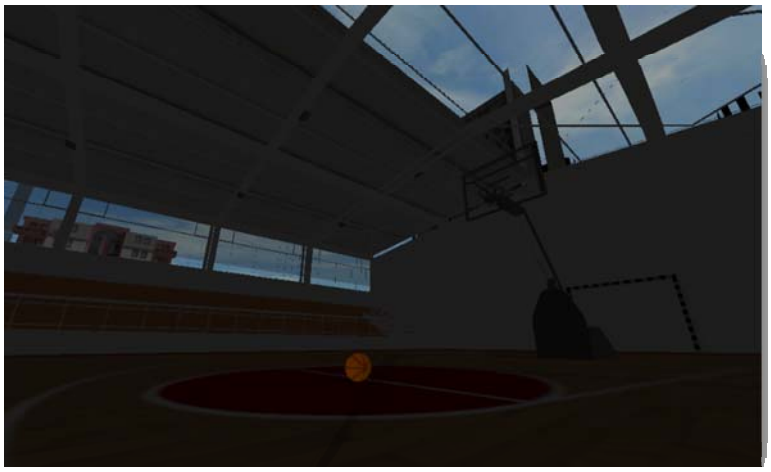


Figure 8: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a state as it is obtained. The film's transmission coefficient main value is 35.08%. The solar spectrum AM 1.5 is fallen light and the interior lighting is switch offl

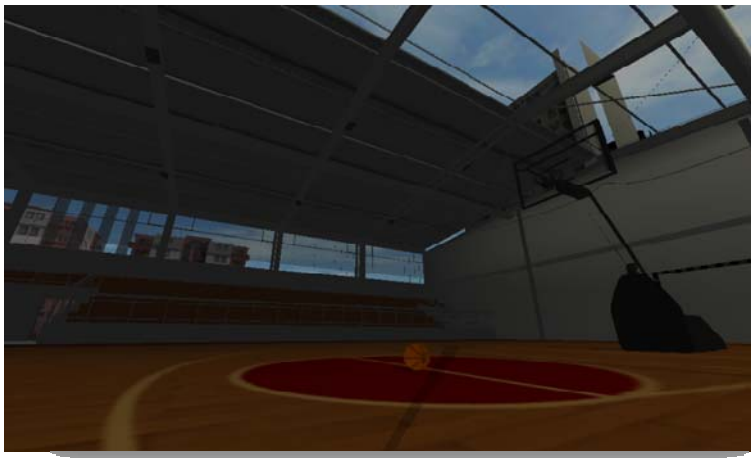


Figure 9: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a shaded state. The film's transmission coefficient main value is 57.06%. The solar range AM 1.5 is fallen light and the interior lighting is switch off

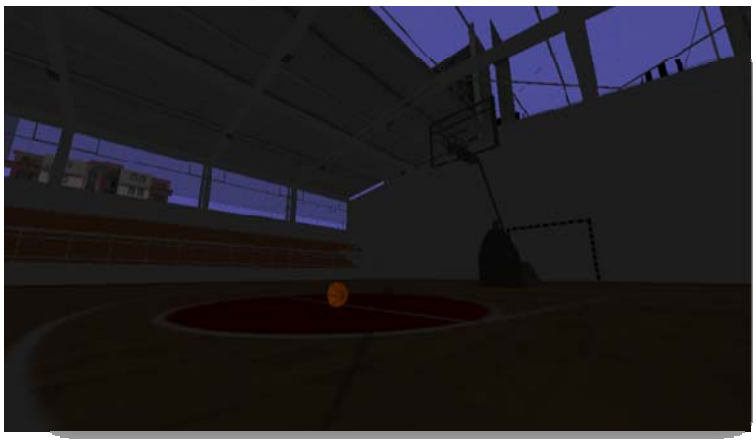


Figure 10: Simulation of the illumination in the interior of the sport hall in daylight, modulated when passing through the electrochromatic film in a coloured state. The film's transmission coefficient main value is 20,0%. The solar range AM 1.5 is fallen light and the interior lighting is switch off

4. CONCLUSIONS

In this scientific paper were obtained electrochromic films from copper(I)oxide in a fast, simple, economical and environmentally friendly method with chemical deposition of two solutions. The mean value of the transmission coefficient of the films in the visible part of the spectrum in the state as it is obtained is in a shaded and coloured state are 35.08%, 57.60% and 20.0%. The values for the transmission coefficient were used for simulation of the lighting of a real object, the sports hall "Forza" in Skopje, in case when an electrochromatic film of copper(I)oxide is set on existing windows of the building in a coloured and shaded condition. Simulations were made with the virtual reality software Quest3D and show that these films can be used in real world so-called "Smart windows".

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THE IMPACT OF RECIPROCITY ON INSTAGRAM PET INFLUENCER POSTING RESPONSE TIMES

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Abstract: *This study investigates the effectiveness of two outreach strategies, reciprocation and conventional, on the response times of Instagram pet influencers when collaborating with a small business. Drawing from the principle of reciprocity, we aimed to determine whether offering upfront favours in the form of digital pet portraits leads to faster influencer posting times. A sample of 232 Instagram pet influencers was selected, with 203 approached using a conventional strategy and 29 using a reciprocation outreach strategy where the portrait was provided upfront. The key parameter analyzed was the time it took influencers to post the provided portrait on their Instagram feed after agreeing to collaborate. Results show that the reciprocation approach prompted faster and more consistent responses, with all influencers posting within five days, compared to 83.33% of conventional outreach participants posting in the first week. These findings suggest that upfront favours may encourage quicker influencer responses, offering insights into more effective influencer outreach strategies for small businesses.*

Key words: Instagram influencer marketing, reciprocity principle, outreach strategies, pet industry

1. INTRODUCTION

Influencer marketing involves social media influencers promoting the products or services of brands in exchange for financial compensation or non-monetary incentives, such as complimentary products or services (Campbell & Farrell, 2020; Kim & Kim, 2021; Tafesse & Wood, 2021). It has become a core component of digital marketing strategies, providing brands with authentic, more subtle advertising. Social media influencers, who are notable users recognized for their expertise in niche areas, can be divided into several distinct groups based on factors such as follower count, authenticity, accessibility, expertise, and cultural capital (Campbell & Farrell, 2020; Tafesse & Wood, 2021).

Instagram is one of the most popular platforms for influencer collaborations, with a large active user base, primarily composed of individuals between their late teens and early thirties (Dixon, 2024). A significant portion of Instagram users follows brands or uses the platform for product research (Newberry, 2024), making it a crucial channel for business-to-consumer marketing. The increasing use of influencers is driven by the rise of social media and concerns over ad-blocking, contributing to the rapid expansion of the global influencer marketing sector, which is projected to grow substantially in the coming years (Grin, 2024). As brands invest more resources into influencer marketing, platforms like Instagram continue to play a key role in driving engagement and conversions (Grin, 2024; Park et al., 2024). The global pet industry has experienced significant growth, driven by the increasing humanization of pets and a rising pet population, with 66% of U.S. households owning pets in 2024, pushing pet-related expenditures to $150.6 billion in the U.S. (Bloomberg, 2023; Megna & Bailie, 2024). A new breed of influencer has emerged, the pet influencer, whose social media accounts, managed by their owners, have become powerful marketing tools, with some gaining millions of followers (e.g., @nala_cat with 4.5M), significantly influencing consumer behaviour, especially in the pet food market (Zhang et al., 2023; Xu, 2022). This trend offers brands in the pet care industry vast marketing opportunities, as the sector is projected to surpass $200 billion globally by 2025 (Niemietz, 2020). Pet influencers engage their audiences primarily through entertainment (Myers et al., 2024; Segmanta Blog, 2020) and providing valuable information on pets and pet-related products (Hartama, 2021), fostering tight-knit online communities (Ngai, 2023; Maddox, 2021). For brands, establishing successful collaborations with influencers requires compelling outreach strategies, with smaller influencers typically being more

ORCID numbers are provided at the end of the paper.

accessible for partnerships due to their focus on growth (Levin, 2020; Trend, 2024). Cialdini (2021) identifies seven psychological principles of persuasion, including reciprocation, that can influence the willingness of individuals to comply with requests, though the effectiveness of these techniques can vary significantly based on the specific principle used and the individual's demographic profile, with factors such as age, gender, and cultural background playing key roles (Orji et al., 2015; Oyibo et al., 2018). The principle of reciprocity stands out, deeply rooted in human interactions across cultures, encouraging individuals to return favours and fostering mutually beneficial relationships. This principle, widely used in marketing, can significantly impact consumer behaviour, with businesses utilizing it to drive engagement and sales, particularly through personalized strategies tailored to recipients' preferences (Cialdini, 2021). Burger et al. (1997) explored the norm of reciprocity by testing how the obligation to return a favour diminishes over time. Their experiments revealed that participants were significantly more likely to reciprocate a favour shortly after receiving it, but as time passed, the likelihood of reciprocity decreased significantly. This demonstrates that the reciprocity norm does not create an indefinite obligation to return favours but rather operates within a limited time frame, suggesting that timely responses are crucial in social exchanges.

This concept of reciprocity is central to our study as we seek to determine whether offering upfront favours leads to faster responses from Instagram pet influencers. Specifically, we aim to evaluate and compare the effectiveness of two outreach strategies, reciprocation and conventional, by analyzing how providing digital pet portraits as upfront favours affects influencer response times (i.e., the time it took them to post the provided portrait on their Instagram feed) during collaborations with small businesses. Building on Burger et al.'s (1997) insights into the time-sensitive nature of reciprocity, we aim to determine which outreach strategy fosters more timely influencer response and whether offering upfront favours leads to faster responses.

2. METHODS

This study examined the impact of two outreach strategies—reciprocation and conventional—on Instagram pet influencer response times in posting a provided digital portrait for a collaboration with a small business, i.e., Petification (Instagram: @petification). This small e-commerce business focuses on creating custom digital art with a pet theme. The outreach strategy involved proposing unpaid collaborations, where influencers were offered free digital pet portraits in return for a post on their Instagram feed. A total of 232 Instagram pet influencers were selected for the study, chosen based on follower count, engagement rate, and their alignment with the brand. The sample represented a wide range of follower sizes, engagement levels, pet types (such as cats and dogs), and geographic locations. The study involved two groups of influencers: 203 influencers were approached with the conventional strategy, offering free portraits if they agreed to collaborate. The remaining 29 influencers were part of the reciprocation strategy, where Petification created and sent portraits upfront, along with a collaboration proposal. Data was collected over a 23-month period, from mid-2021 to mid-2023, including outreach, influencer responses, and posts on their Instagram feeds. The key parameter analyzed in this study was the time (in days and weeks) that Instagram pet influencers took to post, measured from the moment a finished digital pet portrait was provided to them (specifically when they confirmed receipt of the information) to the moment they posted it on their Instagram feeds. The smaller sample size for reciprocation outreach was due to time limitations regarding the preparation of the portraits upfront. Outreach messages for both strategies followed the guidelines of Levin (2020) to clearly communicate collaboration terms and encourage influencers to share their personal impressions alongside the portrait.

3. RESULTS AND DISCUSSION

Figures 1 and 2 illustrate the distribution of days and weeks, respectively, that elapsed from the time point a digital pet portrait was provided to an influencer to the time point it was posted on their Instagram feed, comparing both conventional and reciprocation outreach approaches. More than 50% of Instagram influencers in both outreach approaches posted within 1 day (0-1 days). Reciprocation outreach resulted in a higher proportion of posts within 2-3 days (28.57%) compared to conventional outreach (16.67%). Notably, 100% of the influencers in the reciprocation group posted within 5 days, while 3.33% of those in the conventional outreach posted between days 6 and 7. In total, 83.33% of influencers in the conventional outreach group posted within the first week, with the remaining 16.67% posting within the following 2-6 weeks. In terms of weeks, 100% of influencers in the reciprocation

outreach group posted within the first week, while 83.33% did so in the conventional outreach, with a smaller percentage (16.67%) continuing to post over the next several weeks (2-6 weeks).

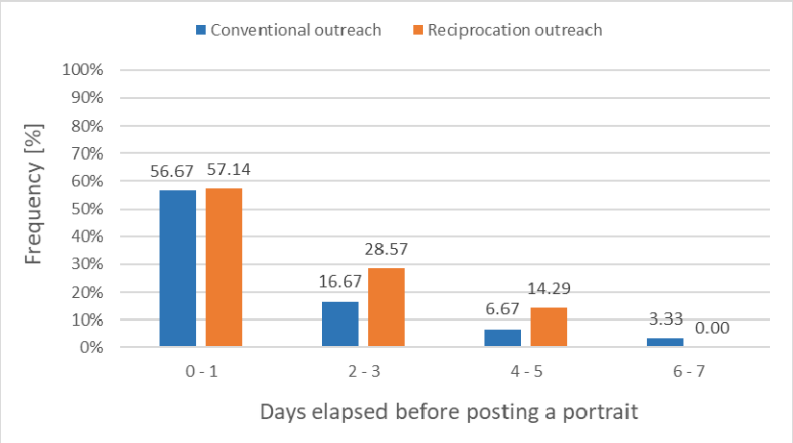


Figure 1: Distribution of days elapsed before posting

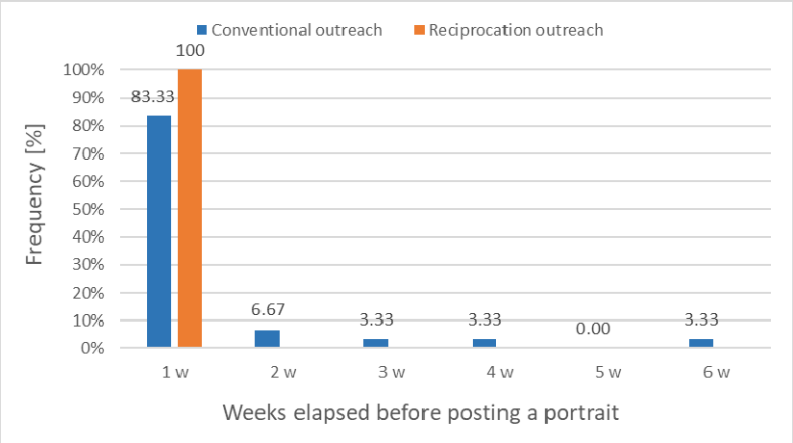


Figure 2: Distribution of weeks elapsed before posting

The average time to post was 1.43 days (stdev. ±1.29 days) for reciprocation outreach, excluding the outlier who did not respond to the collaboration proposal, but eventually posted a portrait after 104 days. This exclusion was made to ensure more accurate data representation, as including such an extreme case would have significantly skewed the average posting time and misrepresented typical influencer behaviour observed. By excluding the outlier, we highlighted that the majority of influencers in this group posted quickly, providing a clearer understanding of general Instagram pet influencer response behaviour. A relatively low standard deviation of ±1.29 days also indicates consistency in posting times, further suggesting that reciprocation outreach encourages a quicker, more predictable response compared to conventional outreach. For conventional outreach, the average posting time was 4.83 days (stdev. ±8.45 days), where the larger standard deviation for the full period reflects greater variability in posting times, indicating a less predictable response pattern. However, when considering only the first week, the average posting time was 1.48 days (stdev. ±1.47 days). Overall, while reciprocation outreach leads to faster and more uniform posting, early responders in the conventional outreach approach exhibited similar behaviour to those in the reciprocation group.

In addition, there are many reasons that led Instagram pet influencers to fail to post or delay their posting. Some may have received too many messages and did not notice the collaboration request at all. Others explained that they were waiting for a specific day or time when their audience engagement is typically highest, as some have observed better responses on weekdays compared to weekends. Additionally, some of them had just posted other content and were waiting a certain amount of time before posting the portrait. There were also instances where the portrait file was lost, and some cited

personal reasons that prevented them from posting, noting that for most, this is not their primary profession, so they might not feel as obligated to complete their part of the task promptly.

4. CONCLUSIONS

Obtained results from the study indicate that the reciprocation outreach approach prompted quicker and more consistent response patterns, whereas much more variability was observed in the conventional outreach approach. The average posting time for reciprocation outreach was 3.38 times faster (4.83 days / 1.43 days) compared to conventional outreach. This aligns with reciprocity principles, suggesting that upfront favours may encourage quicker action, supporting the idea from the study by Burger et al. (1997) that reciprocity motivates timely responses, though the time decay aspect from their original research may not fully apply to the present study. While reciprocation outreach generated faster influencer responses, early responders in conventional outreach posted at similar speeds, exhibiting a similar posting behaviour when considering only the first week. These findings suggest that reciprocation outreach may be more effective for small businesses seeking timely collaborations, which is important for planning campaigns with strict timelines, though conventional outreach can still be effective for some influencers.

In addition to the quantitative results, several factors contributed to the failure of influencers to post or delays in posting. Influencers cited reasons such as missing the collaboration request due to message overload, timing posts for optimal audience engagement, or personal and technical challenges. Furthermore, for many influencers, this is not their primary profession, which may lead to lower motivation to complete the task promptly. These factors highlight the complexities of managing influencer collaborations.

Future research should focus on addressing and overcoming the limitations of this study. Therefore, its findings should be interpreted with caution. These limitations include the small sample size, industry-specific focus, and the niche online community studied, as well as the product-specific context. Expanding future studies in these areas will help confirm the findings and enhance their generalizability across different types of influencers and industries.

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NOVEL TECHNOLOGIES AND ARTIFICIAL INTELLIGENCE



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ARTIFICIAL INTELLIGENCE OR MAN: COLORIZATION OF BLACK AND WHITE PHOTOGRAPHS

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Abstract: *In this work, black and white photographs of Mate Kaić were colorized. Colorization was done manually and using several artificial intelligence software. In this research, 15 photos were colorized, the artificial intelligence needed less time than a human. By conducting an online survey and subjective evaluation, Artificial Intelligence in most cases showed a better result in the choice of colors and a more aesthetically attractive choice of combination of tones. However, artificial intelligence proved to be less intelligent with examples of photos showing traditional clothing. The results show that the best way to colorize photos is actual a combination of artificial intelligence and human.*

Key words: Colorization, artificial intelligence, convolutional neural network

1. INTRODUCTION

Colorization is the process of assigning colors to a black and white photograph. The goal of every colorization is that the result is a meaningful, perceptually accurate and aesthetically appealing photograph. There are various ways to colorize black and white photos. Throughout history, various experiments have been used to leave pigment on an already finished black-and-white photograph. At that time, such processes were called manual coloring, and they were very popular already in the middle of the 19th century and even until the 1980s, with ups and downs in popularity. Today, the term manual colorization is considered digital colorization. The difference between the two manual colorizations is that with digital colorization we do not change the original photo, but it remains preserved as black and white, while in history it had to be "destroyed" with the layer of color that was applied to it. There are many reasons why people throughout history have added color to black and white photos. Nowadays, the most common reason is to "revive" old family photos (Morton, 2023; Paso Robles Daily News, 2021). The purpose of artificial intelligence in photography, as well as in all other areas in which it is applied, is to make work easier for humans. Instead of a person manually or digitally coloring a photo for hours, artificial intelligence does the whole process in a few seconds. She always tries to offer as realistic a solution as possible, this can be concluded from numerous tests of photo colorization software. The goal of every software is to render a photo as believable as possible, even if it didn't really look like that, so every software is trained on millions of photos (e.g. grass is usually green - AI is trained on examples of green grass). The difference between AI colorization and manual colorization is that a person uses his own mind to choose the colors to place on a certain part of the photo in one of the photo processing programs, while artificial intelligence chooses colors based on learned patterns. Both coloring methods have their advantages and disadvantages, and the goal is to choose the method that pays off in the best possible way in terms of quality and coloring time.
The paper is organized as follows. In Section II we give an overview of the robot design and software development, further explaining the methods used for the gameplay. Section III presents the experimental setup and obtained results, while Section IV provides discussion and comments. Finally, section V concludes the paper.

2. COLORIZATION

The term colorization refers to the process of assigning colors to a grayscale image. The reasons for colorizing black and white images can be numerous, but it is important that the image is aesthetically appealing and perceptually meaningful. If the image is colored manually, it is necessary to know the content of that image in order to achieve good quality. Objects in individual photos have different colors, so there are different ways of assigning colors to pixels in the image. So, it can be concluded that there is no single solution for colorizing images (Algoritma technical blog, 2023). In 1839, black-and-white photography

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appeared for the first time with the daguerreotype process, and it was later improved by numerous other processes, such as cyanotypes, but most photographs remained black and white even until the middle of the 20th century. The period from 1900 to 1940 is also called the golden age of hand-colored photography in the West. Wallace Nutting became popular with his colorized landscape photographs of the early 20th century. He became the best-selling hand-colored photographer of all time. In the United States, Canada, Bermuda, and the Bahamas, between 1915 and 1925, hand colorization and such photographs became popular among the middle class as holiday gifts, weddings, souvenirs, and so on. However, its popularity came to an end at the beginning of the Great Depression in 1929. Today, although high-quality coloring processes are available, hand-colored photographs are still popular with some for aesthetic reasons. Also, the pigments used in manual coloring have great durability. For this reason, hand-colored photography was preferred in the 1980s due to the expensive and rare nature of color film and the unavailability of processing. Nowadays, in recent times, photo processing and colorization is possible at every step using numerous software. There are many who do not accept colorization, such as Christopher Bryant, a genealogist. According to his views, the photo should be preserved as it is, because by looking at a photo, you can determine which period it is from. So that the black and white tones show a historical feature and not just a black and white photograph. In the early days of using today's digital colorization, Maureen Taylor initially disagreed with what it offered. It raises the question why one would change color or add color to the historical value and beauty of old paintings.

AI has increasingly started to be used in mathematics, economics and operations research. At the beginning of the 21st century, machine learning techniques are advancing. In 2016, artificial intelligence reaches great popularity. Due to advances in deep learning, artificial intelligence is increasingly being used in image processing, video processing, text analysis and speech recognition.

There are many methods and algorithms that can facilitate the coloring process using artificial intelligence (Rao et al., 2022). Automatic coloring of black and white photos is becoming more and more advanced. New methods of coloring black and white photographs are being created in order to display the results as authentically as possible. There is always an effort to improve algorithms for colorizing black and white photos, and the desire is to write such a good algorithm whose results will show such accurate and correct photos that people will not know if the photo is original or colored.

It is possible to separate the subject and aesthetics of several images and then recombine them into a single image using a pre-trained convolutional neural network first developed for image categorization. A convolutional neural network (CNN) consists of multiple layers of small computing units that process only parts of the input image in a feed-forward manner. Each layer is the result of applying different image filters, each of which extracts a specific feature of the input image, to the previous layer. Therefore, each layer can contain useful information about the input image at different levels of abstraction (Figure 1) (Smith, 2019).

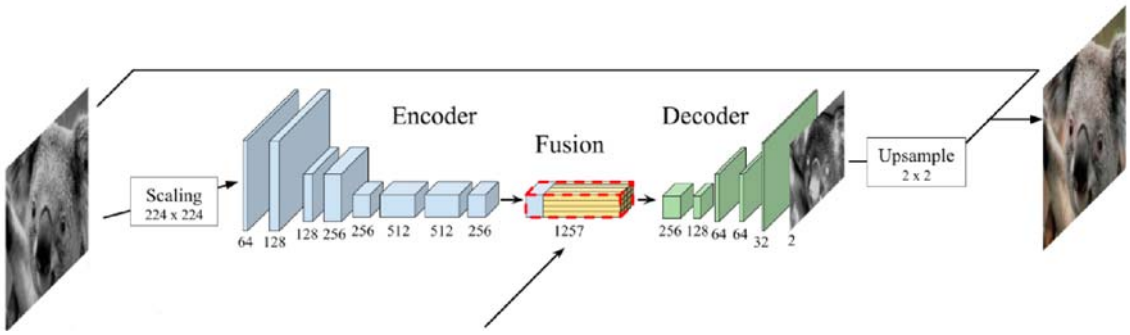


Figure 1: Colorization by convolutional neural network

3. RESEARCH

15 photos of Mate Kaić were used for colorization. Two websites were chosen for coloring: myheritage.com and img2go.com.

Myheritage.com is a free genealogy website that allows you to upload black and white photos and automatically colorize them using artificial intelligence. The site's colorization algorithm is trained on

historical photos, so it tends to produce more accurate colors. The site also includes additional functions such as Color Restoration, also a DeOldify product. This feature restores colors to photos originally taken in color that have faded or were not captured or processed well in the first place. Adobe Photoshop was used for manual colorization.
A survey was conducted and posted on Facebook pages. There were 61 respondents in total. The survey consisted of 15 questions. The focus was on the photographs, and the survey did not ask the gender and age of the respondents. Each question contained only two photos, one that was colored by hand and one that was colored by artificial intelligence. The respondent was asked which photo, in his opinion, shows the correct colors.

4. RESULTS AND DISCUSSION

The Figures 2 and 3 show the results of manual colorization (picture on the left) and colorization by artificial intelligence (picture on the right). Figure 2 shows the old folk costume of the Livonian region, which consists of a red cap, a bluish waistcoat, and a red belt; AI fell. For photo shown in Figure 3, human did a better job than artificial intelligence. The differences are obvious, they can best be seen on the example of a wooden roof. The Figure 4 shows the results of the survey, which picture reproduces the colors better. Most respondents were not from the city of Livno, they could not know the traditional folk costume. It is assumed that this is one reason why their colors were more natural in the right photo.



Figure 2: Colorization by convolutional neural network



Figure 3: Colorization by convolutional neural network



Figure 4: Colorization by convolutional neural network

The difference between human and AI can be seen in some traditional details of the images, and in case when the AI needs to recognize what season it is. AI colorized images have better tones and more vivid colors, and the colorization time is much shorter.

5. CONCLUSIONS

In most cases, artificial intelligence showed a better result in the choice of colors and a more aesthetically attractive choice of tone combination. However, artificial intelligence proved to be less intelligent with examples of photos showing traditional clothing. With those photos, it was important to know history and tradition. For this reason, it can be mentioned that artificial intelligence is still not sufficiently developed to be able to replace humans in such situations. It really took a lot more time for a person to colorize a certain photo. In this case, artificial intelligence has many more advantages. In the example of this work, 15 photos were colored, which means a lot of work and concentration for a person, which is not always possible with so many tasks. In conclusion, it can be said that the best way to colorize photos is a combination of artificial intelligence and human intelligence. In many cases, artificial intelligence has proven to be better and more cost-effective when it comes to color selection and performance time, but it still needs to be historically accurate.

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USE OF AI IN MHEALTH MOBILE APPLICATIONS: THE INFLUENCE OF VIRTUAL THERAPISTS' VISUAL CHARACTERISTICS ON USER PERCEPTION

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Abstract: *Implementing artificial intelligence within the applications for mental health has improved their services. As the most common application, Chatbots that simulate communication with a therapist stand out. With this feature, individuals who shy away from accessing therapy due to the stigma associated with mental health have the opportunity to access therapy without fear of negative feedback. This research aimed to investigate the impact of virtual therapists' visual characteristics on users' reactions. Six characters, created using MetaHuman Creator software and augmented with audio recordings, were evaluated by respondents on parameters such as likability, naturalness of appearance, excitement, positivity, and sense of trustworthiness. Video stimuli were employed to encourage these assessments. Results indicated that the third female character received the highest likability rating, while the first male character was considered the most natural and reliable. The first female character aroused the most incredible excitement and positive feelings. In contrast, the second male character received the lowest ratings across multiple parameters, and the second female character scored poorly overall. Statistical analyses, including T-tests and one-factor ANOVA, revealed no significant variations across characters for most parameters except for excitement. Post hoc tests highlighted notable differences, especially between the second female character, other female characters, and the first male character. Correlation analysis revealed a strong positive relationship between likability and the naturalness of appearance with user trust. These findings underscore the importance of planning virtual therapists' visual characteristics to suit users, revealing interesting observations such as respondents' perceived differences in character voices and the greater attention to detail exhibited by male subjects towards male characters.*

Key words: mHealth, mobile apps, virtual therapists, visual characteristics, user perception

1. INTRODUCTION

The use of medical mobile applications is extensive and varies depending on the field of medicine and its specific requirements. Consequently, the tasks and functions within the application also vary. This means that the functions of artificial intelligence implemented in these applications also differ. Some of the applications that stand out are used for contacting emergency medical help vehicles (Ghani et al., 2021), medical consultation (Sindhumol & Ardhet, 2019), public health promotion (Biswas, 2023), chronic disease monitoring (Neuhauser et al., 2013), monitoring of dermatological changes (Freeman et al., 2020), particular diseases diagnostics (Verde et al., 2019), physical rehabilitation (Lo et al., 2018), oral hygiene (Al-Jallad et al., 2022) and mental health.

Mental health is one of the fields of medicine in which communication and fast and easy contact with medical personnel are crucial. Since the patient's condition cannot be predicted, it is impossible to plan therapeutic sessions that will be carried out at the exact moment of relapse. Therefore, the availability of mobile applications specialised in mental health is a facilitating circumstance that can only benefit the therapeutic process. The application of artificial intelligence (AI) in these applications has extended their importance to a considerably higher level. Along with machine learning, artificial intelligence has significant potential to transform healthcare and improve efficiency and innovation in clinical practice (Agarwal et al., 2022). Milne-Ives et al. (2022) conducted a general review of the use of artificial intelligence in mobile applications for mental health. The most common uses are predicting various factors (stress, mood, risk), supporting conversations, providing diagnostic support in decision-making, personalised notifications, and recommending interventions. It was further highlighted that the applications addressed various mental health conditions such as depression, mood disorders, stress management, suicide risk, as well as diagnostic support. It was shown that this type of mobile application has no negative impact on its users. Results show that progress and improvement of the condition were noted, or there was no significant impact. The authors pointed out that the collection of indirect data and the direct information obtained from the user form a quality basis for planning the following steps (Milne-Ives et al., 2022). Gamble (2020) also reviewed the use of artificial intelligence in mental health

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applications. The author points out that the most common implementation is through chatbots and as an additional resource during therapy with therapists. The chatbot can psycho-educate by recognising the user's feelings and finding material suitable for them. Additionally, it can offer mental health information anytime without analysing feelings. It was found that by monitoring user-approved activities or analysing their emotional status based on interactions, AI has the capacity to provide recommendations based on user preferences. As a result, content customisation can effectively motivate users, thereby encouraging constant engagement with the application. It was pointed out that by regularly monitoring mood data, artificial intelligence algorithms can create databases containing habits, moods, preferred coping mechanisms and other factors without fear of compromising the privacy and security of personal data. In addition, it was observed that the application of cognitive behavioural therapy (CBT) through applications is at a desirable level, with results that rival the application of live CBT techniques. In addition, diagnosing post-traumatic stress has proven to be very effective when using chatbots specialised for these purposes. Interestingly, certain age groups, such as adolescents and the younger population, avoid pursuing help when it is needed due to the stigma surrounding mental health. This is exactly where these mobile applications stand out. It is considerably more comfortable for this group of users to relax and venture into therapy through digital devices than in-person therapies. This shows that the benefits of applying artificial intelligence to mental health applications are fundamental. However, the author lists certain aspects that should be considered and improved. For example, there is a need for accountability, transparency, supervision, and the application of standards regarding chatbots so that ethical aspects are not questioned. Also, the target groups of users should be examined, and depending on their needs and preferences, the application should be designed in terms of both interface and functionality (Gamble, 2020). D'alfonso et al. (2017) wrote about using artificial intelligence through chatbots on a platform dedicated to mental health therapy in youth. The authors state that previous research indicates that users are more open and share information more efficiently, especially about sensitive topics, when they know they are interacting with a machine interface. It was pointed out that the benefit of using chatbots is reflected in the fact that an immediate psychological assessment and additional learning can be carried out based on the user's response in real time. It is indicated that this type of technology could be used to collect information about a patient before they come in contact with a professional. Based on the collected information, a preliminary profile of the patient could be formed. Additionally, with platforms intended for user-therapist communication, it has been suggested that the chatbot can be used for casual conversation while the patient waits for an appointment (D'alfonso et al., 2017). Berrouiguet et al. (2019), as well as Haines-Delmont et al. (2020), discussed the importance of applying artificial intelligence in mental health applications with implications for suicide prevention. Preliminary research has found that the application can identify changes in mobility patterns, which can be used as proxies for behavioural changes and mental health relapses (Berrouiguet et al., 2019). It has also been established that certain machine-learning algorithms can recognise real signs of suicidal desire and separate users who have this desire from those who do not (Haines-Delmont et al., 2020). Inkster, Sarda and Subramanian (2018) conducted a study on the effectiveness of the Wysa application in monitoring depressive conditions. Wysa is an AI-powered mobile application featuring emotional intelligence that aims to improve users' mental health using a text-based interface. It allows users to create a pleasant environment and adequately express their feelings. The results of the research showed that the conversations offered by the application have an impact on improving the symptoms of depression. A more significant impact was observed in users with more severe symptoms of depression. Users expressed a rather positive user experience with recommendations for improving the application. They expressed the desire for the application to understand them better and for the questions not to be asked repeatedly (Inkster, Sarda & Subramanian, 2018). Research conducted by Fitzpatrick, Darcy, and Vierhile (2017) aimed to evaluate the feasibility of delivering cognitive behavioural therapy via an artificial intelligence-based chatbot (Woebot). This software is designed to present appropriate cognitive-behavioural concepts to the user based on mood data through video content or word games that serve to educate the user about their current state. Functions that contributed to a positive user experience when using Woebot were the empathy shown by the chatbot, and its "personality"; encouraging learning was also highlighted as a positive side. Users mostly pointed out that a negative side of the software was the limitation of communication. They stated that they encountered a lack of understanding of certain topics by the chatbot or that confusion occurred if unexpected answers appeared. In addition, it has been observed that conversations can be repeated as completely identical (Fitzpatrick, Darcy & Vierhile, 2017). Ly, Ly, and Andersson (2017) tested the Shim chatbot. Shim is a fully automated agent (chatbot) created as an application whose user interface is similar to the interface of text messaging applications. The communications within the

application are based on strategies and activities aimed at positive psychology. The research showed that when using Shim, users often had the impression of communicating with a human being and developed a sense of some relationship. Users pointed out that the application also impacted their everyday lives, i.e., they began to apply the behaviour patterns suggested by the application. Additionally, as a positive side of the application, users pointed out that it was beneficial to have it with them at all times and to be able to access it. Also, the weekly status and progress reports were essential to the users so that they could follow their personal progress. On the negative side, they pointed out the repetition of content, the impossibility of entering deeper conversations, and that misunderstandings occur in certain situations. Based on all user responses, it is obvious that, at times, the application gives the feeling of a human being; however, when it continues to be used, there are disadvantages that artificial intelligence has compared to humans (Ly, Ly & Andersson, 2017). In 2020, Dosovitsky et al. researched the use of the Tess chatbot. This application offers numerous chatbot interaction modules that have proven to be a promising practice. Availability of modules led to a heterogeneous application usage pattern. The authors point out that focusing on developing short, simple, and consistent modules would be desirable, and testing them with small iterative studies would increase usability and user engagement (Dosovitsky et al., 2020). Fulmer et al. (2018) also examined the usability of this application. They determined that as many as 86% of respondents were satisfied when using the application, while 80% gained new knowledge during use. As the best aspects of the application, users highlighted responsibility and accessibility, the empathy shown by the chatbot, and the accession to new knowledge initiated by the bot. As negative aspects, users cited limitations like conversations and limited understanding. Most importantly, a significant reduction in anxiety symptoms was observed in users who continuously used the application. They showed a higher level of engagement and overall satisfaction and emphasized that the therapeutic experience was pleasant (Fulmer et al., 2018). Jiménez-Serrano, Tortajada, and García-Gómez (2015) investigated the ability of a machine learning-based application model to predict symptoms of postpartum depression. The application is based on a simple questionnaire on which it is determined whether a new mother is at risk of developing postpartum depression. The obtained results enable early diagnosis and intervention if the need arises. It was found that this type of application can provide early detection of postpartum depression, that the results are easy to interpret, and that the approach is cost-effective. This application has not been clinically evaluated, and a proposal was made to implement it to be applied in actual practice (Jiménez-Serrano, Tortajada & García-Gómez, 2015).

The newest implementation of AI in mental health applications is through virtual humans. Ellie represents one of the most interesting implementations of artificial intelligence within mental health applications. Ellie is a virtual human who conducts semi-structured conversations aimed at creating an interaction that will enable the automatic assessment of stress indicators, defined through verbal and non-verbal behaviours related to depression, anxiety or post-traumatic stress disorder. It is designed to follow the micro-expressions of the person with whom it communicates, react to facial expressions and gestures, perform compassionate gestures, and, therefore, build a more pleasant relationship with the patient. Some research has shown that Ellie can recognize subconscious physical cues much better than many highly trained psychologists. She is designed to recognize 60 non-verbal cues per second, everything from eye gaze to facial tilt to tone of voice. These abilities have proven to be highly significant and effective in diagnosing mental illnesses. It was also observed that users who interacted with Ellie would rather interact with her again than with an actual therapist. Experts believe this is due to the absence of judgment in communication with Ellie (Pearce, 2020). The research conducted by Rizzo et al. (2016) showed that the subjects felt comfortable communicating with Ellie and shared intimate information without problems during the conversation. However, respondents pointed out that Ellie did not adequately recognize their nonverbal behaviour and that her body language and nonverbal behaviours were often inappropriate (Rizzo et al., 2016). Ellie is yet to be available for public use. Through their research, Philip et al. (2017) examined the abilities of a virtual human (Julia) to diagnose depressive disorders with a comparison to the diagnosis of a clinical psychiatrist. In this research, it was determined that Julia showed satisfactory results when it came to diagnosing depressive conditions. Although the diagnostic efficiency was at a high level, it was observed that there were deficiencies in patients with milder symptoms. It was additionally pointed out that it would be essential to enable her to recognize non-verbal aspects, such as facial expressions and changes in the tone of her voice, which could lead to exceptional progress in psychiatry. The authors believe using artificial intelligence through virtual humans could significantly save doctors time during diagnosis and provide patients with a completely unbiased approach based on a theoretical diagnosis model (Philip et al., 2017).

2. BACKGROUND

The literature review reveals that the predominant utilisation of artificial intelligence within mental health applications is through the integration of chatbots. This type of chatbot primarily aims to replicate interactions with a therapist, typically through written exchanges. However, a relevant concern arises regarding the deficiency in emotional intelligence exhibited by these chatbots. In addition to this application of artificial intelligence, the question arises about what functions it could fulfil while positively influencing users and allowing them to free themselves from inner turmoil. Some potential possibilities for implementing artificial intelligence within applications intended for mental health are mood monitoring, personalised recommendations, virtual therapist, recognition of emotions, analysis of feelings, user engagement and gamification, monitoring medication therapy, and early diagnosis and risk assessment. Considering the insights into both present and prospective utilisation of artificial intelligence in mental health applications, the concept of a virtual therapist is particularly interesting.

3. METHODS

The research is based on analysing user responses to virtual characters whose role is to simulate a virtual psychotherapist. A survey served as the fundamental tool for documenting participants' reactions.

3.1 Characters

Models of virtual humans were used as stimuli, presented as six characters - three female and three male characters (Figure 1).



Figure 1: Characters

These characters were designed to exhibit maximal diversity, achieved through facial features, skin tones, hair, and eye colours. MetaHuman Creator software generated 3D character models (Figure 2). Initially, a selection of pre-existing models served as the foundation for character development, with subsequent adjustments to align with the predetermined appearance criteria. Regarding the character's surroundings, a studio setting with a neutral grey backdrop was chosen to minimise potential distractions for participants.



Figure 2: The work environment of the MetaHuman Creator software

In addition to character development, voice content was recorded to simulate introductory communication with a virtual therapist. Two audio recordings, one featuring a male voice and the other a female voice, were utilised to ensure compatibility with characters of both genders. Employing a unique voice for each gender aimed to direct attention solely towards the visual attributes of the character, thus ensuring that only the physical appearance influenced respondents' reactions. The audio recordings were based on a predefined script, which simulated a welcoming and familiarising interaction with the application. The D-ID AI Video Generator was used to obtain the final video, seamlessly integrating visual and audio components, which allowed the characters to synchronise their gestures with the spoken content from the audio. The final stimuli were videos that included generated characters accompanied by audio content. The videos are generated to last 45 seconds each.

3.2 Examination process

In addition to the previously mentioned videos, a survey was also used for the examination. The survey encompassed seven sections, with the initial section addressing general respondent information, including gender, prior utilisation of mental health applications, and familiarity with technologies such as virtual humans. Subsequently, the following six sections comprised six questions, individually assessing aspects of each character. These included the likability of the characters, the perceived naturalness and trustworthiness of their appearance, the level of enthusiasm and positivity experienced during communication, and the inclination to sustain communication with the portrayed therapist.

4. RESULTS AND DISCUSSION

Given that the survey comprises two distinct types of sections, the subsequent analysis of results will adhere to the same principle.

4.1 Analysis of the general part of the survey

Twenty participants were engaged in the study, comprising an equal split of ten females and ten males aged between 25 and 45. The respondent group is characterised by homogeneity in terms of gender, age, and educational background, with each individual having attained some level of higher education, ranging from undergraduate to doctoral studies. Moreover, all participants exhibit familiarity with the concept of virtual humans or analogous technologies (80% of them). Notably, only a minority of the respondents, representing 10% of the group (2 individuals), have previously utilised mental health applications.

4.2 Analysis of the respondents' reaction to the presented characters

The characters were evaluated based on the following parameters:

- likeability,
- naturalness of appearance,
- trustworthiness,
- respondents' excitement,
- inducing a positive/negative feeling in the respondents and
- desires of respondents to continue the conversation with them.

4.2.1 First male character

The first male character is generated to possess dark attributes, including hair and beard colour, eye hue, and complexion. Respondents frequently assigned a likability rating of 4 out of 5 to this character, with an average rating of 3.8. Similarly, its appearance was predominantly rated as natural, with a typical score of 4 and an average rating of 3.95. Notably, observations indicated that these ratings remained consistent across genders. Additionally, it was observed that the ratings for likability and naturalness of appearance did not necessarily correlate proportionally. The parameter of causing excitement among users was predominantly rated 6 out of 9, resulting in an average score of 4.55. Conversely, the sensation of positivity garnered higher ratings, averaging 6.6 out of 9. Regarding trustworthiness, respondents provided an average rating of 4 on a scale from 1 to 5 for this character. Interestingly, a slightly elevated average rating was observed among female respondents compared to their male counterparts. Merely 3 participants, constituting 15% of the group, indicated that they would not pursue further communication with the depicted character. There is a noticeable correlation between this determination regarding continued communication and the overall ratings across all parameters. The generally positive attitude conveyed by respondents towards this character interested them and awakened the desire to explore the possibilities of this character further.

4.2.2 Second male character

The second male character was generated to distinguish itself from the first through fundamental traits. Differences are primarily evident in facial features, hair colour and texture, complexion, hairstyle, and beard/moustache configuration. The likability of this character received an average rating of 2.65 on a scale ranging from 1 to 5, while the perceived naturalness of its appearance garnered an average rating of 3.1. Respondents expressed unfavourable impressions of this character, noting that its physical attributes evoked negative associations and even elicited fear. The excitement generated by this character among respondents was assessed with an average rating of only 4.1 on a scale from 1 to 9. Similarly, the character's capacity to evoke positivity in users yielded an average rating of 4.8 out of 9. Trustworthiness, as perceived by users, garnered an average score of 2.8 on a scale of 1 to 5. Notably, trust levels were observed to correlate directly with likability and the perceived naturalness of appearance, with respondents assigning similar ratings to these three parameters. Despite the character receiving low average ratings for trustworthiness, 45% of respondents expressed their intention to continue communicating with it.

4.2.3 Third male character

The final male character was generated to diverge from both preceding ones. Similar to earlier, the primary distinctions refer to hair colour, eye hue, complexion, and hair and beard style. Respondents noted, among other observations, that this character possesses softer facial features, evoking associations with a medical professional. Conversely, some respondents expressed that the specific characteristics of this character repelled them, as they triggered associations related to criminality. The likability of this character garnered an average rating of 3.75 on a scale of 1 to 5. Similarly, the perceived naturalness of its physical appearance received a comparable rating, averaging 3.85 out of 5. Notably, female respondents gave slightly higher ratings than their male counterparts. The level of excitement generated by this character among respondents was generally neutral, with an average score of 4.8 on a scale from 1 to 9. However, a slightly more positive sentiment was observed regarding the character's ability to evoke positive feelings, with an average rating of 6.6 out of 9. It was noted that the ratings provided by female respondents were marginally higher than those of male respondents in this aspect.

Overall, respondents expressed a predominantly positive perception of trustworthiness associated with this character, with an average rating of 3.55 out of 5. Once again, evaluations from female respondents tended to be slightly more optimistic. Impressively, 70% of respondents indicated their willingness to continue communication with this character, with a more significant proportion being female respondents.

4.2.4 First female character

Like the initial male character, the first female character is designed to exhibit dark attributes such as hair colour, eye hue, and complexion. The likability of this character received a notably high average rating of 4.15 out of 5. It was noted that male respondents tended to rate the character somewhat less favourably than female respondents. Conversely, the perceived naturalness of the character's appearance garnered a slightly lower average score of 3.7 out of 5, with male respondents assigning higher ratings than female respondents. The excitement induced by the character was rated at 4.95 on a scale from 1 to 9. Additionally, positivity was evaluated with an average score of 6.9 out of 9, with female respondents displaying a more positive inclination towards the character. Users' trust in this character was assessed with an average score of 3.95 out of 5, with male respondents assigning slightly lower ratings than female respondents. Regarding communication with this character, most respondents, accounting for 90% of cases, expressed their intention to continue using the application if it involved interaction with this character.

4.2.5 Second female character

When generating another female character, the attributes were selected to align with an individual's standard with fair skin, hair, and eyes. Regarding likability, this character received the lowest average rating among all female characters, with an average score of 2.85 on a scale ranging from 1 to 5. Similarly, the naturalness of her appearance also garnered the lowest average rating among all evaluated characters, with an average score of 2.7 out of 5. Additionally, the level of excitement experienced by users during interaction with this character was rated the lowest across all characters, with an average score of 3.9 on a scale from 1 to 9. It is apparent that, on average, male respondents reacted more negatively to this character in terms of excitement. The impact on the feeling of positivity was rated as neutral, with an average score of 5 on a scale from 1 to 9. However, female subjects exhibited significantly more positive reactions to this parameter than male subjects. The parameter of trustworthiness was also rated relatively low, with an average score of 2.5 out of 5, marking the lowest rating among all characters. Responses for this parameter were slightly more positive among female respondents than male respondents. Despite evaluating all parameters relatively low, 40% of respondents expressed their intention to continue communicating with this character. Of these, the distribution between male and female respondents is equal, with 20% each (4 respondents).

4.2.6 Third female character

The final character, a female, was crafted with gentle facial features, light eyes, and hair of non-natural colour to maximise differentiation from the preceding characters. The likability of the final character accumulated a notably high average rating of 4.2 out of 5, making it the highest-rated character in terms of likability among all characters. Respondents consistently assigned ratings from 3 to 5 when assessing this parameter, indicating an overwhelmingly positive overall impression. Additionally, the naturalness of the character's physical appearance received a commendable rating, averaging 3.6 out of 5. Interestingly, this parameter received higher average ratings from male respondents. The overall level of excitement induced by the character was perceived as neutral, with an average rating of 5.2 on a scale from 1 to 9. Similarly, the ratings provided by male respondents were slightly higher than those of female respondents for this parameter. With such an average, this character emerges as the best-rated in terms of respondents' arousal levels. The extent of positivity evoked by this character was evaluated with an average score of 6.75 on a scale from 1 to 9. In this aspect, the ratings given by female respondents were slightly higher. The level of trust obtained by the character was predominantly rated as 4, resulting in an average rating of 3.85 out of 5. Notably, female respondents expressed a more positive reaction compared to male respondents in this regard. Remarkably, 80% of respondents expressed their intention to continue communication with this character, aligning with the expected outcome based on all other parameters considered.

4.3 Statistical analysis of the results

A statistical analysis of the acquired results was conducted to ascertain the impact of individual parameters on user perception and overall impression. This analysis employed statistical methodologies such as the one-factor analysis of variance (ANOVA) and T-test to compare groups. At the same time, correlation served as a statistical technique for establishing relationships between variables.

4.3.1 Individual character analysis

To examine the impact of respondent gender on the outcomes, an independent analysis of the results for each evaluated parameter of every character was conducted. Using the T-test, comparisons were made regarding the parameters of likability, naturalness of character appearance, excitement and positivity elicited from respondents, and the level of trustworthiness perceived by respondents during interaction with the character.

The T-test results of independent samples were employed to compare the test outcomes of parameters including likability, naturalness of character appearance, excitement, positivity, and respondents' perception of trustworthiness. The analysis did not disclose a statistically significant variation in the responses between female and male respondents across all investigated parameters for all six characters.

4.3.2 Analysis of individual parameters

Following the determination that gender does not statistically influence the outcomes for all six characters, further analyses were conducted encompassing all respondents. A statistical analysis was performed utilising the one-factor ANOVA to explore variations in parameter values contingent upon the character. The test was executed by summing up all five parameters' values. This procedure tested for deviations within each parameter across all characters (Table 1).

Table 1: Results of the One-Way ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Likeability	Between Groups	44.175	5	8.835	9.579	0.000
	Within Groups	105.150	114	0.922		
	Total	149.325	119			
Naturalness of appearance	Between Groups	23.467	5	4.693	4.842	0.000
	Within Groups	110.500	114	0.969		
	Total	133.967	119			
Excitement	Between Groups	25.267	5	5.053	1.121	0.353
	Within Groups	513.900	114	4.508		
	Total	539.167	119			
Positivity	Between Groups	89.242	5	17.848	5.615	0.000
	Within Groups	362.350	114	3.179		
	Total	451.592	119			
Trust	Between Groups	40.942	5	8.188	6.196	0.000
	Within Groups	150.650	114	1.321		
	Total	191.592	119			

The conducted ANOVA yielded results indicating the presence of variations in the values attributed by respondents to the parameters, which exhibit exceptional statistical significance. The sole parameter where variations were not statistically significant is arousal. For all other parameters, the maximum statistical significance value (<0.0005) was observed.

Since significant statistical differences were identified regarding the likability and naturalness of the characters and the positivity and trustworthiness perceived by the respondents, post-hoc tests were administered to ascertain which characters exhibited notable statistical differences (Table 2).

Table 2: The influence of individual characters on test parameters

Dependent Variables	(I) Character	(J) Character	Mean Difference (I-J)	Std. Error	Sig.
Likeability	Male character 1	Male character 2	1.200*	0.304	**0.002**
		Female character 2	1.000*	0.304	**0.016**
	Male character 2	Male character 3	-1.100*	0.304	**0.006**
		Female character 1	-1.500*	0.304	**0.000**
		Female character 3	-1.550*	0.304	**0.000**
	Male character 3	Female character 2	0.900*	0.304	**0.042**
	Female character 1	Female character 2	1.300*	0.304	**0.001**
	Female character 2	Female character 3	-1.350*	0.304	**0.000**
Naturalness of appearance	Female character 2	Male character 1	-1.250*	0.311	**0.001**
		Male character 3	-1.150*	0.311	**0.004**
		Female character 1	-1.000*	0.311	**0.021**
Positivity	Male character 2	Male character 1	-1.800*	0.564	**0.022**
		Male character 3	-1.800*	0.564	**0.022**
		Female character 1	-2.100*	0.564	**0.004**
		Female character 3	-1.950*	0.564	**0.010**
	Female character 2	Female character 1	-1.900*	0.564	**0.013**
		Female character 3	-1.750*	0.564	**0.028**
Trustworthiness	Male character 1	Male character 2	1.200*	0.364	**0.016**
		Female character 2	1.500*	0.364	**0.001**
	Male character 2	Female character 1	-1.150*	0.364	**0.024**
		Female character 3	-1.050	0.364	0.051
	Female character 1	Female character 2	1.450*	0.364	**0.002**
	Female character 2	Female character 3	-1.350*	0.364	**0.004**

Through a one-factor analysis of variance, the impact of the character models on parameters such as likability, naturalness of appearance, excitement, positive attitude of the respondents, and trust was investigated. Given that six characters were generated, the analysis involved comparing these six groups. A significant statistical difference was observed across all tested parameters, most prominently when contrasting male character 2 with male characters 1 and 3 and female characters 1 and 3. As for female character 2, a notable statistical difference was only detected when compared with male character 2. The most pronounced statistical significance of difference was noted in the likability parameter, particularly between male character 2 and female characters 1 and 3, and when comparing female character 2 with female character 3. The mean values of the differences are presented with either a positive or negative sign based on the direction of the comparison. For instance, when evaluating the likability expressed by male character one and male character 2, the mean difference is 1.2. These findings suggest that the ratings for the likability parameter of male character 1 are higher than those given for male character 2. Conversely, the scenario is reversed when examining the comparison of likability for male character two and female character 1. The mean difference value is 1.5, indicating that, in this case, the ratings of the first character (male 2) are lower than those of the character with which it is being compared (female 1). This interpretation of the results aligns with the ratings observed in the descriptive analysis.

4.3.3 Determination of correlation between parameters

A statistical correlation test was conducted to assess the impact of the likability and naturalness of the character's appearance on user trust. This analytical approach provides insight into the strength of the relationship between the parameters under examination.

Upon analysing the correlation between the parameters of likability and trustworthiness, as well as the naturalness of the appearance and respondents' trust, it was determined that a positive correlation exists between these parameters, exhibiting exceptional statistical significance (Table 3). This positive correlation signifies that the parameters are directly proportional, providing a clear understanding that the more likeable and natural a character is, the higher the level of trust. Regarding the strength of the relationship between the parameters, it was determined that both pairs of parameters were of high strength.

Table 3: Correlation test results

		Trustworthiness
Likeability	Pearson Correlation	0.766**
	Sig. (2-tailed)	0.000
	N	120
Naturalness of appearance	Pearson Correlation	0.600**
	Sig. (2-tailed)	0.000
	N	120

Calculating the coefficient of determination offers insight into the percentage of variance of one parameter caused by the variance of another parameter. In the case of the first pair of parameters tested (likability and trustworthiness), this coefficient stands at 59%. In contrast, in the case of the second pair (naturalness of appearance and trustworthiness) is somewhat lower at 36%. Consequently, likability accounts for 59% of the variance in responses concerning trustworthiness, while naturalness explains 36% of the variance in trustworthiness.

5. CONCLUSIONS

This research aimed to investigate the impact of virtual therapists' visual factors on users' reactions. Respondents' responses to six characters, created using MetaHuman Creator software and supplemented with audio recordings, were examined. Parameters such as the character's likability and naturalness of appearance, user excitement and positivity, and the sense of trustworthiness evoked by the characters were evaluated. Video stimuli were employed.

Based on respondents' subjective assessments, female character 3 received the highest likability rating, while male character 1 was considered the most natural and reliable. Female character 1 produced the greatest excitement and positive feelings among respondents. Conversely, male character 2 received the lowest ratings regarding likability, excitement, and positivity, while female character 2 scored poorly across all parameters. Overall, female character 1 was perceived most positively, while female character 2 garnered the most negative perception. Statistical analyses were conducted to assess variations in respondents' responses for each character individually. The T-test results indicated no statistically significant variations for any parameter across all characters. Additionally, one-factor ANOVA revealed significance only in the excitement parameter. Post hoc tests identified notable differences, particularly between female character 2, the other two female characters, and male character 1. Furthermore, a correlation analysis was conducted to explore the relationship between likability and the naturalness of the character with user trust. Both pairs exhibited a strong positive correlation.

Based on the results, it is concluded that when creating characters representing virtual therapists, it is necessary to take care of their visual characteristics, and adapt them to the user. Interestingly, some respondents perceived character voices as different, even though only one per gender was used. In addition, it was observed that male respondents notice more details when observing male characters and potentially compare themselves to them. In order to carry out the implementation of this type of content within mobile applications for mental health, it would be necessary to expand the base of examined characters with more intense mutual differences and include a more significant number of respondents. It would be interesting to examine the influence of the colour of the voice, the clothing and the environment in which the character is located on the respondents' reactions.

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GENERATIVE ART METHODS FOR IMAGE CREATION

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Abstract: *In this paper, several generative art methods for image creation are discussed. Generative art is a form of image and video creation using artificial intelligence and machine learning. The methods explored include Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Denoising Diffusion Probabilistic Models (DDPMs). GANs involve two submodels: a generator, which generates image examples, and a discriminator, which classifies whether the generated examples are real or fake. VAEs consist of an encoder, which compresses input data into latent variables, a latent space representing the compressed data, and a decoder, which reconstructs the original data from the latent samples. Diffusion models generate image data by gradually adding noise to the data (diffusion) and then reversing the process (denoising) to produce new data. This paper also discusses the challenges, applications, ethical considerations, and future directions of generative art in the field of graphic design.*

Key words: generative art, GAN, VAE, diffusion models

1. INTRODUCTION

When speaking of generative art, there are several definitions that explain the creation of such art. One states that generative art is generated by a system that operates autonomously, and that artist may create the system itself, set parameters that influence image creation but ultimately the system creates the outcome (Tempel, 2017). Cao et al. in their paper define generative art as Artificial Intelligence Generated Content (AIGC), which refers to content generated by generative artificial intelligence (GAI) which can automate the creation of large amount of content in short period of time (Cao et al., 2023). Content can be textual - conversational (as ChatGPT or Microsoft Gemini), it can be images (Dalle -2, Midjourney, Microsoft Designer, Stable Diffusion and many others) and video creation (as Open AI Sora or Runway ML). These tools allow designers, artists and enthusiasts to create art without technical knowledge. Historically, generative art has existed for some time, and its origins trace back to the mid-20th century. There were several artists who contributed to computer generated art, like Vera Molnar, Harold Cohen, Herbert Franke, Manfred Mohr and others. Harold Cohen created AARON, computer software for independent art creation (Crysalis, 2021; Hencz, 2023). In more recent period, with the rise of machine learning generative art is on new heights, enabling creations of many different artistic styles which can be inspired by some already existing art or new, not seen before creations. This all could not be possible without advancements in artificial intelligence, machine learning models such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Denoising Diffusion Probabilistic Models (DDPMs) which are being discussed in section 2. of this paper. Besides these advancements in technology, ethical questions come into the picture. Questions concerning originality of the text or image, authorship and changes in the design process. The aim of this paper is to explore technical aspects of several generative art algorithms, with visual examples of today's possibilities, and to explore possible future directions of generative art.

2. GENERATIVE ART CREATION METHODS

2.1 Generative Adversarial Networks (GANs)

Generative Adversarial Network (GAN) is an algorithm that consist of two neural networks which work in opposition – a generator and a discriminator. The generator attempts to learn from real data in order to create new data, while discriminator attempts to determine whether the input is from the real data space or not (Cao et al., 2023). Figure 1 depicts a simple GAN algorithm.

ORCID numbers are provided at the end of the paper.

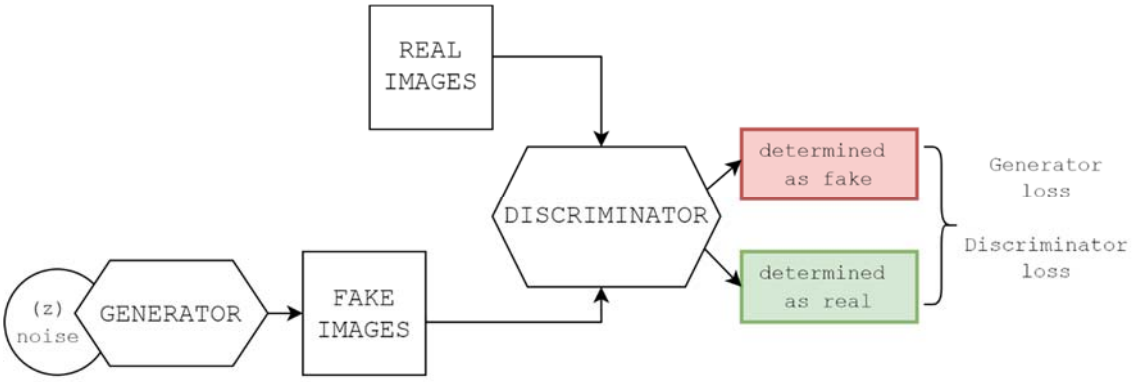


Figure 1: GAN network (adopted from (Wang et al., 2021).)

Both the generator and discriminator are trained simultaneously, where generator creates images and tries to fool the discriminator which tries to distinguish from real images and generated ones, and objective of GAN is to learn the generators distribution that approximates real data distribution (Wang et al., 2021). The generators loss function tries to measure and minimize the probability that the discriminator determines generated data as fake, and the discriminator loss function tries to measure and maximize correctly determined data as real. GANs require to find the Nash equilibrium, which is a state of end game between generator and discriminator, a place where they can't improve in learning. There are several GAN architectures and Das (2023) numbered six of them in his article (CycleGAN, StyleGAN, PixelRNN, text-2-image, DiscoGan and IsGan. He also states that all of these architectures are built on adversarial loss, and have generator and discriminator. Wang et al. (2021) also give an extensive taxonomy of recent GANs in their paper. Figure 2 depicts an image created from Artbreeder website containing "dark brown dog sitting on a bench in a park in front of tall green trees" prompt.

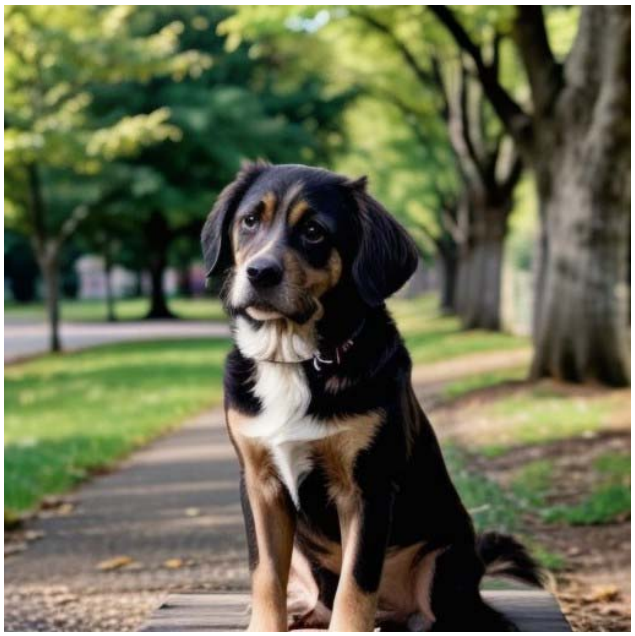


Figure 2: GAN image created from Artbreeder

2.2 Variational Autoencoders (VAEs)

Variational Autoencoders (VAEs) are a type of generator based on probability and include a latent space. Variational means that this technique uses Bayesian machine learning – variational Bayes (Foy, 2021). This feature makes them different from classical autoencoders which are not capable of producing new data, but they are similar because of encoder and decoder (Doersch, 2016). Autoencoders use a fixed (deterministic) latent code to map the input to, while Variational Autoencoders will replace this with a (Gaussian) distribution (Wenzel, 2022). VAEs work by compressing data into latent space (via encoder)

where data is now presented as vectors and then the decoder reconstructs the data from the latent space and generates new data. Figure 3 depicts a simple VAE algorithm.

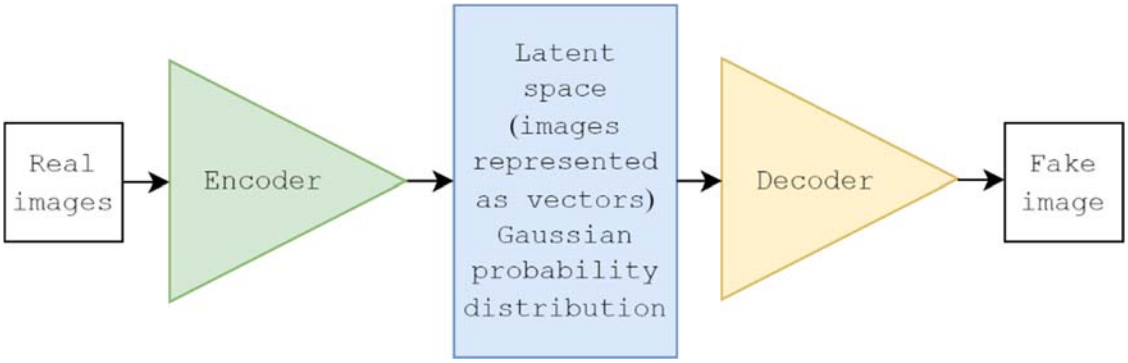


Figure 3: Simple VAE algorithm

Architecture of VAEs has three key components – encoder, latent space and decoder. At the end of encoder, we got samples of data, but presented in a probability distribution, allowing for meaningful interpolation between data samples. After this latent space, the samples of data (vectors) can pass through the decoder which are then passed through the neural network (Foy, 2021). Decoder converts data back into original form, reconstructing them from a lower-dimensional latent space into a higher-dimensional data domain. There can be many data samples in the latent space from which decoder can create new images. VAEs also have a reconstruction loss, which is similar to GAN reconstruction loss (Kullback-Leibler divergence) (Wenzel, 2022). This loss functions ensure that generated data is similar as possible to the original. Kingma & Welling in their paper list several applications of generative art, like training VAE on chemical structures with aim to search for new structures, then to generate natural language sentences, even to do simulations of observations of far galaxies (Kingma & Welling, 2019). Figure 4 depicts an image reconstruction using VAEs. Pros of VAEs are that they are stable and more reliable than GANs, cons are blurry images and not so realistic images.

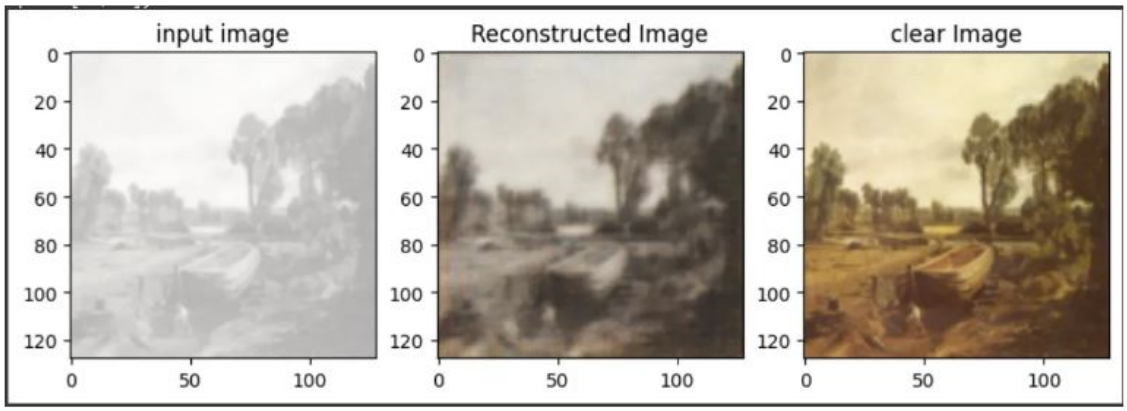


Figure 4: Image reconstruction – image curtesy of: https://pub.aimind.so/image-restoration-using-deep-learning-variational-autoencoders-8483135bb72d

2.3 Denoising Diffusion Probabilistic Models (DDPMs)

Diffusion models are a class of generative probabilistic models that produce images through a process of gradual noise injection into the original data until it turns into the known noise distribution, before reversing this process with noise reduction (Cao et al., 2015). DDPM models make use of two Markov chains - one that adds noise to the data and other which converts data from the noise (Yang et al., 2024). Figure 5 below depicts a Denoising Diffusion Model algorithm. Models are trained on large image datasets, the larger the dataset, the better generated outcome.

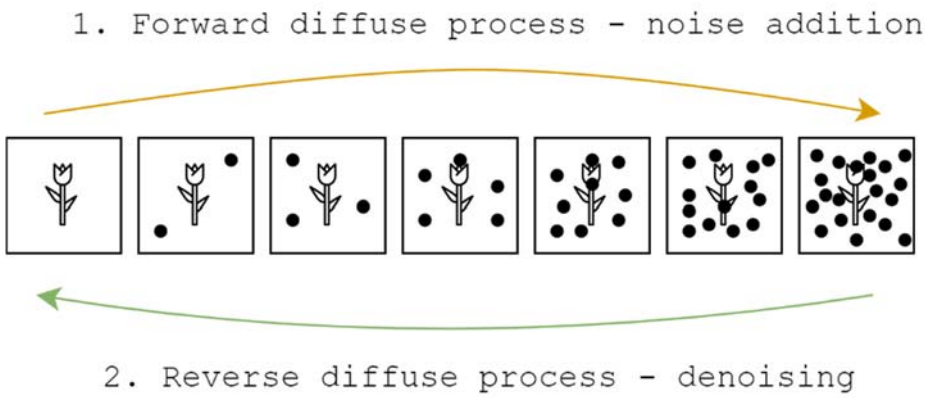


Figure 5: Denoising Diffusion Model algorithm

Ho et al. (2020) in their paper argue that diffusion models are straightforward to define and efficient to train, and show with their experiments that this model can produce high quality outputs (Ho et al., 2020). Besides image creation, diffusion models are now capable of video creations (GANs and VAEs are also capable) from text input (Zhou et al., 2024). Pros of stable diffusion models are high quality images and diverse outputs and cons are the time needed to sample an image, in comparison to other models, and artefacts which can be created during sampling of the image.
And to demonstrate visually stable diffusion, Figure 6 depicts an image created using said model and generating “dark brown dog sitting on a bench in a park in front of tall green trees” prompt.



Figure 6: Image created with stable diffusion model

3. CONCLUSION

In this paper, some of the most prominent generative art models for image creation have been explained in terms of functioning and output generation. Explained were main differences between GANs – which employs generator and discriminator which adversarial positions enable image creation; VAEs – which uses two main components encoder and decoder, which in between them contain a latent space where samples of data in vector format are stored, and finally DDPMs – Diffusion models rendering two processes named forward diffuse process and reverse diffuse process where noise is added and removed in image creation process. Not all generative art models were mentioned in this paper, like Autoregressive models (PixelRNN), Neural Style Transfer, Transformers, Clip, Variational Diffusion Models, but will be in a sequential paper. Generative models have several practical applications in graphic design, digital art, gaming industry and

video generation, and can accelerate processes which would usually take longer. Some downsides of this text/image/video production are beginning to unveil as inability to recognize real from artificially generated content, especially as deepfake videos where fake news can be easily placed in order to spread misinformation. Also, problems with generating delicate and illegal content can be encountered. Finally, it is unlikely that generative image creation will slow down in progress, and rather than avoiding and resisting its presence we can use it as a supplement and use it responsibly.

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https://doi.org/10.24867/GRID-2024-p37 Original scientific paper

AI Effectiveness of Background Removal for Different Depths of Field in Product Images

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Abstract: *AI models are being used and further developed daily. In graphic design, one of the most common uses is background removal from product images. This paper analyzes the effectiveness of background removal for common products by varying the depth of field. Tests were conducted using two AI background removal models on products of different shapes and textures, with both uniform and structured backgrounds. The results indicate that a shallow depth of field can be beneficial for background removal when the background is not uniform. Conversely, for a uniform background, a larger depth of field can aid AI, especially when the product is larger in size.*

Key words: AI model, background removal, product images

1. INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative force across numerous fields, with particular advancements in graphic design and image processing. AI models, particularly those utilizing machine learning and deep learning algorithms, now possess the ability to perform tasks that were once labor-intensive for humans. In the realm of graphic design, AI has become a vital tool for tasks such as image manipulation, enhancement, and background removal, significantly optimizing both the efficiency and quality of these processes. These advancements allow for increased productivity in design workflows while offering more consistent and refined outcomes (Bertão et al., 2023; Naima Obaid & Jarjis Namah, 2023). Background removal, the task of isolating a subject from its background, remains a fundamental step in many creative and technical processes, including photography, marketing, e-commerce, and virtual reality applications. Traditionally, this task required significant manual effort, whether through analogue techniques or early digital methods, making it both time-consuming and prone to human error. With the development of advanced digital tools, such as Adobe Photoshop, and the introduction of AI-powered features, background removal has seen substantial improvements in both accuracy and speed (Warnock & Geschke, 2019).

The integration of AI into modern image editing software, most notably through tools in Adobe Photoshop, has transformed the approach to background removal (Adobe, 2024). AI-driven models offer designers a faster and more efficient means of separating foreground elements from their backgrounds, significantly accelerating the overall workflow in graphic design. AI-based background removal leverages convolutional neural networks (CNNs) and other deep learning architectures to identify and isolate subjects within images, learning from large datasets of labeled images (Shah & Tembhurne, 2023). These models are trained to distinguish between foreground objects and background elements with high precision. However, despite their growing sophistication, the effectiveness of AI-based background removal is influenced by several factors. Complex image patterns, intricate textures, and varying depth of field can challenge the model's ability to perform accurate extractions (Hwang, 2023; Naima Obaid & Jarjis Namah, 2023; Rezk, 2023; Sindhura & Abdul, 2021). Moreover, AI models may struggle in cases where fine details, such as hair or transparent objects, are involved, often requiring manual post-processing (Wei et al., 2018).

This study aims to provide a comprehensive analysis of the performance of AI-based background removal techniques within Adobe Photoshop. Specifically, examines the impact of image complexity, background intricacy, and depth of field on the effectiveness of AI models in background extraction. By conducting a series of experiments, the research seeks to evaluate the success rates of AI-driven background removal methods and formulate recommendations for optimizing their application in professional design workflows.

ORCID numbers are provided at the end of the paper.

2. METHODS

2.1 Samples

Twelve objects were selected as research samples for this study, with a focus on items commonly featured in everyday catalogue sales. The selected objects include a baseball, broccoli, a flower, an instant camera, a pack of coffee, a cabbage, a lantern, a moka pot, a Venus flytrap plant, tomatoes, a tennis ball, and a bottle of water. In addition to ensuring the suitability of the objects for catalogue sales, object size was carefully considered to minimize variation, thereby reducing potential discrepancies in the photographic process. The shape of the objects also played a critical role in the selection process, as the objects were categorized according to both shape and complexity. Objects with more irregular outlines were deemed as more complex as well as objects with holes and transparent surfaces. Objects were also divided in two main categories: organic (have more irregular curves and corners) and non-organic (more regular lines, corners and curves). The classification was: non-organic simple, non-organic medium complexity, non-organic complex, organic simple, and organic complex (Table 1). This classification framework allowed for a systematic analysis of background removal performance across a diverse range of object types. This was also a classification of the expected success rate.

Table 1: Research samples categorized

 ***pack of coffee*** *(non-organic simple)*	 ***bottle of water*** *(non-organic complex)*	 ***lantern*** *(non-organic complex)*	 ***broccoli*** *(organic complex)*
 ***baseball*** *(non-organic simple)*	 ***moka pot*** *non-organic medium complexity*	 ***tomatoes*** *organic simple*	 ***flower*** *organic complex*
 ***tennis ball*** *non-organic complex*	 ***instant camera*** *non-organic complex*	 ***cabbage*** *organic simple*	 ***Venus flytrap*** *organic complex*

2.2 Background

In addition to sample objects, three backdrops are chosen as additional variables. The backdrops simulate different complexity with a goal to function as noise for background removal. Matte grey backdrop with minimal texture as a neutral background (Figure 1a); backdrop with a lighter complex pattern and lower value contrast (Figure 1b); and backdrop with a darker complex pattern and higher value contrast (Figure 1c).



a) matte grey *b) light complex pattern* *c) dark complex pattern*

Figure 1: Background samples

2.3 Photographic setup

The camera used for this research was a Canon 60D equipped with a portrait Tokina 100 mm f/2.8 AT-X Pro Macro lens. For the samples used in this study, three aperture settings were defined to achieve three different depths of field. A shallow depth of field was achieved with aperture f/2.8, medium depth of field with f/8 and large depth of field with aperture f/32. Each depth of field was paired with an appropriate exposure setting 1/40s, 1/5s and 4s respectively. Additionally, the sensor sensitivity (ISO) was set to 100 for all images. This ensured optimal image quality, minimizing digital noise and resulting in sharper, clearer photographs. For the scene setup, specific parameters were established for photographing the objects Figure 2.

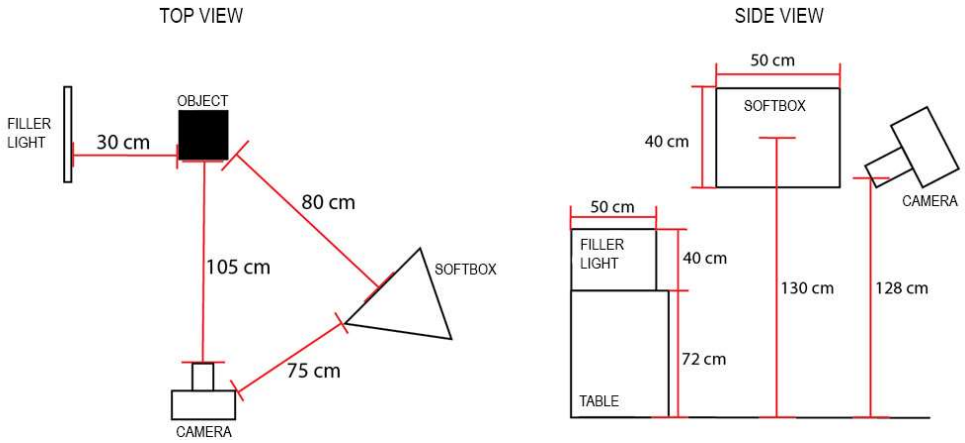


Figure 2: Photographic scene and light setup

The lighting setup utilized a Dedo Weigert Film Munich softbox, in combination with a Dedotec GmbH Munich lighting lamp, model DLH1000S with a 1-N-PE head (50/60 Hz).
ColorChecker Passport Photo 2 was used make a three camera profiles (one for each exposure setting). By utilizing the ColorChecker, consistent colour representation of the photographed objects was ensured.

2.4 AI background removal

After assigning the corresponding camera profile in Adobe Camera Raw 16.3 images were batched saved as JPG format. The images were additionally opened in Adobe Photoshop 2023, where the "Remove background" tool was used from the floating window option. Each image was subjected to three attempts of background removal to check the consistency of the results. The results obtained through AI were not altered or manually refined.
In addition, Removal.ai, was also employed as an open-source AI background removal tool. The photographs in JPG format were uploaded and the "remove background" option was selected. The tool autonomously removed the background from the image, and the resulting images were saved in JPG format same as the Adobe Photoshop workflow.

2.5 Grading

The results of the processed photographs were evaluated on a scale from one to five (Table 2). A rating of one was assigned to results that fully met the expected criteria. Two was given to results where small areas of the background remained, while a rating of three was assigned to results where larger areas of the background were still present.

Table 2: Grading description

Description	Grade
Successful – no visible flaws	1
Small areas of background remaining	2
Large areas of background remaining	3
Small segments of the object removed	4
Large segments of the object removed	5

Photographs in which small segments of the object were removed were given a rating of four, and those with larger portions of the object missing received a rating of five (Table 3). This grading method was adopted to facilitate comparison and better assess the success of background removal. The assumption was that is easier for the user to manually remove any remaining elements that the AI did not detect, rather than restoring portions of the object that were incorrectly removed. It is important to state that image results graded as 4 can be more acceptable if demonstrates no objection to losing smaller parts of the object that cannot be recognized as missing.

Table 3: Grading example

				
Successful – no visible flaws (1)	*Small areas of background remaining (2)*	*Large areas of background remaining (3)*	*Small segments of the object removed (4)*	*Large segments of the object removed (5)*

3. RESULTS AND DISCUSSION

The background removal process was conducted on June 24th, 2024, for Adobe Photoshop and on July 18th, 2024, for Removal.ai. Each result remained consistent when repeated three times. The results are presented in Tables 4, 5, and 6, based on the background used. The mean results provide as a general overview but examining individual cases is necessary for deeper insights and more conclusive findings.

Table 4: Grading results for matte grey (MG) background

		Adobe Photoshop			Removal.ai		
	aperture	**f 2,8**	**f 8**	**f 32**	**f 2,8**	**f 8**	**f 32**
matte grey (MG) background	Baseball	1	1	1	1	1	1
	Broccoli	4	1	1	4	1	1
	Flowers	3	4	3	2	2	2
	Instant camera	2	2	2	1	1	1
	Coffee pack	1	1	1	1	1	1
	Cabbage	1	1	1	1	1	1
	Lantern	3	3	3	2	2	2
	Moka pot	4	4	4	1	4	4
	Venus flytrap	4	4	4	1	1	1
	Tomatoes	4	4	4	1	1	4
	Tennis ball	4	4	4	4	4	4
	Bottle of water	4	4	4	1	1	1
	mean	2,92	2,75	2,67	1,67	1,42	1,67

Results from the MG background (Table 3) generally show superior background removal performance within the assigned grading system compared to other backgrounds, with a few exceptions. The LC background produced better results with tomatoes when using Adobe's AI and with the tennis ball when using both Removal.ai and Adobe across all aperture values (Tables 3 and 4). Additionally, the DC background showed improved results for the tennis ball when using Removal.ai at f/8 and f/32 aperture settings.
For the MG background, different aperture values mostly yielded consistent results, with two exceptions: parts of the broccoli were removed at f2.8 for both AI models, and a similar issue occurred with the tomatoes at f/32 using Removal.ai.

Table 5: Grading results for light complex (LC) background

		Adobe Photoshop			Removal.ai		
	aperture	**f 2,8**	**f 8**	**f 32**	**f 2,8**	**f 8**	**f 32**
light complex (LC) background	Baseball	2	4	4	1	3	3
	Broccoli	5	5	5	5	3	3
	Flowers	5	5	5	4	3	3
	Instant camera	5	5	5	5	5	5
	Coffee pack	4	3	4	4	2	2
	Cabbage	4	4	4	1	1	3
	Lantern	3	4	5	2	3	3
	Moka pot	5	5	5	4	4	4
	Venus flytrap	4	4	4	4	3	3
	Tomatoes	2	2	4	1	3	4
	Tennis ball	1	2	2	3	3	3
	Bottle of water	4	4	5	2	2	1
	mean	3,67	3,92	4,33	3,00	2,92	3,08

The LC background posed several challenges for the AI models, leading to inferior results compared to the MG background, but marginally better performance than the DC background (Tables 4 and 5). The LC background caused difficulties with the cabbage, while the DC background produced slightly better results for the moka pot and lantern when using Adobe AI. Removal.ai showed improved performance with broccoli, flowers, the coffee pack, and the Venus flytrap at f2.8 on the DC background, as well as with the Venus flytrap and cabbage at f/8 and f/32, respectively.

Table 6: Grading results for dark complex (DC) background

		Adobe Photoshop			Removal.ai		
	aperture	**f 2,8**	**f 8**	**f 32**	**f 2,8**	**f 8**	**f 32**
dark complex (DC) background	Baseball	4	4	5	4	5	5
	Broccoli	5	5	5	4	4	4
	Flowers	5	5	5	2	5	5
	Instant camera	5	5	5	5	5	5
	Coffee pack	4	4	4	3	2	2
	Cabbage	1	1	2	2	2	2
	Lantern	3	3	4	5	5	5
	Moka pot	4	4	4	4	4	5
	Venus flytrap	4	4	4	2	2	3
	Tomatoes	4	4	4	2	4	5
	Tennis ball	4	4	4	4	3	3
	Bottle of water	4	4	4	2	2	2
	mean	3,92	3,92	4,17	3,25	3,58	3,83

Overall, the results from Removal.ai were rated higher than those from Adobe, except for the tomatoes at f/8 and the tennis ball across all apertures with the LC background (Table 4). According to the grades 4 and 5 it is indicated that Adobe AI has a more aggressive process that results in smaller and larger parts of the objects removed. This can be observed as an advantage as Adobe AI removes more background than Removal.ai but Removal.ai process can be seen as a safer approach.

3.1 Different background discussions

LC and DC backgrounds introduced noise into the AI background removal process, as was expected based on the literature. It was observed that background texture and colour posed multiple types of issues. In the case of the baseball, the red stitching was recognized as part of the background, resulting in the removal of part of the ball (f/8 and f/32) in Adobe AI, and leaving the background in Remove.ai results (Table 4). The similarity between the pink background and the red coffee package also posed a challenge for AI models. In the MG background, Adobe AI removed parts of the tomato stem, while Remove.ai only related the stem to the background at f/32. This is likely due to the similarity in lightness, possibly caused by the lack of sharpness and chromatic aberration in the photograph.

3.2 Different object discussions

Broccoli was the largest object that had parts of the product out of focus at f/2,8 which is assumed to be the reason the AI mistakenly related it to the background. Similar issue was visible in the cabbage images but only for Adobe AI results. Conversely, the background reflection in the top of the moka pot also caused parts of the object removed. Larger portions were removed when complex background was used. Both AI tools remove background from holes in the objects (instant camera and lantern) but Adobe Ai struggles with smaller openings. It is also observed that both AI models cannot recognize transparent surfaces. The assigned complexity was mostly correct. Irregular curves in the organic object did not cause additional difficulties when compared to non-organic object but small details and thin elements, like fuzz on the tennis ball, are more prone to cause an issue (Microsoft, 2024; Wei et al., 2018). Improved results in Hair removal and similar issues can be expected in the future (Liang et al., 2023; Wei et al., 2018).

3.2 Different depth of field discussions

The results indicate that the depth of field does not pose a significant issue when dealing with uniform backgrounds. Therefore, using an aperture of f/8 is recommended to minimize the impact of camera lens imperfections, provided the size and distance of the object permit. For complex backgrounds, the findings suggest that a shallow depth of field can enhance the effectiveness of AI-based background removal. Moreover, complex backgrounds tend to interfere with background removal, particularly when a larger depth of field is used. The AI models appear to more accurately detect objects when the background is blurred, as they do not recognize perspective. In the case of reflective objects, a smaller depth of field has been observed to yield better results.

4. CONCLUSIONS

The primary goal was to assess how well the AI model distinguishes between the subject and various background types. As anticipated, the use of the matte grey background resulted in more accurate object extractions indicating that uniform background is better for obtaining successful outcomes. The analysis showed that, when using the Adobe Photoshop AI model, incomplete background removal or partial object removal frequently occurred. In contrast, the AI model used in Remove.ai produced superior results, successfully separating nine out of twelve objects from the background (Adobe achieved only four out of twelve).

When using uniform grey background, it can be concluded that depth of field is not a factor in AI object/background recognition. It is only observed as a factor when parts of an object fall out of focus meaning that for a successful background removal the whole object needs to be in focus. As expected, the light and dark complex background demonstrated that a shallow depth of field (while the full object is in focus) produces slightly better results, especially in Adobe AI model. This also produced better results in the product with the reflective surfaces. This suggests that out-of-focus areas help AI models distinguish background from object. However, this presents a challenge, as it is known that the middle value aperture of a lens produces the best picture quality but large object require higher aperture value to achieve larger depth of field (full focus). When object is not on a uniform background it can also be concluded that Adobe AI model has a more aggressive process that often results in partial object removal. This can be observed as a possible advantage if the main goal is speed over accuracy. It is also concluded that AI doesn't offer solutions for objects with small holes and transparent and semitransparent surfaces. As AI is constantly improving it is expected that the same images will produce better results on the same platforms in the

future. This research will be extended to investigate the influence and contrast as well as improvement in the AI models by repeating the process in a later time using the same samples.

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EXPLORING THE VERSATILITY OF OPEN-SOURCE SOFTWARE FOR INDUSTRIAL IMAGE PROCESSING: A CASE STUDY

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Abstract: *The article investigates the potential applications of free open-source software in image processing for a diverse range of industrial uses, including laser texturing, machining, and additive manufacturing. A case study is presented, wherein digital photography is utilized to capture a scene, followed by processing in the GNU Image Manipulation Program. The processed image in the form of a height map is then imported into the Blender software suite to generate a high-resolution 3D model. The quality of this model is further enhanced using various software functions such as object modifiers, and mesh sculpting. Based on the high-quality 3D model, a high-resolution height map is rendered. Subsequently, the exported height map is utilized for surface modification through laser beam technology and additive manufacturing via fused deposition modeling. This analysis aims to investigate the efficacy and adaptability of open-source software in industrial settings. The article also highlights the steps involved in: 1) capturing an image digitally through photography, 2) creating a 3D artistic relief in Blender, 3) converting the polygonal model of the relief for laser micromachining graphics, and 4) adapting the polygonal model for 3D printing graphics. The study concludes with an evaluation of the results, examining the suitability of use of open-source software for generating relief from photographs for various industrial applications.*

Key words: 3D relief, 3D printing, Laser micromachining, Blender software

1. INTRODUCTION

Utilization of 3D models for manufacturing processes has been a technical method of choice in the past decades, and at present it still remains a highly relevant approach (Chlebus & Krot, 2016). Currently, there are multiple different ways of obtaining a three-dimensional model such as parametric or box modeling, sculpting, or optical scanning (Rusinkiewicz et al, 2002; Pollefeys, 2004). Case use of these methods depends on many factors and also the limitations of each method (Vranic & Saupe, 2004). In general, entry data containing information such as dimensions, surface characteristics, or constraints are needed to begin the creation of the model (Rivers et al, 2010). The practice of using visual cues to sketch the base model and then continue further with its refinement can often be a viable solution, especially if the source material is of poor quality or a highly detailed and precise model is needed for the application (Remondino & El-Hakim, 2006; Chen et al, 2003). This is especially important for high-precision industrial manufacturing methods such as laser beam machining. However, in some cases using a highly detailed model can be an issue due to drawbacks when it comes to computation time resulting from a high number of polygons requiring processing as well as large file size (Bernardini & Rushmeier, 2002). Therefore, adequately adapting both the source images and the final model is a much-needed step in the preparation for the subsequent manufacturing process, as it can significantly influence the resulting quality an accuracy.
This article examines the innovative application of Blender, a highly advanced and robust open-source software tool specifically engineered for the complex creation and editing of three-dimensional data, which can also facilitate the development of reliefs derived from images captured digitally via a camera. Following this preliminary phase, the prepared relief is subsequently utilized to generate the precise CNC paths that are implemented for laser micromachining and additive manufacturing processes. Thereafter, this generated data is employed in the fabrication of samples to evaluate the appropriateness of the constructed three-dimensional relief.

2. MATERIALS AND METHODS

2.1 Source image processing

An uncompressed photograph in the .ARW format was captured with a digital camera to ensure sufficient clarity for further editing. Parameters with which the photograph was taken are following: 1/1250 exposure, focal length of 28 mm and ISO of 100. The file was loaded in the GNU image manipulation

ORCID numbers are provided at the end of the paper.

software, where it was desaturated and separated into layers depending on the image depth and perspective. Layers were then overlayed with black and white color gradients to produce an initial height map with a resolution of 6048 x 6048 pixels. Figure 1 shows initial layer separation of the grayscale photograph.



Figure 1: Initial layer separation of the grayscale image

2.2 3D model preparation

Following the initial manual editing, the height map was loaded in the Blender software. A simple plane object which was subdivided 10 times was added to the scene. Subdivision surface object modifier with the setting of simple algorithm and six levels of subdivision was applied to produce a mesh with a high enough polygon count, to ensure matching texel density with the pixels on the height map. Another object modifier was used to produce displacement of the subdivided plane, into which the texture with the height map was linked. While the height map was of sufficient resolution, the 3D object generated with it was still lacking features that would produce the desired result. In order to continue with further editing in the sculpt mode, all the object modifiers were applied, and the subdivided plane was turned into a 3D object. Prominent visual features from the original photo were hand-drawn using multiple brushes in the sculpt mode and some artifacts from the height map were smoothed. Additionally, a simple text object was inserted into the scene as well. Figure 2 shows final 3D model. Total polycount of the model was more than 10 million triangles.



Figure 2: Final 3D model

2.3 Height map rendering

After the 3D model was finished, it needed to be turned into a higher resolution depth map in order to be used for the laser micromachining. A simple node setup in the Cycles rendering engine was used to transfer the mesh into a depth map. Render settings were following – resolution of 8128 x 4096 pixels, 16-bit color depth and no compression. Adjustment of the gamma value was required to achieve full grayscale range

that could be utilized for laser micromachining software. Figure 3 shows height map render setup in Blender application.

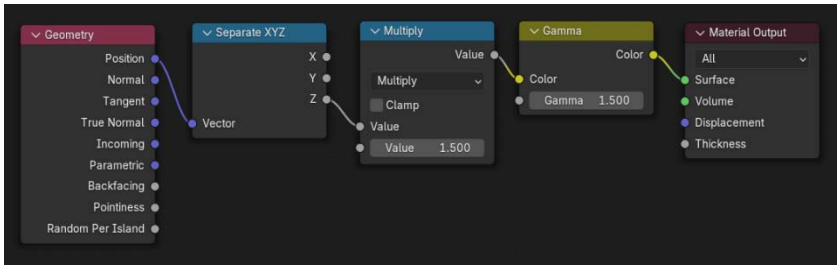


Figure 3: Height map render setup

Figure 4 shows final render of the 3D model as a height map, which was then imported into the software for laser micromachining.



Figure 4: Rendered height map

2.4 Laser micromachining

The 3D relief model was initially produced using laser micromachining on a stainless steel plate. The production process and program generation for the machine require a BMP map as the template. From this BMP map, layers are generated, and the material is subsequently removed by the laser. In the case of the white layer (represented by a pixel value of 0), the laser does not pass over the surface, while for the black layer (represented by a pixel value of 255), the laser passes over the surface multiple times, penetrating deeper into the material and forming the 3D relief. A critical factor for successful laser micromachining is the accurate setting of machining and laser beam parameters. To determine the optimal parameters, experimental methods and statistical models are utilized, as outlined in the literature (Šugár et al, 2018; Kuruc et al, 2015), which employed the same machine used for our relief fabrication. The machine parameters in this process were as follows: laser beam power of 65 W, frequency of 80 kHz, scanning speed (i.e., beam movement speed) of 1800 mm.s^{-1}, and a path spacing of 10 µm. These settings corresponded to a material removal rate of 2 µm per layer. With 255 layers being removed, the maximum depth of the relief was calculated as 255 layers × 2 µm = 510 µm, approximately 0.5 mm.

The Figure 5 shows the generated paths to be used for laser machining and the solid colors correspond to the different relief layers. Each color represents a distinct layer, illustrating the intricate process of laser micromachining. The visual representation emphasizes the substantial number of generated trajectories, with the spacing between each trajectory set at a mere 10 micrometers. This close proximity results in a densely packed network of paths, highlighting the precision of the laser machining process. The multitude of trajectories indicates a meticulous approach to material removal, where each pass of the laser is finely tuned to achieve the desired depth and detail. The high frequency of these paths not only contributes to the overall complexity of the relief but also reflects the advanced capabilities of the laser technology employed. As the laser moves across the surface, the layering effect becomes apparent, with each

trajectory contributing to the gradual buildup of the final 3D form. The figure effectively captures the essence of the laser micromachining process, showcasing how the narrow distance between trajectories allows for the creation of intricate details and textures within the relief. This dense layering is crucial for achieving the desired depth and fidelity in the final product.

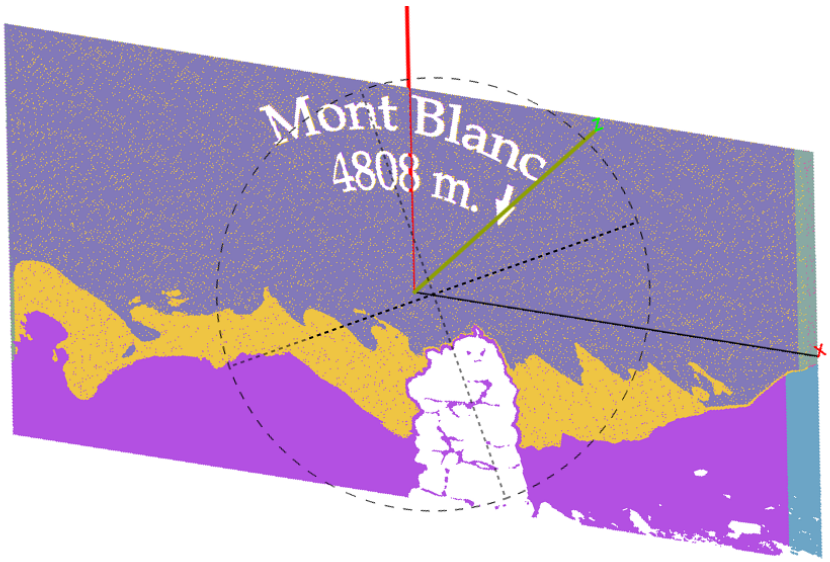


Figure 5: Generated paths for laser micromachining

2.2 3D printing

The 3D printing of the relief was carried out using a MARKETBOOT Replicator 2x, a non-professional standard FDM printer. Standard PLA was selected as the material due to its suitability for single-layer printing and its cost-effectiveness. The printing process followed the recommendations provided by the 3D filament manufacturer. The layer height was set at 0.2mm. The print speed was adjusted to 60 mm/s to ensure a balance between quality and efficiency, while the nozzle temperature was maintained at 210°C to achieve optimal adhesion and flow of the filament. After the initial print, a thorough inspection was conducted to identify any imperfections or areas that required post-processing.
The Figure 6 illustrates the process of generating layers in a 3D relief model during the additive manufacturing stage. It visually represents how the relief is constructed layer by layer, showcasing the incremental buildup of material. The figure may also highlight the specific parameters used, such as layer height and material type, emphasizing the precision and detail involved in creating the final printed part. Overall, it effectively conveys the methodical approach to layering in 3D printing.

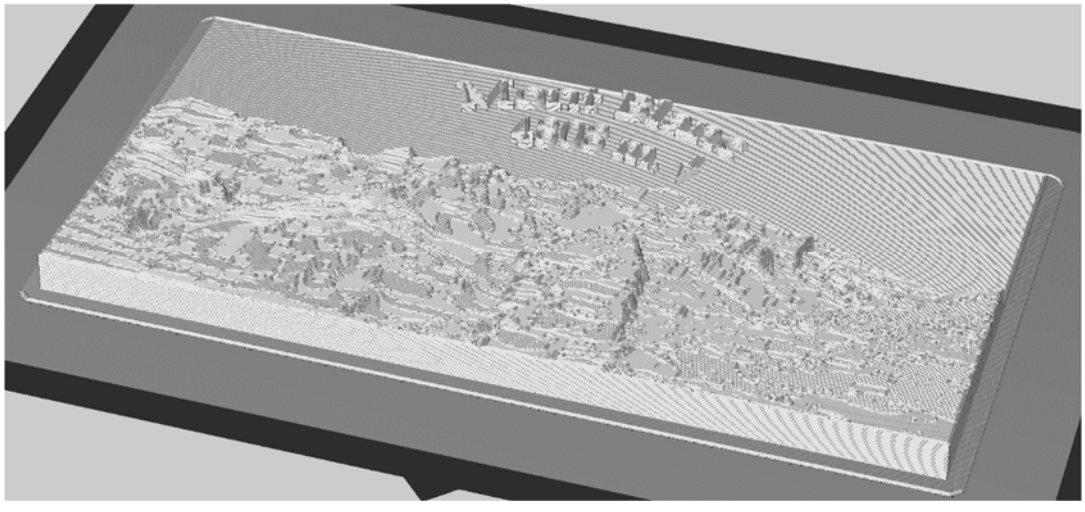


Figure 6: Generated layers in MakerBot slicer application

3. RESULTS AND DISCUSSIONS

3.1 Result of laser micromachining

The result of the laser machined part demonstrated a successful retention of small-scale visual details from the original photograph. However, the overall perceived depth of the relief was somewhat limited, which is expected due to the differences between the two-dimensional height map representation and the physical depth achieved through laser micromachining. Despite this limitation, the process effectively translated the digital model into a tangible relief, showcasing the capabilities of laser micromachining technology in preserving intricate details. This limitation highlights the challenges faced in translating complex designs into tangible forms, where the nuances of light and shadow play a crucial role in depth perception. Further refinement of the machining parameters could enhance the depth effect, allowing for a more pronounced three-dimensional appearance that better captures the original photograph's essence. Figure 7 shows a photograph of a laser machined sample of a complete 3D relief. It can be seen that there remain parts of the material unaffected by the laser beam, which is due to the high sensitivity of the software for color profile of the depth map. Having set too high cutoff for the white color resulted in the affected machined surface being incomplete. This error underlines the importance of adjusting the black and white levels of the imported height map in order to produce desired result.



Figure 7: Result of laser micromachining

3.2 Result of 3D printing

The 3D printing of the relief using the MARKETBOOT Replicator 2x resulted in a model that fell short of perfection. The printed output exhibited noticeable limitations in both quality and depth, impacting its overall appearance. To address these shortcomings, it is crucial to investigate and optimize the 3D printing process parameters. Adjustments in temperature, speed, and material could enhance the final product's detail retention. Additionally, reconsidering the design of the relief itself may also contribute to improved results. By refining both the printing techniques and the relief design, there is potential for a more visually appealing and detailed outcome. This dual approach could significantly elevate the quality of future 3D relief productions. Ultimately, striving for these improvements is essential for achieving better print results. The figure 8 shows a 3D printed relief created from PLA plastic material, showcasing noticeable imperfections that highlight the limitations of the printing process. The surface of the model reveals distinct layering, characteristic of Fused Deposition Modeling (FDM) technology, where each layer is visibly stacked upon the previous one. The visibility of the layers is pronounced, with each horizontal line marking the transition between layers clearly discernible. This results in a lack of fine detail, as the intricacies of the original design are lost in the pronounced ridges and valleys formed by the layering process. Additionally, the edges of the relief appear less crisp, further emphasizing the low-quality output. The overall appearance is somewhat blocky and lacks the desired depth. This is in part the result of the need to simplify the mesh density of the 3D model, since the 3D printer slicer software had issues processing the high polygon density of the sculpted model.

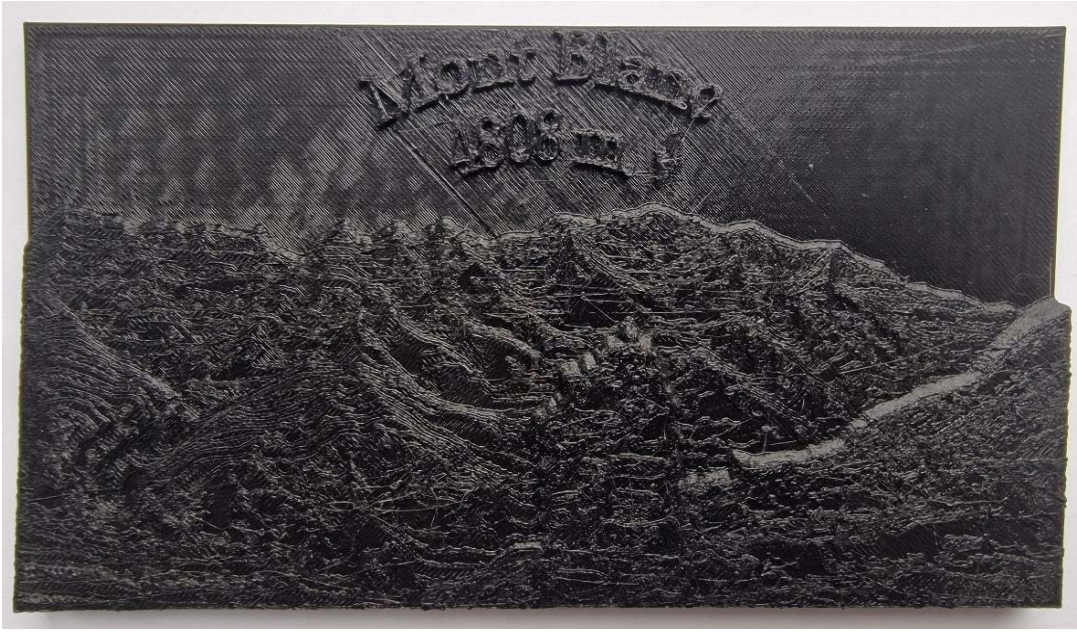


Figure 8: Result of 3D printing

4. CONCLUSIONS

The conclusion highlights the successful translation of the digital model into tangible 3D relief using Blender free software, sophisticated image processing and 3D modelling. Laser micromachining technology demonstrates the ability to preserve the intricate details derived from the original photograph. While the results demonstrate the effectiveness of the process, they also reveal significant limitations in the depth and quality of the 3D printed relief. The perceived depth of the relief, while retaining small visual details, was somewhat limited. Factors such as temperature, printing speed and material selection play a significant role in determining the quality of the final product and the retention of detail. By conducting systematic experiments to fine tune these variables, it may be possible to achieve a finer and more accurate representation of the intended design. In addition, a thorough rethinking of the relief design itself could yield improvements in visual appeal and detail, ensuring that the final product is more in keeping with the artist's or designer's vision.
Optimizing 3D printing parameters and reevaluating the relief design is important to improve future results. In conclusion, while the study successfully demonstrates the viability of using open source software to generate high quality industrial applications, it also highlights the need for continuous improvement and optimization. By addressing the identified limitations and taking advantage of technological advances, future projects can achieve a higher level of accuracy and artistry in the production of 3D reliefs. This constant pursuit of excellence not only improves the practical applications of these techniques, but also contributes to the broader field of digital fabrication, paving the way for innovative solutions in a variety of industries.

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RESTORATION OF OLD PHOTOGRAPHS USING AI APPLICATIONS

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Abstract: *Restoration of old photographs is a demanding task that requires a lot of skill and attention to detail. It can involve many different steps in photo editing and, until recently, was almost always done by photo editing professionals. Thanks to numerous photo editing AI applications, nowadays even the inexperienced users can perform this task. However, the results may not always be satisfactory. In this work, we evaluated the effectiveness of different free web-based AI applications in restoring old photographs that exhibited the most frequently seen damage. Tested AI solutions enabled significantly faster photo editing compared to manual techniques, while still providing visually pleasing results. On the other hand, they showed tendency to smooth out graininess, important details, and textures in images. When automatic processing failed to correct certain details, the results heavily depended on the user's skill to recognize and mark the errors for post-processing. Therefore, we believe that AI tools for photo restoration are a great choice for fast image processing, but their outcomes should be manually adjusted to ensure the authenticity and naturalness of old photographs.*

Key words: photo restoration, AI software, old photographs, photo editing

1. INTRODUCTION

The term 'old photography' informally refers to photographs taken in the past, typically before the widespread use of digital cameras, i.e., from the 19th to the mid-20th century (Moorshead & Chapman, 2000). It does not refer to a single technology, but includes every type of analogue photography - from early photographic processes to the film cameras many of us still remember. Therefore, 'old photography' encompasses a wide range of historical periods and styles (Frisch-Ripley, 1991). Photographs were printed on paper using various techniques (Mulligan & Wooters, 2012), and often hold historical, emotional, and/or cultural value. Preserving old photographs is essential for safeguarding memories and historical moments for future generations.

To adequately preserve old photographs, they must be stored and handled properly. Even with proper care, the materials used in their production deteriorate over time. The most evident change is fading – image became less vivid, details tend to blur and disappear, and the paper colour shift to yellow.

There are many other changes and errors that can be seen in old photographs. They can be caused by both internal (nature of the process and the durability of the materials used) and external factors (mechanical, environmental and other external influences) (Tamino Autographs, 2022). Damage caused by the internal factors are often observed as discolorations and other changes of colour and contrast, excessive graininess, dots and lines (if information was transferred from the film that was scratched), solarization and many others (Van Camp, 2010; Xu et al., 2023). On the other hand, mechanical damage can be seen as scratches, cracks, tears, loose emulsion, blots and stains, traces of adhesive tape, additional inscriptions, seals, glue residues, etc. (Tamino Autographs, 2022; Xu et al., 2023).

The process of repairing and enhancing old, damaged or deteriorated photographs, with the intention to return them to their original or even improved state, is known as photo restoration (Whitman, 2023; Lin, 2024). It is a challenging process that requires both technical skills and artistic abilities, as well as a lot of patience and attention to detail (Whitman, 2023). Photograph had to be properly evaluated in order to get an idea of how it looked in the past. All the damage needed to be meticulously restored, which can even require reconstructing the missing parts.

As photography transitioned from analogue to digital, photo restoration followed the same path. Digital tools revolutionized the field by enabling precise and controlled correction and enhancement of digital images, while offering photographers greater flexibility in making adjustments (Whitman, 2023). Digital photo restoration does not involve any physical manipulation of the analogue photography, except of its digitization, and is stated to produce better results in comparison to manual techniques (Ctein, 2010; Whitman, 2023).

ORCID numbers are provided at the end of the paper.

In recent years, we have witnessed a new advancement in the revival of old photographs: AI-powered image restoration. Artificial intelligence is nowadays able to create photographs, so it is no surprise that it can also restore them.

There are many AI software solutions for photo editing and restoration. Some of them rely on models specialized in correcting specific errors, while others employ more general ones (Wan et al., 2020). Key functions providing fast and efficient results in restoring old photos include scratches removal, colour restoration, detail enhancement and sharpening, noise reduction, facial features enhancement and reconstruction of details (Xu et al., 2023; Tang, 2024; Lin, 2024). These functions rely on deep learning methods, where complex neural networks are trained on extensive datasets containing both damaged and restored photos, to enable accurate learning and effective restoration (Wan et al, 2020; Xu et al, 2023). In addition, newly proposed model (Conde et al., 2024) incorporate natural language processing, and is designed to restore images by following human-written instructions.

The effectiveness of AI tools mostly depends on the dataset used for the training, as well as the proper training of the model. Since the lost or damaged parts of the photograph are generated from the scratch, the results can sometimes look unnatural.

In this study, we evaluated free web-based AI applications designed to correct and restore old photographs. The objective was to assess the effectiveness of widely accessible AI tools in addressing various types of damage present in old photographs and, ultimately, in producing images that appear natural and visually coherent.

2. METHOD

For the purpose of this work, we chose two old photographs that belong to the corresponding author of this paper – one black-and-white (Figure 1a) and one in colour (Figure 1b). The photographs were selected because they exhibited a range of common deteriorations typically observed in old images. Different kinds of damage were caused both by the aging and an inadequate storage of the photographs.

Due to improper storage conditions, both photographs exhibit visible stains, spots, and specks on their surfaces, likely caused by dust accumulation and soiling (Figure 1). Additionally, the photographs show signs of fading and mechanical damage, including scratches. In the black-and-white photograph surface cracking, splitting, and larger stains on the surface structure can be seen, as well as creases resulting from bending (Figure 1a). The colour photograph also shows a lack of contrast, slightly yellowish tone and reduced saturation (Figure 1b).

The selected photographs were scanned using the HP LaserJet M1120 MFP multifunction device. The scanning was conducted at a resolution of 300 ppi in the RGB colour space. Before further processing, the black background present after scanning was removed. In order to preserve jagged edges of colour photograph (Figure 1b), removing of the black background was done in Photoshop 2022. The image was saved in PNG format so as to preserve transparency.

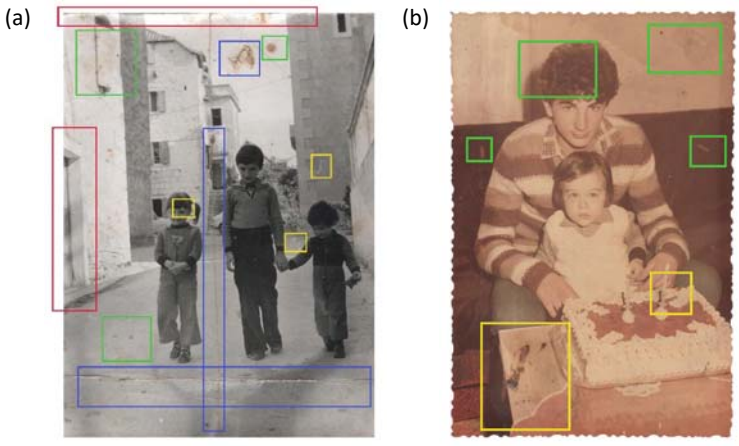


Figure 1: Selected photographs: (a) black-and-white and (b) colour. Various types of damage are highlighted with the following colour codes: red – colour fading; yellow – scratches; blue – cracks, creases, and torn areas; green – blots and stains.

When choosing AI applications for photo restoration we focused on the options that are available to the most of the users. Hence, only free programs that don't require instalation and operate online were selected. An analysis of the available solutions revealed that no single application could correct all types of damage seen in the photographs. Therefore, a combination of different software tools was required to restore the photographs properly.

After researching and testing different solutions (such as Bringing-old-photos-back-to-life, Restorephotos.io, Repairit, MyHeritage, Hotpot, Pixelcut, PhotoBooth, PicWish), we decided to use Nero AI, SnapEdit and Fotor (Nero AI, 2024; SnapEdit, 2024; Fotor, 2024). These applications were shown to be easy to use, they offer a range of options for solving specific problems, and provide very good results with minimal effort.

The Nero AI was used to correct creases and torn areas in photos, as well as to blend stains and scratches. SnapEdit was employed for additional stain removal and texture correction, while colour and contrast corrections were done in Fotor. The detailed steps of photo reconstruction process, as well as the obtained results are presented as follows.

3. RESULTS

3.1. Reconstruction of black-and-white photograph

On Nero AI website (Nero AI, 2024) *Photo restoration* option can be found in the menu *AI Tools*. Upon uploading an image, there are three options - *Scratch fix*, *Colorize* and *Face enhancement*. We chose to correct the scratches, and the application automatically corrected all the parts in the photo recognized as ones. After a couple of seconds, the photo with a slider for quick assessment of its appearance before and after the processing was displayed. We had an option to download the photograph, improve its resolution or perform a manual correction.

Since some errors in the sky, road, buildings, children's clothes and faces were not corrected, we chose to reconstruct those parts manually. Option *Manual fix* allowed us to paint over the parts that needed further processing (Figure 2a). It was possible to define the size of the brush to paint with, erase or move previously painted or processed areas. After this step, all the damage marked manually was successfully removed, as shown in Figure 2b.

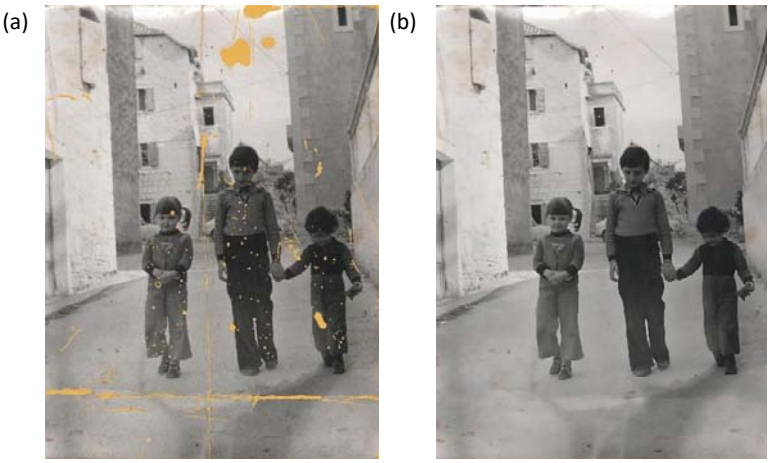


Figure 2: (a) Parts of the photograph manually marked for further processing and (b) image after the processing

The further corrections included the reconstruction of the sky, buildings and road, faded parts of an image, as well as removal of the spots and stains still visible in the background. All the corrections were done in SnapEdit application by activating option *Remove object* from the menu *Al Products*. The process of reconstructing/removing objects was similar to the previously described – we had to mark parts of an image to be processed and the application perform the correction. In order to obtain better outcome, we corrected the image partially, by marking and processing small regions in each pass (the parts marked when reconstructing the road can be seen in Figure 3a). The results of the correction can be seen in Figure 3b.

(a) (b)

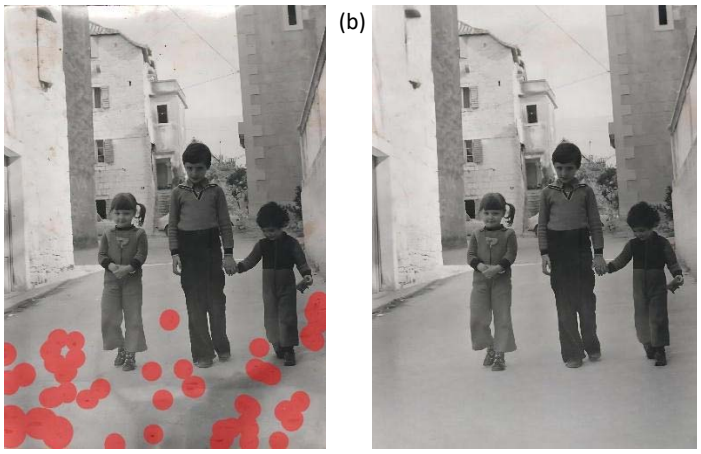


Figure 3: (a) Parts of the photographs manually marked when reconstructing the road and (b) image after the processing in SnapEdit

Colour and contrast corrections were performed in Fotor by choosing the option *AI Photo Editor*. Since regions of yellow pixels were noticed in some parts of the photo, to remove the yellow tone we first applied *Grayscale filter* (*Effects/Filters* tab). Of many available filters, we chose *Classic2* with an intensity of 80%. This had improved the contrast of an image to a certain extent, so in the following step the contrast was increased only slightly. The *Contrast* (*Adjust/Basic Adjust* tab) value was set to 20% which resulted in an image shown in Figure 4.



Figure 4: The final result of image processing after colour and contrast correction

3.2. Reconstruction of colour photograph

The reconstruction of the colour photograph was performed by following the same steps as in the case of black-and-white photograph. We first employed Nero AI to remove most of the damage including stains, scratches on the wall, bed, table, hair and sweater of the young man, as well as errors on the boy's face. SnapEdit was used for more detailed correction of the wall, jeans, table and tablecloth, while contrast and colour were corrected in Fotor.

In Nero AI we first used *Scratch fix* option, which did not yield satisfactory results. The part of the tablecloth was incorrectly recognized as damage, while some scratches on the table, wall, bedspread and other areas were not removed (Figure 5a). Therefore, as in the previous case, we had to manually mark those parts using *Manual fix* option. Parts that were incorrectly processed were deleted by using *Eraser tool*, and those parts that needed further refinements were marked. The result of this action is shown in Figure 5b.



Figure 5: Photograph processed in Nero AI (a) before and (b) after manually fixing all the errors

Additional adjustments were done in SnapEdit in order to correct the texture of the wall, table, tablecloth and jeans. We used Remove object option, and all the parts to be corrected were marked manually, as explained before. The result of this step is shown in Figure 6a.
The colour of the image was corrected in Fotor by applying filter belonging to the *Vintage group*. After testing different options, the best results were achieved with filter *HK film* set to the intensity of 50%. Additional adjustments included correction of the brightness (increased by 5%) and contrast (increased by 30%) (*Adjust/Basic Adjust* tab). The final result of image processing is shown in Figure 6b.

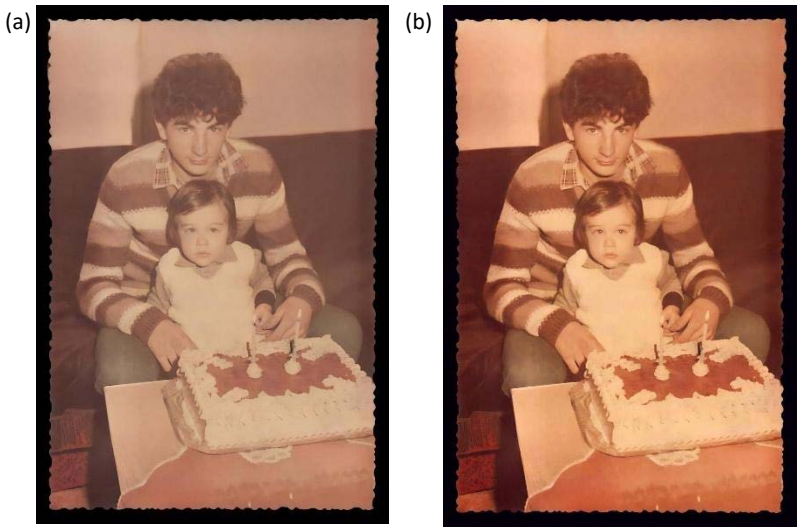


Figure 6: Photograph after processing in (a) SnapEdit and (b) in Fotor

4. DISCUSSION

By comparing original and restored black-and-white photograph (Figure 7) it is evident that AI applications managed to remove all the surface structure damage (like dots and stains), reconstruct the mechanical damage (scratches, tears, bends, folds and cracks on the surface), as well as the worn edges. The contrast and brightness of the photograph had also been improved.
However, it can be also seen that the restored photograph lacks the grain structure, an imminent characteristic of its analogue counterpart. This results in the loss of details and textures in an image. Additionally, the colour correction applied to the door of the building on the left side of the image was inadequate; the upper half of the door was restored, while the lower half remained desaturated,

significantly altering the overall appearance. The image also exhibits a loss of details in the background, where certain elements were either removed or inadequately restored, likely due to the complexity of the damaged texture.

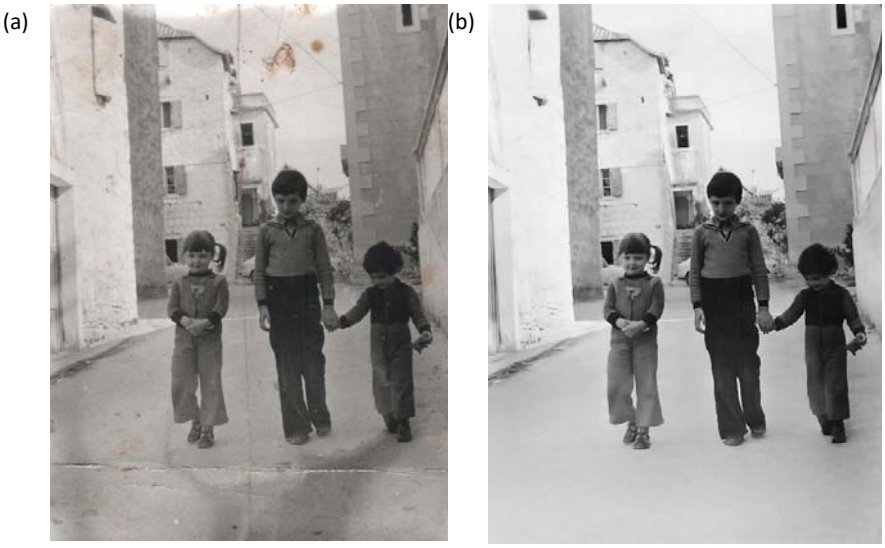


Figure 7: Black-and-white photograph (a) before and (b) after processing in AI-based applications

The most prominent difference in the colour photography reconstructed using AI-based applications (Figure 8) is a noticeable colour imbalance, with red tones dominating while other colours appear desaturated. Variations in tone are visible on the tablecloth, where colour was not accurately restored on the entire surface. We tried to further adjust the photo, but the options for colour correction were limited and there was no way to alter one colour channel or the selected tones.

Similar to the black-and-white version, the lack of texture is evident in the colour photography as well (Figure 8b). This is particularly noticeable on the boy's sweater, where the fabric's structure has been entirely removed. A reduction in detail is also apparent on the cake. Moreover, the AI software did not accurately recreate the reflection of the cake on the table, nor did it effectively correct damage seen on the small elements (birthday candle on the right, for example).

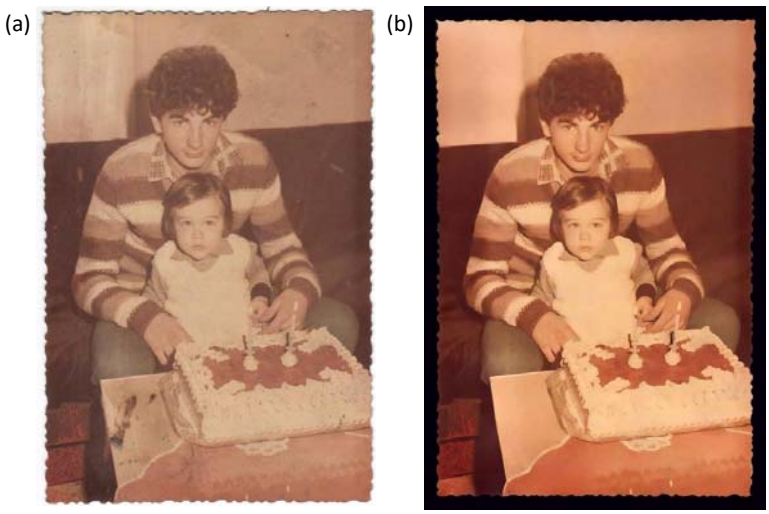


Figure 8: Colour photograph a) before and b) after processing in AI-based software

Even though SnapEdit supports the PNG format, it failed to preserve the transparency of the areas outside the wavy edges when image was saved. All transparent pixels were replaced with black, and as a result the restored photograph had a black frame around its borders.

5. CONCLUSIONS

With the advancement of artificial intelligence, numerous opportunities for substantial improvements across various domains of human activity are emerging. Notably, the availability of AI-based software solutions for photo editing is expanding, including specialized tools for the restoration and reconstruction of old photographs.

In this study, we evaluated various free web-based AI tools that can be used for reconstructing old and damaged photographs. We selected black-and-white and colour analogue photographs that exhibited typical types of damage associated with poor storage and handling. These photographs were digitized and processed using AI-based applications to assess the effectiveness of the AI in restoring the details and characteristics of the original image.

It became evident that AI-based applications allowed for rapid processing while delivering visually pleasing results. As a comparison, an outcome that would require several hours of meticulous work by a skilled professional can be achieved within seconds.

On the other hand, tested solutions adequately removed damage only on the low frequency image areas – monochrome surfaces, simple textures and areas containing little details. On the other parts of photographs, AI applications failed to reconstruct details properly. The missing parts were either smoothen out, or wrongly interpreted and, therefore, recreated in a different manner.

The AI tools also demonstrated a tendency to remove grain from the photographs, likely mistaking it for noise. Since the grain is a fundamental characteristic of a film image, its removal can affect the authenticity of the photograph.

Furthermore, in most of the applications, the results of automatic processing required manual adjustments. This was particularly true for the reconstruction of details, colour and contrast correction. As a result, the effectiveness of the restoration heavily depends on the user's skill to identify errors and their willingness to take a detailed approach in marking specific areas for processing.

Taking into account that all the tested AI-based solutions were designed to be very intuitive and easy to use, we believe that they are great solution for amateurs who want to quickly and efficiently bring their old photographs back to life. These tools can be of great help to professionals as well, for quicker processing of the areas that do not contain many significant details. Nonetheless, for intricate restoration work, manual intervention and expert skill are still irreplaceable.

6. ACKNOWLEDGMENTS

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AI-ENHANCED DESIGN AND LEGAL FOOTPRINT FROM INTELLECTUAL PROPERTY PERSPECTIVE

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Abstract: *The introduction of artificial intelligence into graphic design is widely understood as a fundamental game-changer. The rise of artificial intelligence (AI) in the form of applied machine learning has revolutionized the field of graphic design, introducing advanced tools to foster creativity and productivity. Machine learning has brought forth tools that enhance creativity and speed up work processes.*
However, this technological progress also presents significant legal, especially intellectual property (IP) challenges that need to be addressed to safeguard innovation and ownership rights. This paper explores the intersection of AI-enhanced graphic design and IP issues. The core of AI enhanced design is commonly based on generative adversarial networks (GANs) and machine learning algorithms (MLA) in the design process where input parameters often include existing protected works under copyright.
These processing activities often present a challenge from an IP rights perspective. By analysing current EU legal framework and relevant case law, we present examples of processing activities where AI systems contributing to creative outputs fall under regulatory obligations and potential risk of litigation. The paper presents potential solutions and best practices for interdisciplinary work that includes engineers, designers and lawyers to navigate these challenges, hopefully contributing to bridging the gap between diverse fields incorporating technology and law that designers face in the era of AI-enhanced creativity.

Key words: Intellectual property, machine learning, artificial intelligence, copyright limitations, digital rights management

1. INTRODUCTION

In the recent years, AI-enhanced design (AIED) rose from an interesting and entertaining tool for creating design and various images for personal use to a semi or even fully professional tool potentially applicable in a variety of professional uses. With this advent of new capabilities inevitably came en enhanced PR coverage on social media, followed by a multitude of so-called “design gurus” providing tutorials how to make a quick profit using AIED. What often fails to be mentioned is the (mis)use of intellectual property and (lack of) its management when it comes to professional and commercial licensing and use. One of the most adopted AIED tools is Canva, with market share of 46.29% in September 2024, followed by Dall-E3, Leonardo AI and Adobe Firefly, all in their own domains of use (6sense, 2024).
According to the survey conducted for the purposes of this paper (with a survey group consisting of 62 respondents), nearly 43% of individuals using AI-enhanced design (AIED) tools fall within the 30-40 age group, with most holding graduate degrees.
Approximately 46% of respondents are familiar with AIED platforms, while 7% have never used them. (Google, 2024) Usage patterns show that 43.5% use these tools occasionally. Interestingly, a significant majority—almost 80%—believe that AIED enhances overall creativity and efficiency in the design process. However, 26% feel that AIED has the opposite effect.
When it comes to the artistic value of AI-generated designs, 46% of respondents believe they should not be considered works of art. Despite this, 58% are aware of the associated copyright issues, with 30% expressing significant concern and 46% somewhat concerned about them. Regarding ownership, a striking 55% of respondents think that all intellectual property (IP) rights related to designs should be attributed to the user (designer), while only 4% believe that the platform should hold these rights.
An overwhelming 90% of participants are concerned that AIED could lead to unintentional plagiarism or IP infringement. In terms of IP rights protection, 30.4% of respondents believe new regulations should offer greater protection to designers, while an equal percentage think the approach should be more collaborative. Additionally, 18% feel that AI developers deserve more protection. A staggering 91% agree

ORCID numbers are provided at the end of the paper.

that a new IP strategy should specifically address AIED, while only 3% believe that current regulations are sufficient.

2. AI-ENHANCED DESIGN ALGORITHMS

AI-enhanced design refers to the integration of artificial intelligence (AI) technologies into the design process to augment human creativity and optimize design outcomes. This approach leverages machine learning algorithms, neural networks, and data-driven insights to assist designers in tasks that range from generating design variations to automating routine processes, such as background removal, colour correction, and layout adjustments. This is made possible via machine learning algorithms (MLA) or more precisely, by Generative Adversarial Networks (GANs) (Cohen & Giryes, 2023).
The GANs are a class of machine learning models that consist of two competing neural networks, known as the generator and the discriminator, which are trained together in a process of adversarial learning (GeeksforGeeks, n.d.). Introduced by Ian Goodfellow and colleagues in 2014 (Cohen & Giryes, 2023), GANs operate by having the generator create synthetic data—such as images, audio, or text—intended to be as realistic as possible, while the discriminator attempts to distinguish this fake data from real data drawn from a training set (Viso.ai, 2024; Chen et al., 2022).
Through this trial-and-error process, the generator improves its ability to produce data that can deceive the discriminator, while the discriminator becomes more adept at identifying fake data Figure 1. The training continues until the generator's output is nearly indistinguishable from real data. GANs could be used in various fields, including image generation and data augmentation, where they generate additional training data.

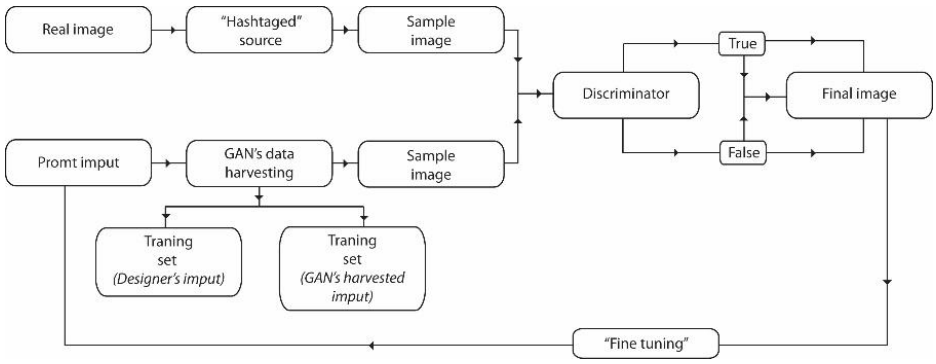


Figure 1: AIED/GAN diagram

With this in mind, GANs are the main sours of so-called deepfakes used to created illegal, harmful and misleading content such as various forms of pornography (Machine Learning Mastery, 2019; CVisionLab, 2024).
All these tools can operate autonomously or in collaboration with human designers, providing real-time feedback and recommendations. To create an image user is mostly required to insert a prompt code (PC). PCs are essential in building and directing GANs in applications like "text-to-image generation".
In these contexts, a prompt serves as an initial input that instructs the generator on what type of content to create. For example, a textual prompt such as "river in the mountains" directs the generator to produce an image that aligns with this description. The GAN uses the prompt text to find its counterparts from the image library and test sets. This is not a new concept, but seen before with "#" options in various computer languages modules and later on in the so-called "hash-tagging" in the various social networks. One could conclude that the training set data was established years ago, when GANs were only doing data harvesting (AltexSoft, 2023; Gupta, 2023).
GANs can also effectively handle colour information in images by processing the pixel-based data that forms each image, rather than reading colour codes like RGB or hexadecimal values directly, which are also implemented in the image meta data. In practice, GANs treat images as matrices of pixel intensities, where each pixel's colour is represented by its red, green, and blue components (Boroujeni & Razi, 2024; Demir & Unal, 2018).
Through training, the generator in the GAN learns to reproduce the colours and patterns found in real images, while the discriminator evaluates both the colour and structural accuracy of the generated images

to determine in which amount each colour can be applied. This enables GANs to learn and replicate realistic colour patterns naturally, without explicit colour labelling. By doing the “fine tuning” in in the midst of a training process, designer (human counterpart) can give specific directions which will then be used as a learning curve that will create images in the future (Demir & Unal, 2018; Lin et al., 2020).
GANs work with mostly RGB images, but they can be adapted to different colour spaces such as grayscale or HSV, depending on the specific task given by the designer. By learning colour distributions and intensity by data, GANs learn to produce precise images and patterns (Afifi et al., 2021).

3. THE INTERPLAY BETWEEN AI AND COPYRIGHT LAW

The legal implications of AI's growing role in the design industry remain uncertain, particularly concerning intellectual property rights. The challenges are arising around the identification, protection, and ownership of AI-generated designs. While the interplay between AI and copyright law, as well as AI and patent law, has garnered significant attention in the last couple of years, the relationship between AI and design law has been less explored (Lucchi, 2023; Quang, 2021). The use of AI technologies has been recognized as a major challenge for the European Union industrial design law framework. Both the European Union Intellectual Property Office (EUIPO) and the World Intellectual Property Organization (WIPO) have published studies assessing AI's impact on design infringement and enforcement (Kuypers & De Clercq, 2024).
Some AIEDs like Canva, do give the copyright to its creators under certain terms. The copyright will be granted to the creator of the original content (designer), but if the portions or even a training set was used from other websites as stock content, IP rights could be a subject of possible infringement of third parties right's. Canva in this case is not responsible for any third-party infringement issues that may arise, since the user has to comply with the terms of use. When it comes to AI generated content, such as images, most AIED such as DALL-E (Shoemaker, 2024), Imagen, Magic Media, the AI provider gives you exclusive rights. However, intellectual property rights are territorial rights and the scope of protection varies in different jurisdictions (Kuypers & De Clercq, 2024; Canva, 2024).
The question of design “ownership” arises when AI assists in the creation of designs with material human input. Under the Community Design Regulation of 2001, design rights belong to the designer or their successor, with joint ownership applying if multiple designers are involved. Most EU jurisdictions and EU regulation itself define the designer as a natural person or a legal entity who creates a design with a unique and individual character. Consequently, AI programs, even if true broad general-purpose intelligence was achieved, which is currently not the case, cannot be considered designers under EU law, as they lack legal personhood (Chen & Burgess, 2019; O’Leary, 2022). The European Commission suggests that the individual using AI technology should be regarded as the designer, provided the design meets the requirements of novelty and individual character (Kuypers & De Clercq, 2024). The bearer of registered design could be legal entities such as companies (i.e. Coca-Cola ®), but only natural entity can be considered as a designer. Person who gave limited amount of assistance in the creation of design could not be considered as designer nor have any right arising from that design. If legal framework would be changed in the future regarding the term “person”, it could potentially give a legal leverage for AIED.
Moreover, during the “data harvesting” stage legality deepens on various factors, such as copyright, licensing and data protection (in US: data privacy) laws. It is well known that if the data used for training set is copyrighted, using it without permission can potentially lead to legal implications, especially if GAN will produce the end image that looks very similar to the original. In the Figure 2 one can see the proximity of the image tagged as “Snow-white” which refers to Disney’s cartoon character. In some cases, the fair use for specific situations can be applied, as for scientific research, academia or even to write an article of some sort, but those limitation are mostly very context-dependent. Some meta data with so-called open licences like CC or Creative Commons (Katulić & Jurić, 2014), depending on the class, comes with various restrictions and rules for commercial use, may require some sort of author attribution meaning that the best practices is to licence it prior using.
Another legal issue to consider are data protection laws, such as the EU GDPR or less ambitious sectorial or state laws in the US (HIPAA, CCPA) which regulate the protection and flow of personal data. Most of these laws, especially those based on the model of the earlier EU Data Protection Directive of 1995 or the 2016 General Data Protection Regulation operate under a strict set of principles (Art. 5 of the GDPR) which require a lawful, fair and transparent basis for the processing of personal data (Art. 6). Just because (personal) data is available online, does not necessarily imply that processing of such data is also allowed or legal. Data harvesting from various websites can also raise copyright issues. Finally, data sets used to

train GANs can lead to various other implication such as ethical issues or biased opinion, for instance, if someone would want to create harmful image of some religious, ethnical or other group, data set used to do so would lead the AIED powered by GAN in the direction that is set by that very training set. From the legislative perspective this is also addressed by new specific AI legislation, such as the EU AI Act (Figure 2).

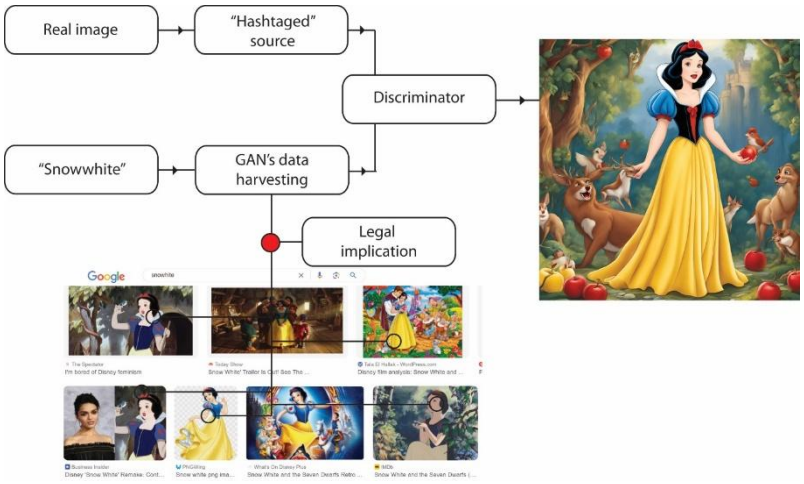


Figure 2: GAN harvesting (left and down) and end image (right)

4. EU LEGISLATION ON DESIGN PROTECTION IN DIGITAL AGE - *DE LEGE FERENDA*

Having in mind that the European legislation on industrial design protection has remained the same for the past 20 years or even longer, the EU lawmakers have made a decision to align the design protection in a way that it fits new digital age as well to align the procedures for application in a way that it is cheaper, faster, simpler and that it attracts more SMEs as well as design heavy industries to apply for design protection in the EU (EU Commission, 2024).

Industrial design rights protect the appearance of the product and therefore highly encourage innovation and creativity while giving the designer a legal monopoly on the design for a certain period of time in a certain territory. Under current design protection system in the EU, protection is granted for a period of 5 years, with the possibility of the proprietor to extend the protection up to 25 years.

More than 20 years ago, when design protection system was introduced, it was convenient and in line with the needs of the market. All EU Member States have partially harmonised systems of protection by implementation of the Directive 98/71/EU whereas at the EU level Council Regulation (EC) No 6/2002 established an independent system for the protection of design rights at the EU level as registered Community designs (RCDs) and unregistered Community designs (UCDs) that are protected without being registered if made available to the public. This EU level system is administered through European Union Intellectual Property Office, while complementary national systems are administered through national intellectual property offices (IPOs). The EUIPO is responsible for managing the registration of the European Union's trademarks and designs, ensuring protection across all EU Member States. It serves as a central hub for the enforcement of intellectual property rights, providing services and support for businesses, innovators, and legal professionals. The office also works on initiatives related to counterfeiting and intellectual property education across Europe. The Croatian State Intellectual Property Office (DZIV) is responsible for the protection of intellectual property rights in Croatia. It handles patents, trademarks, industrial designs, and copyright-related matters, offering services for registration, information, and support to creators, inventors, and businesses within Croatia. The office plays a key role in ensuring compliance with national and international IP regulations (Dziv, n.d.; EUIPO, n.d.).

Today, more and more designs are strictly used in a digital environment, and the end-products utilizing those designs are no longer just physical.

As design protection is often seen as a possible bridge between copyright and other industrial property rights, new EU design protection proposals suggest adapting the existing EU design protection legislation so that it would include digital designs, graphical user interfaces (GUIs), metaverse, non-fungible tokens and advanced technologies such as 3D printing. The design protection will also extend to movement, transition and any other sort of animation of the design's features.

At this point, it could be argued that design protection could in the future be a "tool" to be taken into consideration as a possible solution to the question of intellectual property rights on AI enhanced works containing design. In the resolution of 11 November 2021, European Parliament stressed that the EU design protection system is outdated and should be updated to allow new forms of design, apart from GUIs, also virtual and animated designs, fonts and icons. Also, it's is necessary to update the legislation as well as supporting systems such as special tools to conduct image searches to examine prior art that will give inputs to the examiners in IPOs as to what is considered to be "new". This is most definitely an aspect in design protection that will most likely be conducted through artificial intelligence searching tools.
EU lawmakers are also suggesting to harmonise EU design protection system with EU trademark system in order to allow design holders to prevent design infringing products to enter the EU. This way, design proprietors will have certain powerful tools in order to fight infringements. Current proposals on updating of the legal framework both introduce broader definitions of the terms "product" and "design". New broader definitions both include new designs that are not part of the physical product as well as objects that are available only in digital form. As far as visibility requirement goes, the proposals introduce that the protection should be granted only to features that are shown visibly in the application for registration. For instance, updates on definitions go in the direction that the word "digital" should be replaced by word "non-physical".
Current EU legislation as well as the case law on the copyright protection of GUIs, which rules can easily be applied to other digital designs, grants copyright protection to such works. Specifically, the graphical user interface as a subject of copyright protection includes the visual elements and functions through which a user interacts with the computer program.
The graphical user interface as an object of copyright protection is also part of the definition in the Directive on the Legal Protection of Computer Programs, specifically in recital (10) of the preamble:

The function of a computer program is to communicate and work together with other components of a computer system and with users and, for this purpose, a logical and, where appropriate, physical interconnection and interaction is required to permit all elements of software and hardware to work with other software and hardware and with users in all the ways in which they are intended to function. The parts of the program which provide for such interconnection and interaction between elements of software and hardware are generally known as 'interfaces. This functional interconnection and interaction is generally known as 'interoperability'; such interoperability can be defined as the ability to exchange information and mutually to use the information which has been exchanged.

The Court of Justice of the European Union (CJEU) in its judgment in Case No. C-393/09 (Bezpečnostní softwarová asociace v Ministerstvo kultury) dated December 22, 2010, expressed the view that the design of a graphical user interface is subject to copyright protection, stating as follows:

In this regard, it is important to determine whether the graphical user interface of a computer program can be protected under general copyright law pursuant to Directive 2001/29. The Court concluded that copyright protection under Directive 2001/29 applies only to a subject matter that is original in the sense that it is the intellectual creation of the author himself (see, in this regard, with respect to Article 2(a) of Directive 2001/29, Infopaq International, paragraphs 33 to 37). Thus, a graphical user interface can be protected by copyright as a work if it is the intellectual creation of the author himself.

The idea of transparently involving copyright protected works into design protection systems on the EU level will require further legislative amendments in order for it to be possible to cumulate protection of designs and copyright (European Parliament, 2023).

5. CONCLUSION

The integration of AI into the graphic design field, particularly through AI-enhanced design (AIED) tools like Generative Adversarial Networks (GANs), has led the industry toward advancements in creativity and efficiency. However, these technological innovations bring with them significant legal challenges, especially concerning intellectual property rights and copyrights. As AIED for common use mostly rely on pre-existing meta data, which is often protected by copyright, determining ownership of AIED becomes a complex issue. The European Union is beginning to address the intersection of AI and design law, further clarity and fast paced updates of legal frameworks are necessary to ensure that both creators and AI developers are adequately protected. There is a constant growth in need for interdisciplinary collaboration between designers, developers, engineers and legal entities for establishing clear IP guidelines for AI-enhanced

creativity. This collaboration will be essential to push the innovation forward while safeguarding legal and ethical standards in the digital age.

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HEATMAP ANALYSIS OF PROFILE FACIAL IMAGES

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Abstract: *Facial images are a very common element on the World Wide Web and in mobile applications. With the widespread use of eye-tracking systems, research in the field of viewing and memorizing facial images has greatly expanded. The main issue in analyzing facial images is to understand the way of viewing, memorizing and recognizing. Most of the research is done for the frontal facial images, but we focused on profile facial images. One of the most widely used methods for determining memorization and recognition of facial images is the internal facial feature method. However, in our research we have focused on the new heatmap method. In this method, the results of area, perimeter and circularity of heatmaps are analyzed. For the whole research we used a standardized memory test comprising two phases: an observation test and a recognition test. To analyze the influence of time on recognition success, we set four display times of facial images in observation test (1 s, 2 s, 4 s, 8 s). The results show that the recognition success increases with increasing display time of the facial images in the observation test. The turning point occurs at a display time of 4 seconds, as the recognition performance in the 8 s test is almost the same as in the 4 s test. The heatmap analysis method shows an increase in the area and perimeter of the heatmap areas up to the 4 s test, after which both values remain practically the same. After that, both values remain practically the same. At this point, the circularity of the viewing areas also no longer decreases and is the same in the 8 s test as in the 4s test. The results of the heatmap analysis are therefore in good correlation with the results of the facial recognition and proved the usefulness of heatmap analysis for research into the observation and recognition of facial images.*

Key words: profile facial images, observation test, recognition test, eye tracking, heatmap

1. INTRODUCTION

In visual perception, we are dealing with two types of eye movements: fixations and saccades (Harrington, 1981; Robinson, 1963). Fixations are quick stops of the gaze during the process of observation (Abdallahi et al., 2007). A quick jump between one fixation and another is called a saccade. These movements are very fast and are caused by the user's desire to move the gaze (Abdallahi et al., 2007). For fixations, the duration of the fixation is important, for saccades its length.
When using eye-tracking systems, we essentially obtain two results: Gaze plots (duration of fixations and length of saccades) and heatmaps. Figure 1 shows the average of both.



Figure 1: Gazeplot (Tobiipro, 2024) and Heatmap (Ovano, 2012)

As can be seen from Figure 1, the gazeplot is a sequence of eye stops (fixations) and movements between them (saccades). The size of the fixation circle provides information about the duration of the fixation at the point where the eye stops. The heatmap provides information about the time the eyes spend in certain areas. Figure 1 shows that the eye stayed the longest on the red-coloured areas, slightly less on the yellow and least on the green.

ORCID numbers are provided at the end of the paper.

All research in the field of facial image viewing is based on analysis, i.e. the duration of fixations and the length of saccades. These analyses usually also include the use of area of interest (AOI), with which we define areas in the image where we analyse the above results.
So far, however, we have not come across any research that includes Heatmap analysis. The first obstacle is that these images are usually in colour. In our case, we first converted the heatmaps to grayscale and then to black and white. These areas were then analysed by calculating the area, volume and circularity of these areas. The results were compared with the results of recognition success and false recognition.

2. METHODS

2.1 Participants

As mentioned above, we conducted 4 tests for each observation time. Every test was done for 6 participants, so all together we recruited 24 participants (7 male and 17 female). They were our students and had normal vision. Average age was 20,3 years (SD = 0,96).

2.2 Stimuli

We took the images from the Minear and Park Face Database (Minear & Park, 2000). The facial images were prepared according to the conditions of natural observation (Kealey, Sekuler & Bennet, 2008; Henderson et al., 2001). The conditions of natural observation mean that we look at a real face at a distance of one meter. Since the distance of the participants to the test screen was 60cm, the faces on the screen were displayed at 60% of their natural size. The average height of a face in nature is 18.5cm (Park Aging Mind Laboratory, 2024), and according to this calculation, the faces on our screen were on average 11.1cm high. Depending on the screen resolution and the size of the faces in the facial images, we prepared our facial images at a size of 640 × 480px. The set of images was equally selected by gender (10 male and 10 female). For the recognition test we added 20 new faces to these faces (also 10 male and 10 female).

2.3 Apparatus

All tests were carried out in the Laboratory of Visual Perception and Colorimetry at the Department of Textile, Graphic and Design of the Faculty of Natural Sciences and Engineering at the University of Ljubljana. Setting up the environmental and testing system was based on the standards and recommendations (Pernice & Nielsen, 2009). We performed the test with the Tobii X-120 eye tracking system. Analysis were done in Tobii Studio 3.4.5 software. The defaults setting for definition of fixation was 100 ms for 30 px area. That means if eyes stayed in the area 30 pixel for at least 100 ms it was concerned as one fixation (Tobii Connect, 2016).

2.4 Procedure

We have conducted a memory test according to the previously mentioned YES/NO principle. We performed two tests, an observation test, and a recognition test. The procedure observation test is shown in Figure 2.

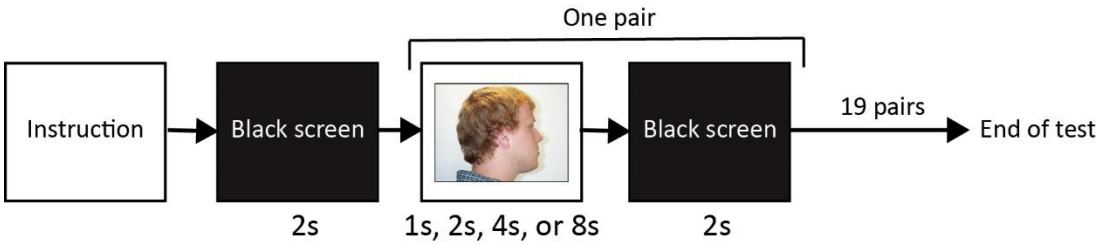


Figure 2: Procedure of the observation test

The observation test included 20 facial images (10 male and 10 female). According to the procedure in Figure 1, the tests lasted 1 minute (Test1s), 1 minute 20 seconds (Test2s), 2 minutes (Test4s), and 3 minutes 20 seconds (Test8s). The observation test was followed by the recognition test (Figure 3).

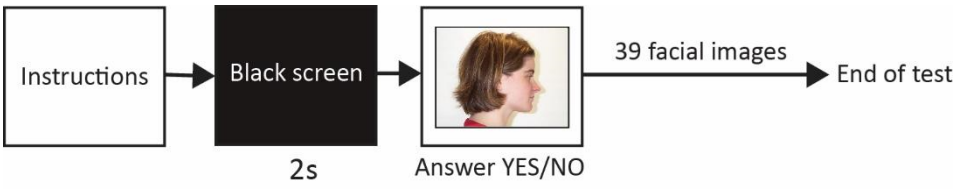


Figure 3: Procedure of the recognition test

Here we have added 20 new facial images to the original 20 facial images of the observation test. For each facial image displayed on the screen, participants were asked to indicate whether they had seen it in the observation test. We recorded their responses as correct or incorrect.

2.5 Analysis of results

The first part of the study provided us with the results of the average time of correct answers (CA) and incorrect answers (FA – False alarm) for each of the 4 tests. Those two data are then used to calculate recognition success (discrimination index A') with equation 1.

$$A' = 0{,}5 + \frac{(CR-FA)(1+CR-FA)}{4CR(1-FA)} \quad (1)$$

For the second study, we first set the eye-tracking system to create heat maps in grayscale instead of colour. So instead of red, yellow and green, we set black (R = G = B = 0), dark grey (R = G = B = 85) and light grey (R = G = B = 170). These greyscale images were then converted into black and white images using the ImageJ program. The process is shown in Figure 4.

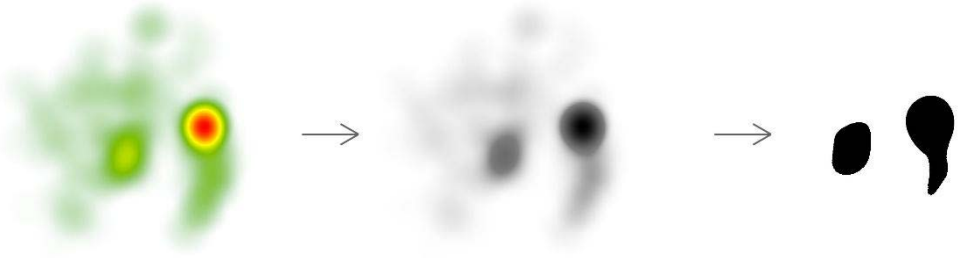


Figure 4: Converting color heatmaps to grayscale heatmaps to a black and white image

We then used the ImageJ program to calculate the area size, perimeter and circularity of the black and white heatmaps. The latter is calculated from the two previous parameters according to equation 2.

$$Circularity = 4\pi \frac{A}{P^2} \quad (2)$$

3. RESULTS

3.1 Recognition success

As already mentioned, we first determined the success of the recognition as a function of the observation time. The results are shown in Figure 5.

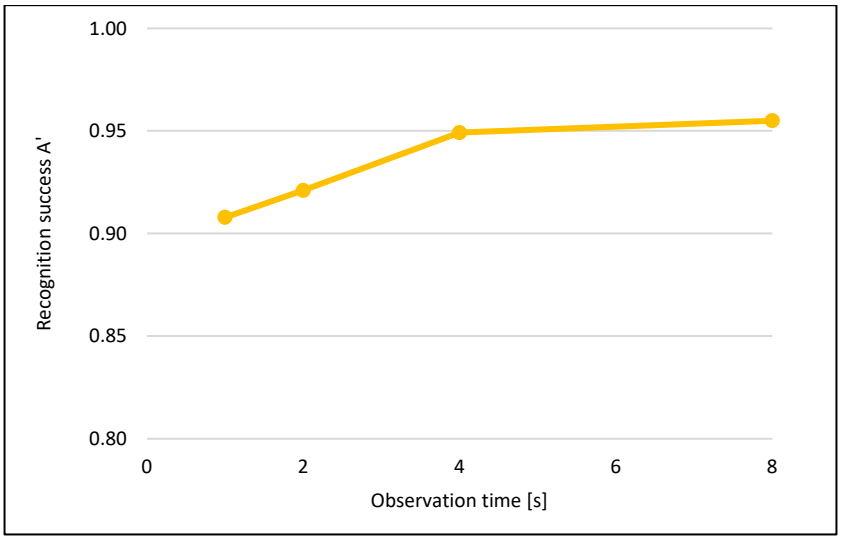


Figure 5: Results of recognition success for profile facial images

The second result of the first part of the experiment is incorrect recognition (false alarm). These results are shown in Figure 6.

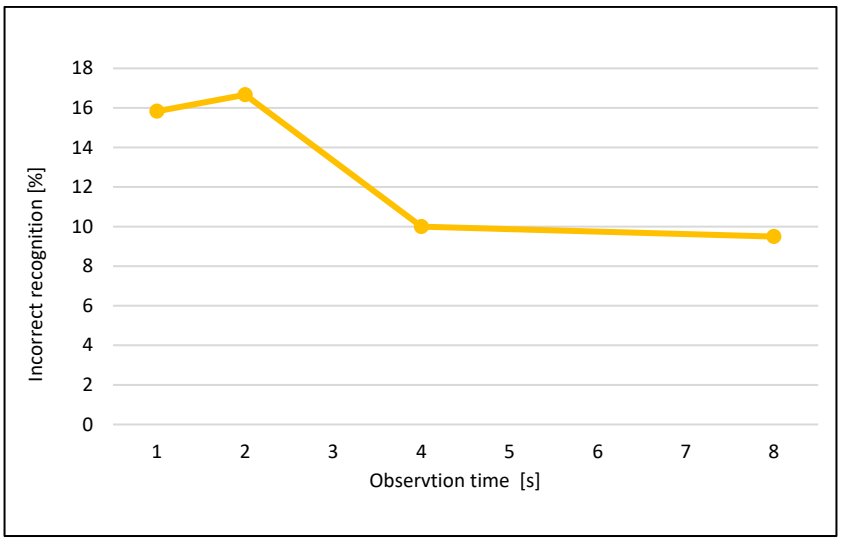


Figure 6: Results of incorrect recognition for profile facial images

3.1 Heatmaps results

As already mentioned, the second part of the experiment was the measurement of heatmap parameters. Figures 7, 8 and 9 show the results of the area size, extent and circularity of the converted heatmaps.

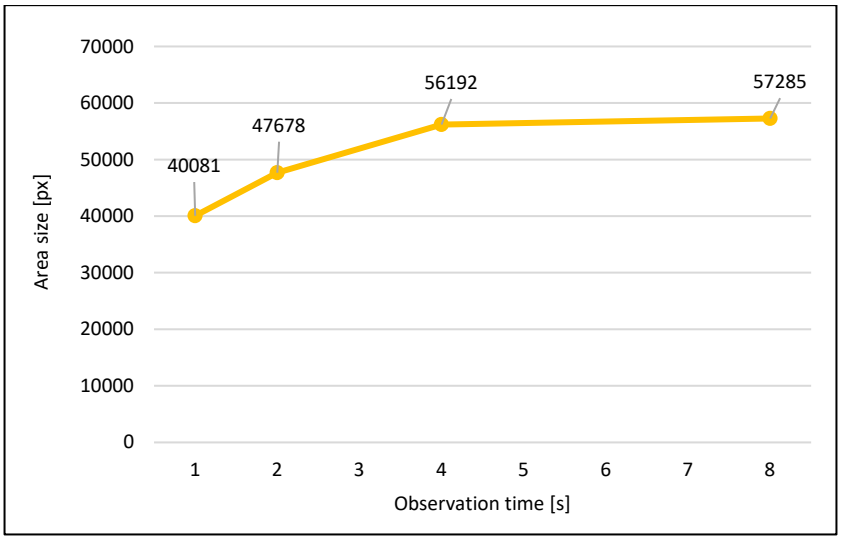


Figure 7: Results of area size of Heatmaps

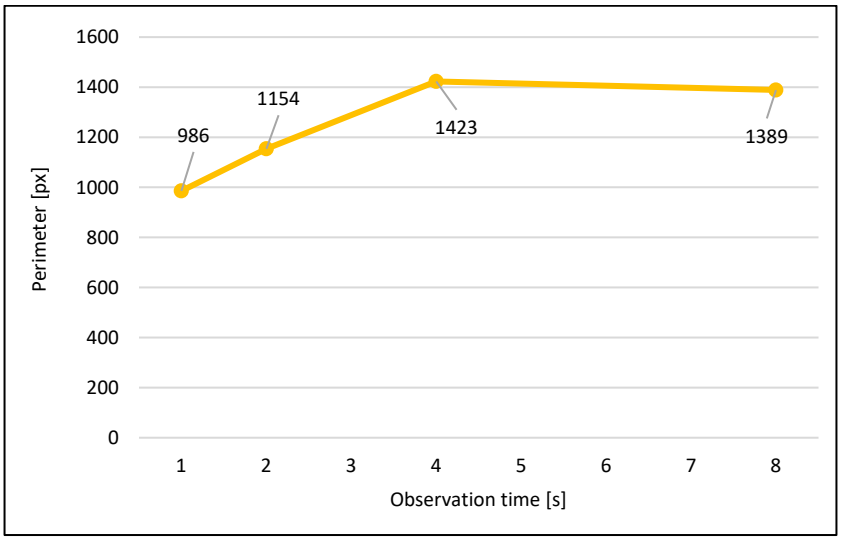


Figure 8: Results of perimeter of Heatmaps

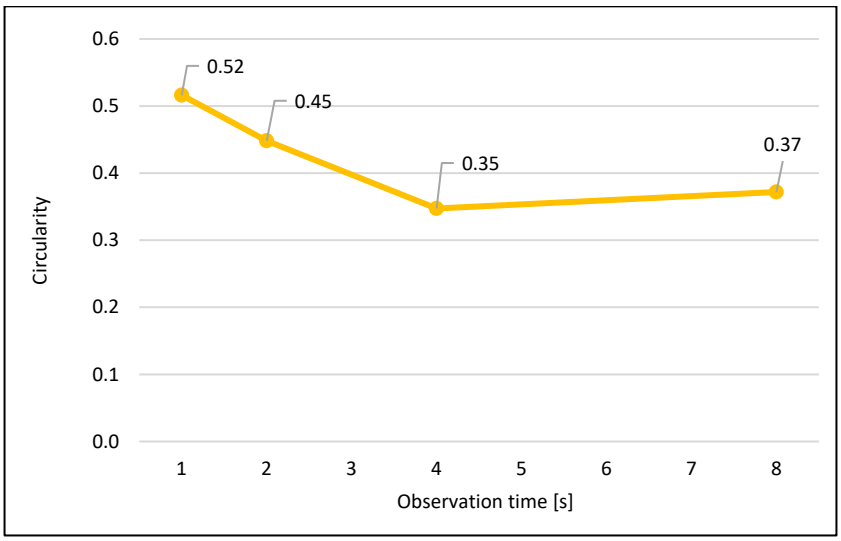


Figure 9: Results of circularity of Heatmaps

4. DISCUSSION

As we suspected, the recognition success increases with a longer observation time of the facial images in the observation test (Figure 5). This increase takes place up to an observation time of 4 seconds. In the 8-second observation test, the recognition performance is almost the same as in the 4-second test. This means that a longer observation time does not improve the memorization of facial images. For satisfactory memorization of facial images, an observation time of 4 seconds is sufficient.
The same applies to the result of incorrect recognition (Figure 6). With short observation times of facial images, the memorization ability is naturally poorer and thus the incorrect recognition is higher (15.8 % in the 1-second test and 16.7% in the 2-second test). At the same time, memorization of facial images is much better in the 4-second test and incorrect recognition falls to 10.0%, and it remains at approximately the same level in the 8-second test (9.5%).
When analysing the Heatmaps, it can be seen in Figure 7 that their area is smallest when the observation time of facial images is 1 second, which is of course to be expected. With a longer observation time of facial images, users saw a larger part of the face, which also means a larger area of the Heatmaps. This increase happens up to the 4-second test, and in the 8-second test we see that the area of the Heatmaps is almost the same as in the 4-second test. This indicates that between 4 and 8 seconds, participants mostly looked at previously observed parts of the face. Again, this does not contribute to better memorization, as we have already seen in Figures 5 and 6. The same thing happens when measuring the perimeter of the Heatmaps (Figure 8). As the observation time increases, the Heatmaps become larger and thus the perimeter also become larger. However, there is an interesting change here, as the perimeter of the Heatmaps is larger in the 4-second test than in the 8-second test. The reason for this is that there are certain cases where we obtained two separate Heatmaps in the 4-second test, for example, whereas in the 8-second test the participants observed a larger part of the facial image and these two Heatmaps merged into one. The perimeter of two Heatmaps is thus larger than the perimeter of one common heatmap. Therefore, the average perimeter of the Heatmaps for the 8-second test is even slightly smaller than for the 4-second test.
Figure 9, which shows the results of the circularity as a function of the observation time of the facial images, shows that the circularity is highest in the 1-second test and then decreases towards the 4-second test. This is because in the 4-second test the participants observe at a larger part of the facial images, the views are more scattered and the Heatmaps have more varied shapes than in the 1-second test, where the views are more concentrated on the centre of the facial image and the Heatmaps are more circular. There is practically no difference between the 4-second and 8-second test, which we have already seen from the results of the area and perimeter of the Heatmaps. During this extra time between 4 and 8 seconds, participants mostly observe parts of facial images that they have already observe before.

5. CONCLUSIONS

In our study, we attempted to compare the results of facial image recognition and the results of Heatmaps measurements as a function of the time of observing facial images in the observation test. We had 4 of these times (1, 2, 4 and 8 seconds). All results showed a similarity between the measured values. Thus, we found that a turning point occured everywhere at the observation time of 4 seconds. Up to this point, as the time observation increased, the recognition success (A') increased, the false recognition decreased, the area and perimeter of the Heatmaps increased and the circularity decreased. All these values remained almost the same for the 4-second and 8-second tests. With these results, we can explain the nature of observing facial images, which is such that the participants' gaze first land on the eyes, then in 4 seconds they observe the remaining parts of the face image, and between 4 and 8 seconds, participants observe parts of the faces in the facial images that they had already seen before.
With our study, we have demonstrated the usefulness of measuring Heatmaps. To further confirm the usefulness of this method, it should also be tested on images with other content (landscape, objects, interiors, etc.), which we plan to do in one of the future studies.

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AI VS. HUMAN DESIGNERS: EVALUATING THE EFFECTIVENESS OF AI-GENERATED VISUAL CONTENT IN DIGITAL MARKETING

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Abstract: *In the rapidly evolving landscape of digital marketing, the quest for more effective and engaging visual content is relentless. With artificial intelligence (AI) making significant strides, an important question arises: Can AI tools for design surpass the creativity and effectiveness of human graphic designers? This intriguing inquiry forms the cornerstone of our study. We aimed to evaluate the effectiveness of AI-generated versus human-designed advertisements through a practical approach. In the first phase, both a human graphic designer and an AI tool were given identical tasks and prompts to create visual ad solutions. In the second phase, the efficiency of these designs was assessed using Meta's A/B testing solution for Facebook and Instagram ads. This method allows the testing of visual variables by showing different ad versions to segmented audiences, ensuring that no individual sees both versions and that the budget is evenly distributed. The test duration is recommended to be two weeks or until 100 conversions are collected. This experiment, conducted in August 2024 as part of a campaign for FTN Business School's 2024/2025 enrollment, aims to provide a comprehensive insight into the actual capabilities of graphic solutions created by human designers versus AI tools. The outcome of this test promises to offer valuable insights into the real-world performance of AI-generated designs compared to those crafted by human designers. Will AI tools emerge as the new maestros of design, or will the nuanced touch of human creativity prevail? Our research aims to shed light on this cutting-edge debate, providing data-driven conclusions.*

Key words: Artificial Intelligence, Graphic Design, Digital Marketing, A/B Testing, Visual Content Effectiveness

1. INTRODUCTION

Although artificial intelligence (AI) has been present for decades and it is not considered a new discovery, the development of AI models and their integration with various applications in recent years have made AI more accessible to a broader audience. This growing accessibility has sparked increased interest in the potential applications of AI across different fields. Unsurprisingly, this trend has also reached the realm of graphic design.

The impact of AI in graphic design manifests in various areas, such as automating tasks for graphic designers, generating AI graphic designs, and providing AI tools for assistance in graphic design (Mustafa, 2023). On one hand, some authors express concern that AI will “deskill the profession and create a second tier of ‘non-professional’ designers, particularly within less creative work that emphasizes fast turnover and functional artifact production” (Meron, 2022). In contrast, other authors do not perceive AI as a threat, arguing that aspects defining our humanity-such as originality, creativity, and empathy-will remain areas where AI cannot compete with human designers (Tomić et al., 2023). While authors like Tomić et al. (2023) agree that AI tools will not replace human designers soon, this paper aims to explore the current capabilities of AI tools in autonomously creating graphic solutions. Additionally, we will compare the results achieved by AI-generated graphic designs in social media advertising with those produced by human graphic designers. Previous research (Dehman, 2023) has highlighted the limitations faced by AI tools in attempts to replace human designers, including challenges such as misunderstanding or failing to generate vector graphics, issues with positioning objects in 3D space in cases of non-standard perspectives, generating visual clichés, and the inability to produce text within graphic solutions. These authors suggest that graphic designers should utilize AI solutions like DALL-E and Midjourney for visualizing ideas during the ideation phase of the creative process. Research has also been conducted on the impact of AI graphic design tools on designers' creative thinking (Lin & Liu, 2024). The results indicated that these AI tools play a significant role in stimulating designers' creative thinking while also emphasizing the importance of understanding their advantages and limitations for successful integration into the creative process.

ORCID numbers are provided at the end of the paper.

2. RESEARCH METHODS

The research was conducted in two phases. In the first phase, the same task was given to both the designer and AI tools using identical instructions, or prompts. The designer first used the AI tools, and on the second day, created the social media post from scratch, based on the brand guidelines. In the second phase, the effectiveness of the graphic solutions in digital marketing was tested using Meta's A/B testing tools for Facebook and Instagram ads.

2.1 The first phase of research – AI designer

In the first phase of the research, the capabilities of various AI tools for designing social media posts were tested. Using the tool Chat GPT-4o-mini, prompts for the AI tools were written. When testing the capabilities of the Midjourney v6.1 (Basic Plan) tool for creating posts, the result shown in Figure 1 was obtained. In this solution, besides the provided prompt, one graphic element from the brand book was included as an additional reference. What can be observed in these solutions is that this AI tool attempted to apply the references specified in the prompt, but was largely unsuccessful in reproducing the exact graphic solution. In the attempt to generate several iterations, it was noticed that this AI tool tries to modify the provided graphic elements, fails to apply the specified font, and has difficulty accurately applying the given text.



Figure 1: Examples of social media posts created with Midjourney v6.1

In the ChatGPT-4o-mini tool, the prompt was adapted for DALL-E, OpenAI's image generator. In this case, DALL-E produced a solution shown in Figure 2. From this example, it can be observed that DALL-E currently has more limited capabilities for generating social media posts compared to the Midjourney V6.1 tool. DALL-E generates visuals according to its own interpretation, disregards the specified color parameters and graphic elements, and is unable to accurately interpret the text in the image. Additionally, it tends to "invent" nonsensical text.



Figure 2: Social media post created with DALL-E by OpenAI

In the next step, it was attempted to find an AI tool specifically designed for creating social media posts. A Google search highlighted the tools SocialBee and Canva PRO. After signing up for the SocialBee platform, no tool for creating social media posts was found, despite being advertised. This tool is focused on applying AI technology in creating social media editorials and assisting with writing content. For this reason, it was

decided to use Canva PRO in the final version, along with a photo created using the Midjourney v6.1 tool. Figure 3 shows the photos that were created based on the given prompt.



Figure 3: Photos created with Midjourney v6.1

It could be observed that when additional variations were initiated, errors such as unnatural hands, wrists, legs, and feet were made by Midjourney v6.1. As presented in Figure 3, the first photo on the left was chosen for the social media post. This selected photo also shows flaws that occurred during image generation, but it was decided that this solution would be used to check whether any social media users would notice and report these defects after the ad is published.

In the next step, the final visual solution was created using Canva PRO. In its PRO version, Canva features Magic Design™, an AI tool for design. The PRO version of this tool also allows for the addition of Brand Kits, where, similar to brand guidelines, all elements of the brand's visual identity can be added – different logo variations, primary and secondary colors, fonts, photos, graphic elements, icons, as well as brand voice that can be used in the AI assistant for writing with Magic Write™. Based on the given prompt, the parameters from the Brand Kit, and the photo generated in Midjourney v6.1, the graphic solutions shown in Figures 4 and 5 were obtained.

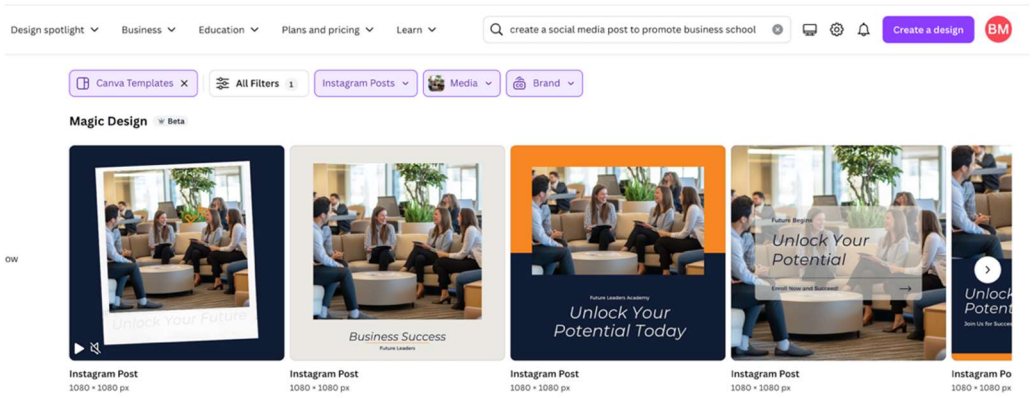


Figure 4: Social media posts created with Canva PRO's Magic Design™

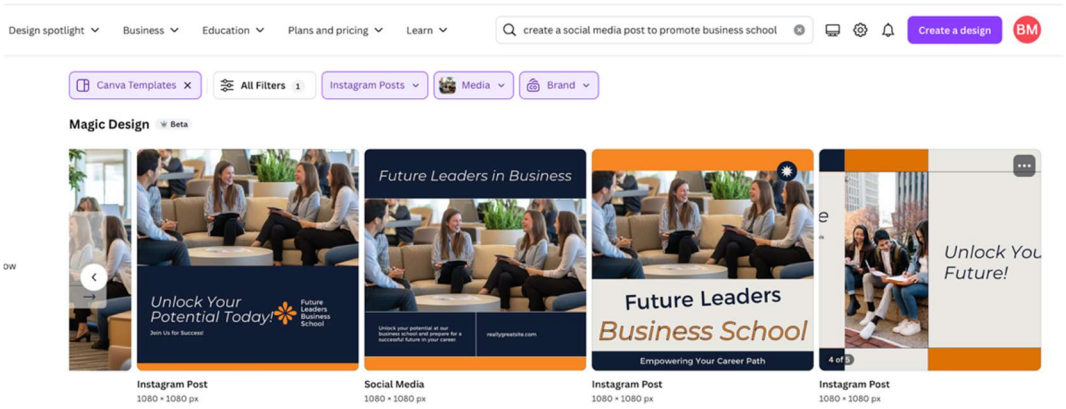


Figure 5: Social media posts created with Canva PRO's Magic Design™

The next step required human intervention. From the proposed graphic solutions, it was necessary to choose one design. Since Canva PRO does not have the capability to automatically insert the specified text and logo into the proposed design, the designer replaced the placeholder text and logo in the selected solution. The chosen design is shown in Figure 6, while the final AI solution after the graphic designer's intervention is shown in Figure 7.



Figure 6: Social media post created with Canva PRO's Magic Design™



Figure 7: Social media post created with Canva PRO's Magic Design™ – edited by a graphic designer

2.2 The first phase of research – Human designer

The next day, the graphic designer was assigned the task of creating a social media post. The task was given to him through instructions similar to the prompts written for AI tools. The graphic designer then familiarized himself with the graphic standards book and proceeded to produce the graphic solution. In creating the social media post, he used real photos available on stock photo websites and did not utilize AI-assisted tools and options available in illustration and photo editing software. The final graphic solution, which was fully produced by the graphic designer, is shown in Figure 7.



Figure 8: Social media post created by a graphic designer

3. RESULTS

3.1 The second phase of the study – Advertising A/B testing

In the second part of this study, the effectiveness of the proposed graphic solutions for social media advertising was evaluated using Meta's A/B testing solution. This method allows for the testing of visual variables by presenting different ad versions to segmented audiences, ensuring that no individual sees both versions and that the budget is evenly distributed. The recommended test duration is two weeks or until 100 conversions are achieved. The testing was conducted from September 7 to September 14 as part of the campaign for enrollment at FTN Business School for the 2024/2025 academic year. The test lasted for 7 days, having exceeded the required minimum of 100 conversions. Figure 8 shows examples of the ads displayed on the social media platform Facebook.



Figure 9: Ad solutions A and B as shown on Facebook

The A/B test in Facebook Ads Manager was set up with the graphic design as the test variable. Both versions of the test were configured with identical parameters, including the same budget, target audience, and

text accompanying the graphic design. The overall results of the advertising campaign are illustrated in Figure 8.

Ad set	Results	Cost per result	Reach	Impressions	Post engagements	Cost per post engagement	Link clicks	CTR (link click-through rate)	CPC (cost per link click)
Test_AI	762 Link Clicks	€0.07 Per link click	29,495	121,631	767	€0.07	762	0.63%	€0.07
Test_HUMAN	756 Link Clicks	€0.07 Per link click	37,439	156,063	759	€0.07	756	0.48%	€0.07
Results from 2 ad	**1,518** Link Clicks	**€0.07** Per link click	**59,817** Accounts C...	**277,694** Total	**1,526** Total	**€0.07** Per Action	**1,518** Total	**0.55%** Per Impressions	**€0.07** Per Action

Figure 10: Ad results for A/B test

At the conclusion of the test, no winning solution was identified based on the key metric, Cost per Result. However, a top performer was determined according to two metrics: Cost per 1,000 Accounts Center accounts reached (Figure 9) and Cost per landing page view (Figure 10). Meta indicates that the confidence level of these results is at least 95%.

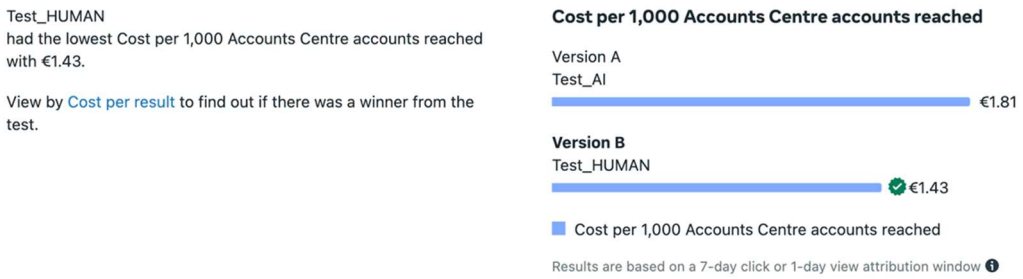


Figure 11: A/B test winner based on the metric: Cost per 1,000 Accounts Center accounts reached



Figure 12: A/B test winner based on the metric: Cost per landing page view

4. DISCUSSION

When considering the overall advertising results, it is observed that both the AI and Human versions of the ad achieved comparable outcomes. Both versions yielded similar results in terms of link clicks to the website and incurred the same cost per click. Notably, the Human version of the ad reached more users-specifically, 7,944-with 34,432 more impressions. However, Meta's algorithm did not recognize these differences as statistically significant. Statistically significant differences were found in the parameters of Cost per 1,000 Accounts Center accounts reached and Cost per landing page view. Although these metrics were not selected as primary parameters, they are significant in the field of advertising, as it is important for advertisers to achieve the best possible results for the same budget. Additionally, it is important to note the time spent on producing these two ad solutions. Creating the AI version of the ad took approximately 6 hours, while producing the Human version of the ad took 30 minutes. It is crucial to recognize that, while we evaluated the effectiveness of graphic solutions created with AI tools versus those created by a graphic designer, the human influence in the production of AI-generated solutions cannot be disregarded. This small experiment demonstrates that current technological advancements do not yet allow AI to achieve

complete autonomy in creating social media content. Had we applied any of the graphic designs shown in Figures 1 and 2 in the A/B test without any graphic designer intervention, we believe that both the A/B test results and user feedback would have been markedly different. As previous studies have concluded (Dehman, 2023) artificial intelligence tools in graphic design can currently accelerate certain design processes and help designers focus on the creative aspects of their work.

5. CONCLUSIONS

The findings suggest that while current AI tools can support and expedite certain aspects of graphic design, they do not yet fully replace the nuanced and creative input of human designers. The results underscore the importance of integrating human expertise in the design process to ensure high-quality outputs and effective advertising strategies. Future research should continue to explore the evolving capabilities of AI in graphic design and assess how these tools can be further optimized to enhance their effectiveness and autonomy in content creation. In conclusion, AI tools hold promise for accelerating graphic design processes, but human involvement remains crucial for achieving optimal design outcomes. The study reinforces the need for ongoing evaluation of AI technologies in practical applications and highlights the continuing value of human creativity in digital marketing.

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THE POWER OF ARTIFICIAL INTELLIGENCE IN PACKAGING DESIGN

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Abstract: *Artificial intelligence (AI) is a technology that allows machines or systems to perform tasks that usually require human capabilities such as learning, thinking, or decision-making. AI can be applied to packaging design to achieve more sophisticated features, such as personalization for product specifications or optimal use. AI systems can analyze images to identify defects in packaging materials, ensuring that only high-quality products are delivered to the market. In addition, artificial intelligence can improve production and distribution processes by analyzing historical sales data and market trends, ultimately reducing costs and reducing inventory. Moreover, AI algorithms can create customized packaging designs and propose appropriate materials based on consumer preferences, market trends and product data. Manufacturers can create packaging solutions that are unique and meet the diverse needs of their customers using this. This paper will discuss some of the application of artificial intelligence in packaging design, using the analytical descriptive approach by analyzing emerging technologies, global packaging trends and market needs. The research concluded with a set of results, the most important of which is that AI applications are added value in packaging design as well as the ability to read the future trends of the market based on the use of modern technologies to analyze the different data and variables of the market.*

Key words: Artificial Intelligence (AI), User Experience (UX), Smart Packaging, Packaging Efficiency, Sustainable Packaging.

1. INTRODUCTION

Artificial intelligence (AI) plays a significant role in various industries in this era. Similar to the packaging industry, packaging companies readily utilize the power and potency of artificial intelligence in creating, designing, producing, or experiencing packaging designs. AI packaging is designed to generate the most appealing and enticing packaging designs for consumers, which directly increase business sales and profits (Designer People, 2023).

AI in packaging is a disruption, braced to transform the processes of end-use industries beyond recognition. Over the last decade, sustainability emerged as a paramount focus in the packaging industry, attracting numerous market players to make ground-level changes in their strategies. However, efficiency remained a de facto need for the packaging industry to realize its sustainability goals (FMI, 2023).

AI now focuses on personalization intelligent packaging solutions, supply chain optimization, and other solutions predictive analytics. The global artificial intelligence in packaging market size is estimated to grow from USD 2,021.3 million in 2022 at 10.28% CAGR (2023-2032) to reach USD 5,375.28 million by 2032 (Towards Packaging, 2024), shown in Figure 1.

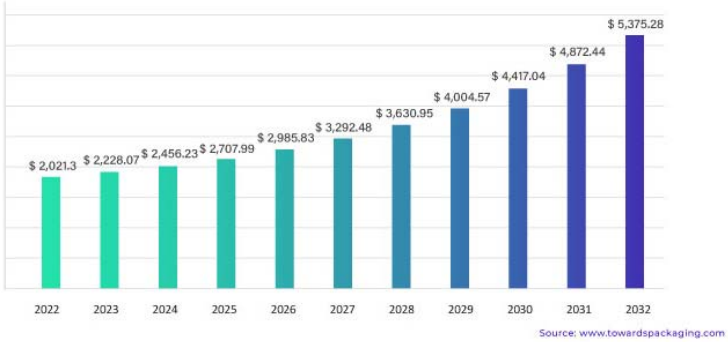


Figure 1: The potential growth of Artificial Intelligence in Packaging industry

ORCID number is provided at the end of the paper.

AI's ability to collect vast swathes of data and use them to build sophisticated models of audience behavior is one of its superpowers, giving brands valuable insights and enabling them to effectively segment their customers. As an example, retailers looking to roll out or redesign tiered own-brand ranges, from entry price point to premium, could make use of this kind of in-depth analysis to inform their packaging decisions, shape their value propositions and target their marketing efforts (Packaging Europe, 2023).

1.1 AI as an emerging technology in packaging design

In 2024, AI is being increasingly employed to enhance the efficiency, creativity, and sustainability of packaging design. Artificial Intelligence, with its ability to analyze vast datasets and draw meaningful insights, is revolutionizing various industries shaping packaging design and its impact on the consumer experience (Haroon, 2023), For the packaging industry, AI paired with other technologies such as digital printing and IoT has the potential to optimize operational processes, reshape business models and transform the customer experience. Learn about the potential impact of AI on packaging from design to consumer experience to recycling (Lawrence, 2024). Artificial intelligence and big data are examples of digital technologies changing traditional industries, including intelligent packaging design.

As the manufacturing industry develops, consumer expectations for packaging are increasing, presenting challenges for technological innovation and integrated development of intelligent packaging. Strategies for the organic integration of technology and environmental protection. And aesthetics in intelligent packaging design. These strategies include strengthening technological innovation, improving environmental performance, emphasizing aesthetic design, and guiding consumer consumption concepts to improve the added value and market competitiveness of packaging. Collaboration between AI and human creativity involves an interaction between human thought processes and an AI algorithm to produce a creative output. Companies offering artificial intelligence development services play a crucial role in bridging the gap between AI capabilities and human creativity, facilitating innovative collaborations across industries.

1.2 AI as a packaging design tool

AI has become an increasingly valuable tool in packaging design, offering innovative methods that enhance creativity, efficiency, and sustainability.
Here are some key methods through which AI is being utilized in this field:

1.2.1 Generative Design

AI algorithms can create a multitude of design options based on specified parameters. Designers can input constraints like materials, dimensions, and sustainability goals, and the AI generates various configurations that meet these criteria.

1.2.2 Predictive Analytics

AI can analyze market trends, consumer preferences, and sales data to predict which packaging designs may perform best. This helps companies make informed decisions about product packaging before they reach the market.

1.2.3 Image Recognition

AI-driven image recognition tools can analyze existing packaging designs in the market, identifying trends and consumer preferences. This analysis can guide designers in creating appealing and competitive packaging strategies.

1.2.4 Customer Insights and Sentiment Analysis

By analyzing social media, reviews, and other consumer data, AI can provide insights into how packaging is perceived by consumers. This feedback can help refine designs to better align with customer expectations.

1.2.5 3D Prototyping

AI can aid in creating virtual 3D models of packaging designs, allowing designers to visualize and test the physical characteristics of their designs before production. This can streamline the design process and reduce material waste.

1.2.6 Sustainability Optimization

AI tools can help optimize packaging for sustainability by suggesting materials that reduce environmental impact, minimizing waste, and enhancing recyclability. This is increasingly important for meeting regulatory requirements and consumer expectations.

1.2.7 Customization and Personalization

AI can enable customized packaging designs tailored to specific consumer segments. This personalization can enhance customer engagement and brand loyalty.

1.2.8 Automated Design Feedback

AI systems can evaluate packaging designs based on predefined criteria, providing automated feedback and suggestions for improvements. This can enhance designers' workflows by streamlining the review process.

1.2.9 Augmented Reality (AR) Integration

AI can support AR applications that allow consumers to visualize products in packaging or understand product information interactively. This technology can be particularly effective for marketing purposes.

1.2.10 Supply Chain Optimization

AI can assist in optimizing packaging choices based on logistics and shipping factors, ensuring that designs are not only visually appealing but also practical for storage and transportation.
By leveraging these AI methods, companies can create more effective, engaging, and sustainable packaging designs, ultimately leading to improved customer satisfaction and brand recognition.

2. METHODS

In this part of the study, the tools and materials used to implement the research idea are summarized according to the research observations of the researcher about the focused discussion with experts and those interested in the field of printing and packaging at paper me & print2pack2024, located in Egypt's Center for International Exhibitions in New Cairo, Egypt, after a set of questions about the role of artificial intelligence in packaging design. A questionnaire was made by 75 people interested in the field and most in food packaging, as shown in Table 1.

Table 1 (part 1): An Overview of expert and packaging industry responses on AI in packaging

Questions for experts and those interested in the packaging industry	*Responses, refer to Number (percentage %)*	
Section 1: Awareness and Usage of AI		
Are you familiar with AI technologies in packaging design?	**YES,** 60 (80%)	**NO,** 15 (20%)
	Most of those interested in the packaging industry are looking forward to emerging technologies.	
Does your organization currently use AI tools in packaging design?	**YES,** 33(44%)	**NO,** 42 (56%)
	If yes, which AI tools are you using?	
	From AI tools used in packaging design - Photo re-coloring tool (a tool trained in a huge number of color images that enables it to understand the image composition) - Photo background removal tool (is a tool used to remove photo background by image analysis) - The image creation tool by writing (it is to create a copy of the text descriptions by inserting text about what you imagine or want and it has to create it for you) - Image quality enhancement tool (a tool used to improve image quality and raise accuracy) - Image dimension change tool (a tool used to change and complement image dimensions and imagine what might be in this extension) - Add some elements to the image (a tool used by deciding where you want to add an element and then writing the element) - Image conversion tool for Victor (a tool used to convert dot images to Victor images and identify basic lines and shapes)	

Table 1 (part 2): An Overview of expert and packaging industry responses on AI in packaging

How would you rate your organization's overall adoption of AI in packaging design?	**Not at all,** 15 (20%)
	Somewhat, 27 (36%)
	Moderate, 24 (32%)
	Extensive, 9 (12%)
	Fully integrated, 0 (0%)
Section 2: Benefits of AI in Packaging Design	
What do you see as the biggest advantages of using AI in packaging design? (Select all that apply)	**Improved efficiency and speed,** 40 (53.3%)
	Enhanced design capabilities, 7 (9.3%)
	Cost reduction, 27 (36%)
	Better understanding of customer preferences, 25(33.3%)
	Sustainability improvements, 16 (21.3%)
	Other (Please specify), 2 (2.6%) **- Innovative Design Concepts** **- Integration with Marketing Strategies**
Can you provide a specific example of how AI has benefited packaging design process?	AI has significantly enhanced the packaging design process in various ways. Here's a specific example: **Automated Design Suggestions:** A packaging design company integrated AI algorithms to analyze past successful packaging designs within specific industries. By understanding patterns in colors, shapes, and materials that have resonated with consumers, the AI system could generate design suggestions for new products. For instance, when a beverage company was launching a new flavored drink, the AI analyzed data on competitor packaging, market trends, and consumer feedback. It suggested a vibrant color palette and a unique bottle shape that stood out on shelves. The design team then refined the AI-generated concepts, leading to a final product that increased shelf visibility and consumer interest, ultimately resulting in a sales boost. This process allowed designers to save time on research and exploration, focus more on creativity and refinement, and produce packaging that is likely to resonate with consumers.
Section 3: Challenges and Concerns	
What challenges have you faced when integrating AI into your packaging design workflow? (Select all that apply)	**Lack of expertise,** 66 (88%)
	High costs of implementation, 28 (37.3%)
	Resistance to change within the organization, 39 (52%)
	Data privacy concerns, 19(25.3%)
	Limited understanding of AI capabilities, 57 (76%)
On a scale of 1 to 5, how concerned are you about the potential implications of using AI in packaging design?	☐ **1 (Not concerned),** 34 (45.3%)
	☐ **2,** 18 (24%)
	☐ **3,** 11 (14.7%)
	☐ **4,** 8 (10.7%)
	☐ **5 (Very concerned),** 4 (5.3%)
Section 4: Future Perspectives	

Table 1 (part 3): An Overview of expert and packaging industry responses on AI in packaging

How do you envision the future of AI in packaging design over the next 5 years?	The future of AI in packaging design over the next five years is likely to be transformative, with advancements leading to greater efficiency, customization, and sustainability. Here are several key trends I envision: 1. Enhanced Personalization: AI will enable hyper-personalized packaging solutions. By analyzing consumer data and preferences, brands will create packaging tailored to individual customer segments. This could include unique designs, messaging, and even customizable packaging options that adapt based on user interaction. 2. Sustainability Optimization: As sustainability becomes a priority, AI will assist in optimizing materials and designs to reduce waste and carbon footprint. Machine learning algorithms could analyze the lifecycle of materials and recommend the most eco-friendly options without compromising design aesthetics or functionality. 3. Rapid Prototyping: AI-powered tools will facilitate faster prototyping and iteration of packaging designs. Designers could use generative design algorithms to quickly create multiple design variants based on specific parameters, significantly reducing the time from concept to market. 4. Smart Packaging Integration: The rise of IoT (Internet of Things) will lead to the development of smart packaging that incorporates AI for better tracking, inventory management, and enhanced customer engagement. Packaging could provide real-time data on freshness, usage, and even personalized experiences via QR codes or NFC technology. 5. Predictive Analytics for Trends: AI will improve the ability to predict emerging design trends by analyzing social media, market data, and consumer behavior patterns. This insight will allow brands to stay ahead of the curve and adapt their packaging to meet evolving consumer preferences more effectively. 6. Collaboration Platforms: AI-powered collaboration tools will streamline communication between designers, brands, and manufacturers, enhancing the workflow and transparency in the packaging design process. This can lead to more innovative solutions as stakeholders can share insights and feedback more effectively. 7. Cost Reduction and Efficiency: Automation through AI will reduce design-related costs, from labor to materials. By optimizing the entire design and production process, brands will save money while producing high-quality, effective packaging. Overall, the integration of AI in packaging design will not only enhance creativity and efficiency but also align closely with consumer expectations for personalization and sustainability, shaping a more innovative future in the industry.

Table 1 (part 4): An Overview of expert and packaging industry responses on AI in packaging

What improvements or advancements in AI would most benefit your packaging design efforts?	Several advancements in AI could significantly enhance packaging design efforts, enabling greater creativity, efficiency, and responsiveness to market needs. Here are some key improvements that would be particularly beneficial: **1. Advanced Machine Learning Algorithms:** Enhanced algorithms that can analyze more complex datasets—including consumer behavior, market trends, and historical design successes—would allow for more informed design decisions. This could lead to better predictions of successful design elements and trends, ultimately improving final outcomes. **2. Real-time Feedback and Analytics:** Systems that can offer real-time feedback on design choices—based on user testing, consumer reactions, and performance metrics—would allow designers to iterate and refine packaging options quickly. This fosters an agile design process that can adapt to customers' needs faster. **3. Augmented Reality (AR) Integration:** Incorporating AR technology in AI tools could help visualize packaging designs in real-world settings. Designers and clients could experience how packaging will look and interact with customers before final production, leading to more informed design decisions and greater market appeal. **4. Collaboration Tools with AI:** Improved collaborative platforms that utilize AI to analyze contributions from various stakeholders (like sales, marketing, and production) can ensure that all perspectives are considered in the design process. AI could highlight potential issues or inconsistencies based on input from different teams. **5. Sustainability Tracking:** AI tools that can automatically evaluate the sustainability impacts of different packaging designs and materials would enable designers to make environmentally friendly choices easily. This could include insights on sourcing, recyclability, and lifecycle analysis of materials. **6. Customization and Personalization Engines:** Enhanced capabilities for creating tailored packaging solutions based on customer segmentation would enable brands to offer personalized packaging experiences. This could include variable printing technologies that adapt designs based on customer data. **7. Integration with Supply Chain Management:** AI improvements in supply chain logistics would ensure that packaging design choices align seamlessly with production capabilities and material availability. This optimization could lower costs and reduce lead times, making the design process more efficient. By focusing on these advancements, the packaging design process can become more innovative, agile, and aligned with both consumer demands and sustainability goals, ultimately driving greater success in the market.

3. RESULTS

The application of analytical methods in AI for packaging design has led to several key results and benefits that improve both the design process and the final product. Here are some notable outcomes:

- Enhanced Design Efficiency: AI analytics tools can automate routine tasks and streamline the design process, allowing designers to focus on creative.
- Data-Driven Decisions: AI algorithms analyze vast amounts of data from customer behavior, market trends, and competitive benchmarks. This leads to more informed design decisions, allowing companies to create packaging that resonates better with target audiences.
- Improved Consumer Insight: Analytical methods employed by AI can extract meaningful insights about consumer preferences and buying patterns through sentiment analysis and social media

monitoring. This feedback helps brands design packaging that aligns closely with what consumers want.

- Cost Reduction: By identifying optimal materials and shapes through simulations and predictive modeling, AI helps reduce production costs and waste. This can lead to more economical packaging solutions while maintaining quality.
- Sustainability Improvements: AI can analyze environmental impacts, helping companies choose more sustainable materials and designs that minimize ecological footprints. This can enhance a brand's image and meet consumer demand for environmentally responsible products.
- Rapid Prototyping and Testing: Analytical AI tools facilitate quick prototyping by enabling virtual testing and 3D modeling. This allows designers to experiment with numerous iterations of their packaging before physical production, accelerating the design cycle.
- Personalization at Scale: AI can analyze data to deliver personalized packaging solutions based on consumer demographics and behavior, leading to increased engagement and loyalty from customers who appreciate tailored experiences.
- Predictive Performance: AI can forecast how different packaging designs will perform in the market by analyzing previous launches and consumer responses, thus reducing the risks associated with new product introductions.
- Innovative Design Concepts: AI analytical methods can identify trends and styles that designers might overlook. By discovering unconventional design patterns, companies can create unique packaging that stands out on the shelves.
- Integration with Marketing Strategies: AI analysis helps ensure that packaging aligns with broader marketing campaigns and brand messaging, enhancing overall coherence and effectiveness in reaching target audiences.
- Regulatory Compliance and Risk Management: AI can help in compliance with packaging regulations by analyzing design specifications against legal requirements, minimizing the risk of costly recalls and penalties.

These results demonstrate how analytical methods powered by AI not only enhance the packaging design process but also contribute to more effective, sustainable, and consumer-oriented packaging solutions. Thus, some design proposals have been made using AI tools to improve the graphic and construction design of food packaging by selecting certain requirements such as colors, design style, packaging dimensions and packaging size, shown in Table 2 (presented in part 2).

In Figure 3, 5, 7 the cocoa packaging, baby pasta and milk different design style were displayed such as choosing a different design type for the cocoa packaging to become more attractive in the shelves and choosing a suitable style with children for the pack of pasta by Using clear window to suitable for graphic design of the baby pasta package and choosing the classic style and the single color in the milk packaging.

Table 2 (part 1): Sample design proposals for food packaging using AI tools

The packaging's graphic and structural design (Before use AI)	The packaging's graphic and structural design (After use AI)
 *Figure 2: Cocoa packaging before redesigning*	 *Figure 3: The proposal of graphic and structural design for cocoa packaging by using AI tools*

Table 2 (part 2): Sample design proposals for food packaging using AI tools



Figure 4: baby pasta packaging before redesigning



Figure 5: The proposal of graphic and structural design for baby pasta packaging by using AI tools



Figure 6: Lamar milk packaging before redesigning



Figure 7: The proposal of graphic and structural design for Lamar milk packaging by using AI tools

Following the great responses to the role of artificial intelligence tools in improving packaging design the researcher presented the project idea to fourth-year students 2024 at the Higher Institute of Applied Arts, Department of Printing, Publishing and Packaging, Titled The Added Value of design in the field of printing and packaging using artificial intelligence and its connection to the Drupa 2024 exhibition, as shown in Figure 8.



Figure 8: Samples of student design outputs using AI tools in design

4. DISCUSSION

AI is perfect for A/B testing packaging designs at the concept stage. This will quicken design variations such as color, placement and type alternatives when creating initial concepts. Using AI in packaging design is a challenge that requires high skills and expertise, and works best with the involvement that comes from a close partnership throughout the design journey. This approach has certainly paid off in helping to generate positive feedback from users as well as experts interested in the packaging industry.

5. CONCLUSIONS

The role of AI in packaging design for 2024 is not just a technological advancement; it's a symphony of innovation. The collaboration between human creativity and AI-driven insights produces a composition that goes beyond the canvas, creating an unforgettable experience for consumers.
Combining AI with professional human expertise is the secret to surpassing your competitors this year. Leveraging this technology to streamline your operations and reduce overall costs will give you a better edge over your competitors. AI recommended to help companies reduce their environmental impact. This will make a change by optimizing packaging to reduce waste as well as assisting in find a more sustainable packaging solution. AI is not everything. You will need a creative mind and experience to know what creative or art direction you will be taking, AI will not take all of human jobs.
Needless to say, I would most definitely recommend AI tools for any designer looking to improve and accelerate their workflow.

ACKNOWLEDGMENTS

I would like to thank the experts and those interested in the packaging industry for their valuable help and opinions.

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CAPABILITIES OF AI IN TEXT-TO-3D MODEL GENERATORS FOR MECHANICAL COMPONENTS DESIGN

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Abstract: *This paper explores how effectively Artificial Intelligence (AI) can translate text descriptions into accurate and functional 3D models of mechanical components, highlighting both the potential and the current shortcomings of this technology. A functional 3D model implies that it is suitable for 3D printing. Three different AI 3D model generators were selected for this analysis. Text prompts involving gear mechanisms were used as input. Each generated model was assessed on key parameters such as the accurate depiction of gear teeth, the correct alignment and meshing of gears, and the overall structural integrity required for functional gear mechanisms. Additionally, the generated models were verified for any deviations from the expected design standards of mechanical gears. The analysis revealed that none of the selected AI 3D model generators could consistently produce fully functional and technically accurate gear models based on simple text prompts. While the AI generators could produce visually correct models that generally resembled gears, significant shortcomings were observed in their functional and technical accuracy. The generated models often failed to meet the precise geometric and structural requirements necessary for practical application in mechanical systems. Automating the 3D modelling process for mechanical components using AI technology would reduce time and cost. However, further advancements in AI and machine learning are required to enhance the accuracy and reliability of AI-generated 3D models for use in real-world mechanical design and manufacturing.*

Key words: 3D Model Generator, Artificial Intelligence, Text-to-3D Model, Mechanical Components

1. INTRODUCTION

The field of Artificial Intelligence (AI) has seen advancements in recent years, particularly in generative models. AI image generators have demonstrated satisfactory capabilities in creating detailed and imaginative images from text prompts, showing the potential of AI to translate textual descriptions into visual content. These technologies have already made a significant impact on creative industries by automating the generation of high-quality images and visual art (Kang et al., 2023; Noel, 2023).
AI technologies have also extended their capabilities to 3D model generation. AI 3D model generators use artificial intelligence and advanced algorithms to create three-dimensional models based on textual descriptions, images, and even video inputs. It enables the automated production of 3D models from a variety of input sources, which can then be used for applications such as virtual reality, augmenter reality, entertainment, or in robotics and autonomous vehicles (Tsalicoglou et al., 2024).
The market currently features a significant number of AI 3D generators, specializing in different applications. These tools offer a wide range of functionalities, including real-time full-body motion capture, applications in gaming and architecture, artistic video creation, while others excel in full-body marker tracking or texture generation, as well as capturing high-quality geometry. Each of these generators has its own strengths made up for specific needs in design and visualization (Unite AI, 2024).
In mechanical design, creating and manufacturing components can be both costly and time-consuming. To address this challenge, AI 3D generators have been explored as a potential solution for automating the design process.
This paper investigates the effectiveness of current AI technologies in translating text prompts into accurate and functional 3D models of mechanical components, with a specific focus on spur gear. The aim is to determine if these generators can provide an accurate and viable model, assessing their effectiveness in reducing the time and expense associated with traditional mechanical design and production processes, while also identifying any limitations in their current capabilities.
Three different AI 3D model generators were evaluated based on their ability to produce models that adhere to key mechanical design standards. These standards include the accurate representation of gear teeth, proper alignment and meshing of gears, and overall structural integrity necessary for practical use.
The research shows the need for further advancements in AI and machine learning to enhance the accuracy and reliability of AI-generated 3D models.

ORCID numbers are provided at the end of the paper.

2. METHODS

Mechanical components, such as gears, are fundamental elements in a wide range of machinery and devices. The design of these components requires precise specifications to ensure functionality and compatibility within mechanical systems. Traditionally, the design process involves detailed manual drafting and modelling, which can be time-consuming and prone to human error. The integration of AI in generating 3D models from text descriptions offers an innovative solution to streamline this process (Obsieger, 2003).
Three different AI 3D generators were used to create 3D models from a text prompt: Luma AI (Lumalabs, 2024), Meshy AI (Meshy AI, 2024), and Rodin AI (Hyperhuman, 2024). These generators were selected based on their availability and the variety of features they offer for different applications. Each of the generators was tasked with interpreting the same prompt to ensure consistency in the testing process.
The key elements required to define gears include the number of teeth, module, pitch diameter, pressure angle, gear ratio, gear width and gear type. These parameters collectively determine the shape, size, and functional characteristics of the gear within a mechanical system. In this study, the text prompt used for generating the 3D model was as follows: "spur gear: 30 teeth, module 2 mm, 60 mm pitch diameter, 20° pressure angle, 10 mm gear width".

3. RESULTS

Text prompt "spur gear: 30 teeth, module 2 mm, 60 mm pitch diameter, 20° pressure angle, 10 mm gear width" was used to represent a standard mechanical component, ensuring that the AI generators were challenged with producing a technically accurate and functional model.

3.1 3D generator Luma AI

The generation time for 3D generator Luma AI was three minutes. The text prompt resulted in a model of an individual gear, featuring a random number of teeth, arbitrary dimensions, tooth angles, and hole diameter. However, the resulting 3D model is not adequately shaped; it exhibits uneven characteristics, gaps between the teeth, and the hole is misaligned. Despite these issues, the topology of the model; with the "Low" (Figure 1) and "Med" (Figure 2) options selected; remains relatively neat and organized. Tooth alignment between two gears is shown in Figure 3.

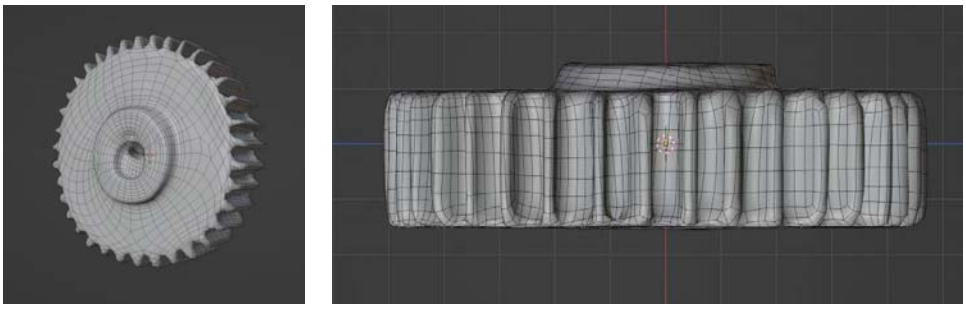


Figure 1: Luma AI model - Topology Display (lower polygon resolution – 5,000 polygons)

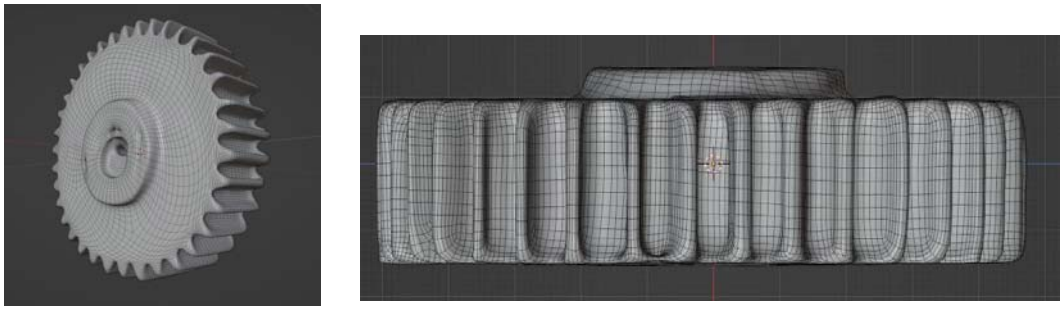


Figure 2: Luma AI model - Topology Display (medium-density polygon resolution – 20,000 polygons)

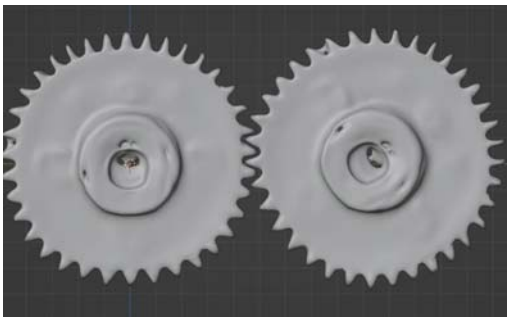


Figure 3: Luma AI model - tooth alignment between two gears

3.2 3D generator Meshy AI

The generation time for 3D generator Meshy AI was one minute. The text prompt yielded several variations of 3D models of different gears. Although these models still featured random parameters and dimensions, they exhibited a correct and adequate appearance, with consistent dimensions, uniform spacing between the teeth, and centered holes with minimal noticeable deviations in geometry. Two out of the four variations were selected for their accuracy, as they displayed no significant irregularities or geometric artifacts (Figure 4).

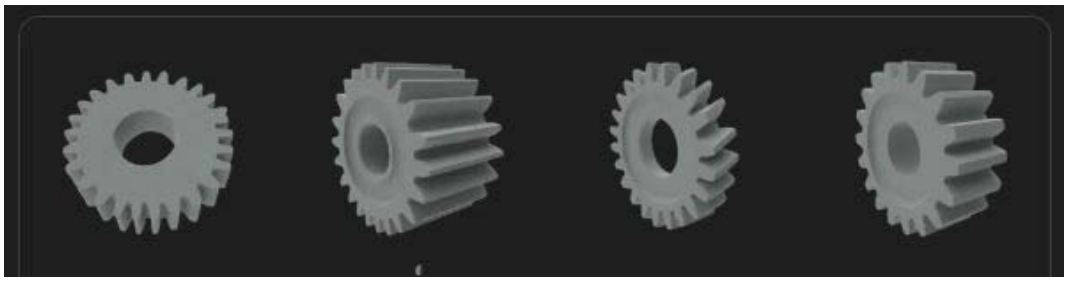


Figure 4: Meshy AI generated 3D models

The first selected variation is an individual gear with random dimensions and a variable number of teeth, exhibiting a slanted horizontal angle. It turned out to be quite accurate, with only minor geometric irregularities (Figure 5). Tooth alignment between two gears is visualized in Figure 6.

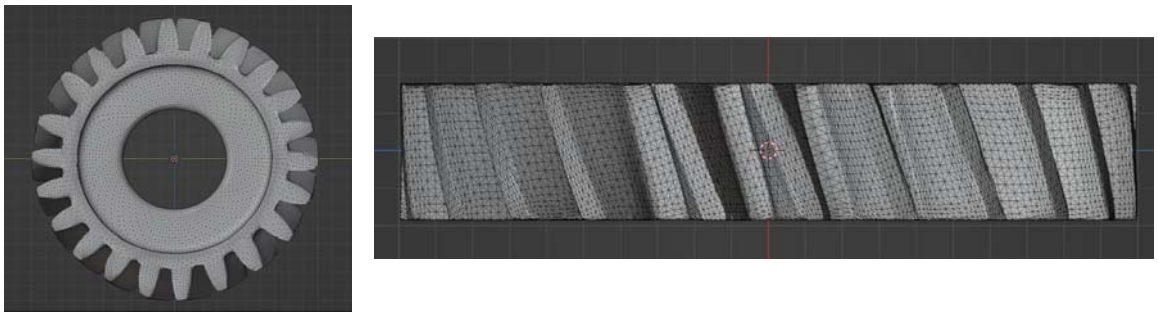


Figure 5: Meshy AI model - Topology Display for the first gear variation

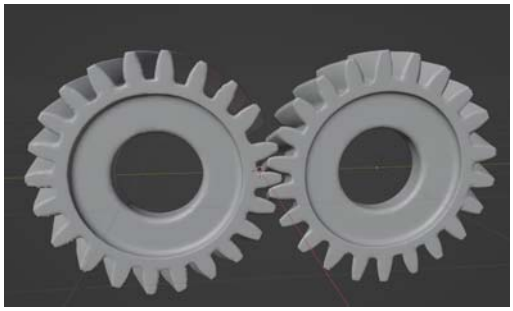
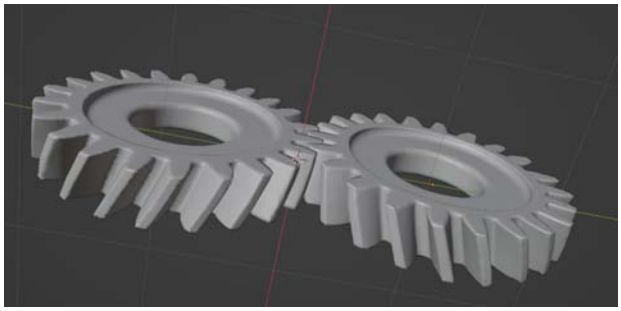



Figure 6: Meshy AI first model - tooth alignment between two gears

The second selected variation is also an individual gear with random dimensions and a variable number of teeth, but it features a correct and uniform shape with straight teeth, equal spacing, and a centered hole, again displaying only minor geometric irregularities (Figure 7). In Figure 8 tooth alignment between two gears can be seen.

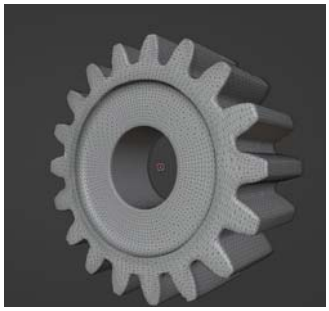
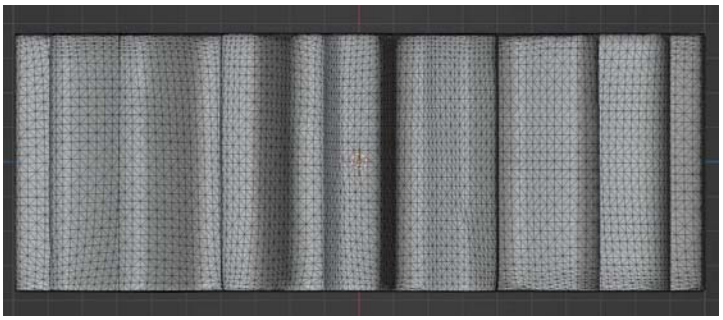



Figure 7: Meshy AI model - Topology Display for the second gear variation

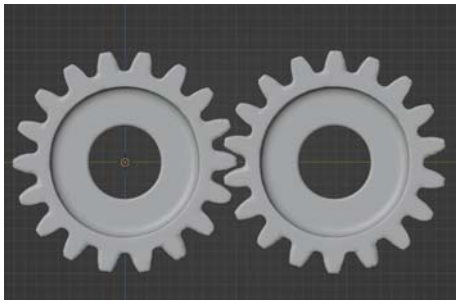


Figure 8: Meshy AI second model - tooth alignment between two gears

3.3 3D generator Rodin AI (Gen-1)

The generation time for 3D Rodin AI was less than a minute. By inputting the textual prompt, a single gear with random dimensions and parameters was generated. It exhibits a correct round shape and a centered hole; however, it features irregular and uneven teeth of varying sizes and spacing. The topology is neat and moderately dense, consisting of 10,000 polygons, although the geometry of the teeth remains irregular (Figure 9). Visualization of tooth alignment between two gears can be seen in Figure 10.

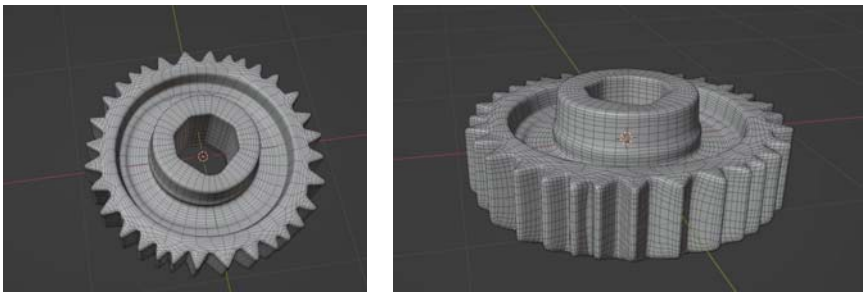


Figure 9: Rodin AI model - Topology Display (10,000 polygons)

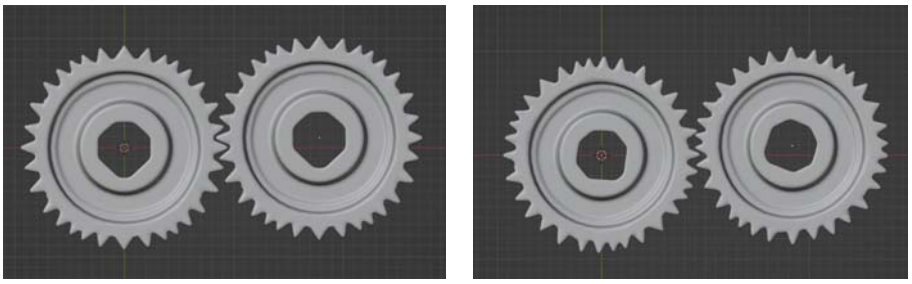


Figure 10: Rodin AI model - tooth alignment between two gears

4. DISCUSSION

The evaluation of three AI 3D generators—Luma AI, Meshy AI, and Rodin AI—provides capabilities and limitations of these technologies in producing functional 3D models of mechanical components from text prompts. Model generated form 3D generator Luma AI is unsuitable for any real and practical use such as 3D printing, meaningful simulation, or 3D animation. However, the polygons create irregular tooth shapes, which limits the model to only potential digital use where precision is not critical. The 3D generator Meshy AI produced four variations, of which two were selected. The first selected variation is relatively adequate in shape for use in a real mechanism or prototype (3D printing). Its topology is neat and moderately dense, consisting of 50,000 polygons, making it suitable for simple 3D models where high resolution is not necessary; however, this density may represent an excess in terms of system optimization or computer performance. The second selected variation is also relatively adequate in shape for use in a real mechanism or prototype (3D printing). Its topology is neat and denser, similar to the previous example, with approximately 50,000 polygons. The 3D generator Rodin AI produced a gear model that is neither adequately shaped nor suitable for practical use in a mechanism or prototype (3D printing). Each AI 3D generator exhibited strengths and weaknesses. These findings underscore the progress made in AI 3D modelling while also highlighting the need for further advancements to enhance the precision and reliability of AI-generated models for mechanical applications.

5. CONCLUSIONS

In examining the capabilities of three different AI 3D model generators: Luma AI, Meshy AI, and Rodin AI; it becomes evident that these generators exhibit both potential and limitations in generating functional mechanical components from text prompts. While Luma AI and Rodin AI failed to deliver models suitable for practical applications such as 3D printing or simulation due to issues with precision and geometry, Meshy AI showed promise by generating two viable variations. Though not perfect, these models demonstrated an adequate shape and topology for prototyping and basic mechanical use. However, the high polygon count in Meshy AI's models could present challenges in terms of optimization and performance in certain cases. Overall, while these AI tools showcase notable advancements in automated 3D modeling, they still require improvements in precision and usability to meet the demands of real-world mechanical applications. Further development will be needed to improve the practicality of these tools for engineering and design applications.

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REINFORCEMENT OF 3D PRINTED PLA WITH CARBON FIBER REINFORCED COMPOSITE AND INVESTIGATION OF MECHANICAL PROPERTIES

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Abstract: *While production methods with 3D printing are developing day by day, studies on this method are also increasing. 3D layered manufacturing is a method of creating layer-by-layer 3D solid models designed with computer-aided drawing (CAD) programs using melted raw material for each layer. In addition to PLA being the most commonly used filament in 3D printing, filaments such as ABS, PETG, and TPU are also used. A wide variety of products can be produced with this production method depending on the design. The mechanical properties of the products resulting from 3D printing depend on many parameters such as the number of layers, fill rate, material used, and printing speed. Various methods are also applied to further strengthen the products produced from printing. In this study, PLA samples obtained from 3D printing were reinforced with carbon fibre reinforced polymer composite (CFRP). The reinforcement process was carried out by placing CFRP material during PLA sample production, and the mechanical properties of the resulting samples were examined. Increased hardness as well as improved tensile, bending, impact, and wear strengths of the CFRP reinforced samples were observed.*

Key words: CFRP reinforced PLA,3D printer, Carbon Fiber, PLA, CFRP

1. INTRODUCTION

A 3D printer is a device that creates three-dimensional objects by depositing materials layer by layer based on digital models. This process is known as additive manufacturing. Unlike traditional manufacturing methods that remove material through cutting or drilling (subtractive processes), 3D printing adds material layer by layer only where needed, based on the 3D design. In this study, the FDM method was used. The basic principle of Fused Deposition Modelling (FDM) involves heating and reshaping the raw material to create new forms. In this process, a filament spool, which is the raw material, is gradually unwound by a mechanism typically involving a drive wheel (Dizon et al., 2018). This filament is then fed into a nozzle with controlled temperature to reach a semi-liquid state (Mitchell et al., 2018). As the filament passes through the nozzle, it is extruded in extremely fine, successive layers. The nozzle moves precisely to deposit each layer, progressively building the object from the bottom up. This movement is typically guided by a pre-programmed design created using Computer-Aided Design (CAD) software, which defines the exact path and shape of each layer. By following these CAD specifications, the FDM printer can construct complex three-dimensional structures layer by layer, with highly controlled and accurate precision (Kristiawan et al., 2021).

Initially, the FDM printer heats the nozzle to a specific temperature. The raw material, typically in filament form, is then passed through this heated nozzle. The molten filament is carefully extruded onto the printer's build platform. Upon contact, the material cools and solidifies, forming the first layer of the object. Once the first layer solidifies, the nozzle extrudes additional filament to form the next layer. As it cools, this new layer fuses with the one beneath it. This process is repeated, with each new layer adhering to the previous one, gradually building the object upward. In terms of printing patterns, FDM printers typically follow a specific order. They begin by printing the object's perimeter, outlining the outer and then inner edges. After these boundaries are established, the printer fills in the interior of each layer. This interior can be completely solid or patterned with an infill matrix, depending on the object's design and structural requirements. The printer continues this cycle of extrusion, cooling, and layer bonding until the entire object is complete. The precise movement of the nozzle, directed by the printer's software, ensures that each layer conforms to the design specifications, resulting in a finished product that matches the intended three-dimensional shape (Mwema & Akinlabi, 2020).

Low melting temperature of PLA filament, typically ranging from 200 to 220°C, makes it an accessible

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material for a wide range of desktop FDM 3D printers (Szykiedans et al., 2017). This low melting point not only simplifies the printing process by reducing the likelihood of clogging but also eliminates the need for specialized printing hardware, such as heated beds or enclosures. Furthermore, PLA's low shrinkage rate minimizes the risk of warping, a significant advantage when printing large objects or designs with substantial contact areas on the print bed (Wewolver, 2024). In terms of mechanical properties, PLA exhibits a tensile strength of approximately 7,250 psi, making it a fairly strong material for lightweight applications. However, its elongation at break is about 6%, which is lower than some other filaments, such as ABS and PETG, making it more brittle (All3dp, 2024). This brittleness limits its use in situations requiring high impact resistance or load-bearing capacity (Bergström & Hayman, 2016).
A notable feature of PLA is its biodegradability. Unlike petroleum-based filaments, PLA can decompose into its components under suitable conditions, typically within a few months to years (Raja et al., 2022). This property is particularly appealing to environmentally conscious users as it addresses growing concerns about the ecological impact of 3D printing materials (Vanaei et al., 2020). Despite its numerous advantages, PLA also has some drawbacks. Its brittleness, sensitivity to high temperatures, and lower chemical resistance compared to other filaments like ABS and PETG may limit its applicability in certain situations (Lugo, 2022). Additionally, its hygroscopic nature, which leads to moisture absorption, can affect the quality and consistency of the filament, necessitating careful storage and handling (Joseph et al., 2023).

2. EXPERIMENTAL STUDIES

2.1 Materials

2.1.1. Epoxy resin and carbon fibre

Epoxy resin was used as the matrix material. The properties of the carbon fibre used in the production of the CFRP plates are shown in Table 1,

Table 1: Properties of carbon fibre (DowAksa, 2024)

Brand	DowAksa
Fiber Type	24K
Fiber Quality	A-42
Tex Amount	1.6 kg per 1000 meters/Nm 1.6
Tensile Strength	2040 MPa

2.1.2 PLA Filament

CBC Filament brand PLA filament was used. The properties of the PLA filament used are shown in Table 2.

Table 2: Properties of PLA filament (ileri3D, 2024)

Marka	CBC Filament
Renk	Beyaz
Çap	1.75mm
Çap Toleransı	±0.02

2.1.3 Cyanoacrylate

Cyanoacrylate was used as the adhesive.

2.2 Test Methods

Tensile test was performed on a Zwick Z010 model device at a test speed of 5 mm/min, and 3-point bending test was performed on the same device at a test speed of 2 mm/min. Izod impact test was performed on a Zwick device with a 5.4 Joule hammer. Tensile, impact, and bending tests were performed at room temperature and the test results were calculated by taking the average of 5 samples.
The hardness test was conducted to each sample by taking 10 measurements on a Zwick Shore D test device and the averages of the measurements were calculated.

For the abrasion test, a Pin-On-Disk Test was performed using a Devotrans GT-7012-T model Taber abrasion device and appropriate apparatus, the test was performed with CS10 abrasive wheels according to the ASTM G99 standard at room temperature at a speed of 72 rpm. Before and after each test, the disk and sample surfaces were cleaned with a brush. In this study, 3 samples from each group were tested to determine the weight loss after abrasion and the arithmetic average was calculated. The weights of each sample were measured at the beginning (before wear) and every 250 turns, for a total of 1000 turns, on a precision balance with a precision of 0.0001 g, and the weight loss (Δm) was calculated.

2.3 Manufacturing Methods

2.3.1 Carbon Fiber Reinforced Composite (CFRP) Plates

Carbon fibre reinforced composite (CFRP) sheets were produced by the pultrusion method. The produced plates were cut according to test standards using a special cutter. The flowchart of the CFRP plate production method is shown in Figure 1. The CFRP plates are 10mm wide for tensile test specimens, 6.5mm wide for other specimens, and full length for all specimens.

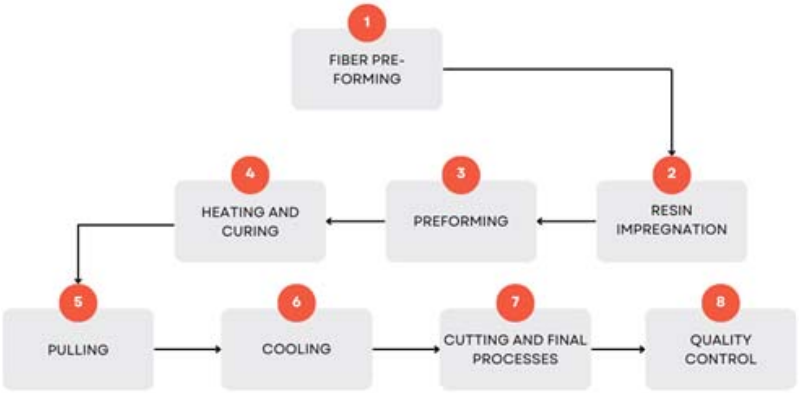


Figure 1: CFRP plate production method flow chart

2.3.2 PLA specimens containing CFRP plates

The production flowchart of the PLA specimens containing CFRP plates is shown in Figure 2.

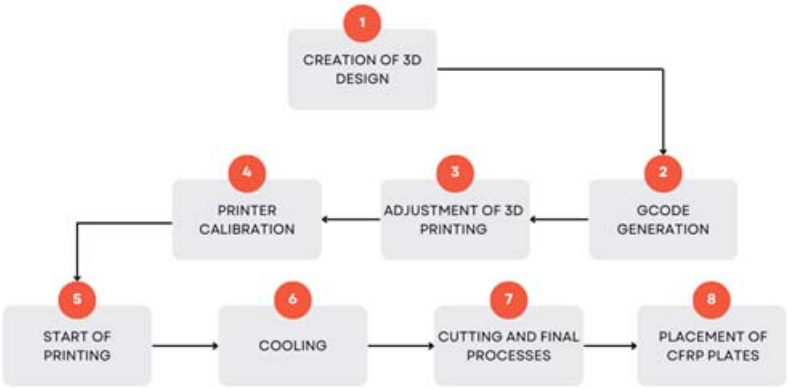


Figure 2: Production flow chart of PLA composite samples containing CFRP plate

In the first stage of the production process, the specimens were designed according to ASTM standards using the Fusion 360 CAD program (Figures 3 and 4).

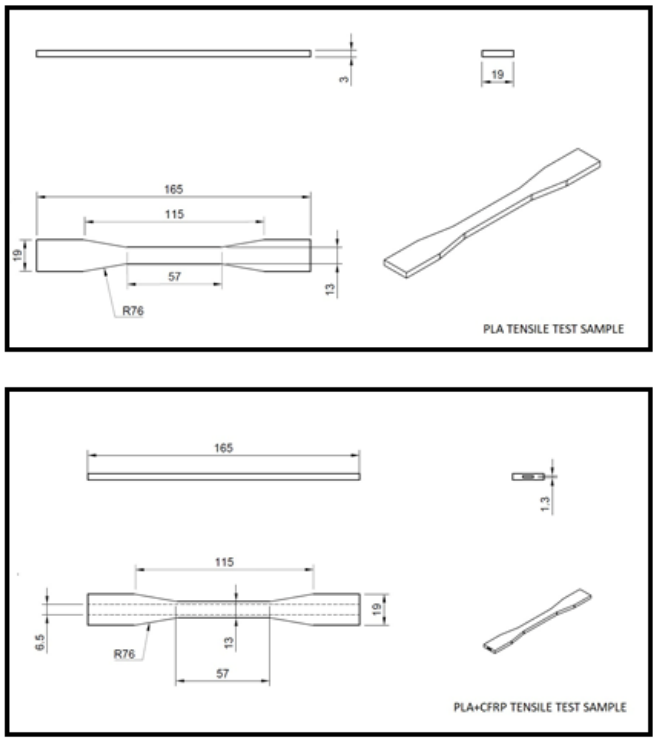


Figure 3: Technical drawing of the tensile specimens

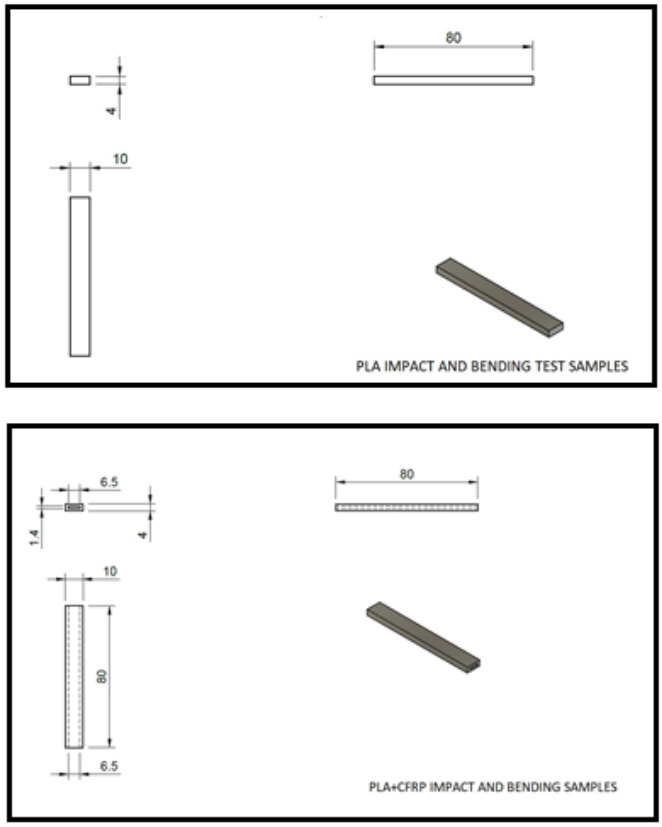


Figure 4: Technical drawing of the impact and bending test specimens

In the next stage, the 3D design (CAD) of the samples was "sliced" in the software called Ultimaker Cura, the parameters were integrated into the printer in a suitable way and converted into Gcode (Figure 5). The files converted into Gcode were transferred to the 3D printer with a USB memory stick.

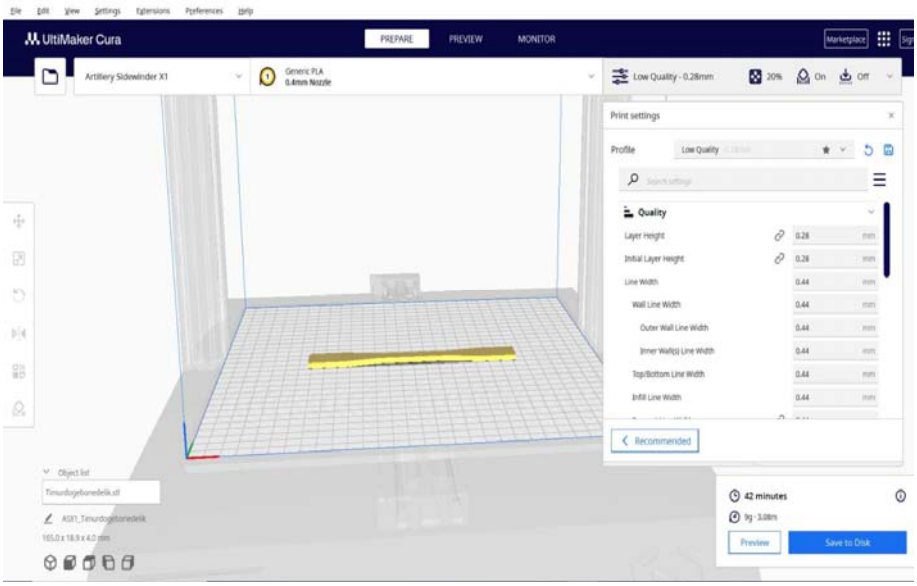


Figure 5: Transfer and adjustment in the Slicing program

After the transfer, the specimens were printed using the 3D printer (Figure 6).

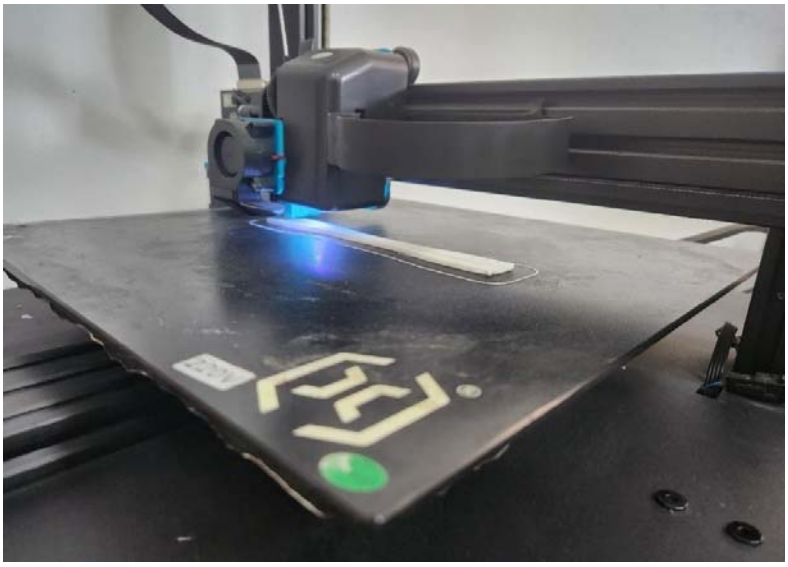


Figure 6: 3D Printing

The samples that finishing printing were slowly removed from the printer platform surface. Then the printer platform surface was cleaned and the process was repeated for the other samples. CFRP plates were placed inside the hollow PLA samples obtained from the 3D printer. Cyanoacrylate adhesive was used to ensure good adhesion between PLA and CFRP (Figure 7).
PLA samples containing CFRP plates were produced as 85% PLA – 15% CFRP. CFRP plates were placed end to end along the length of the PLA samples.

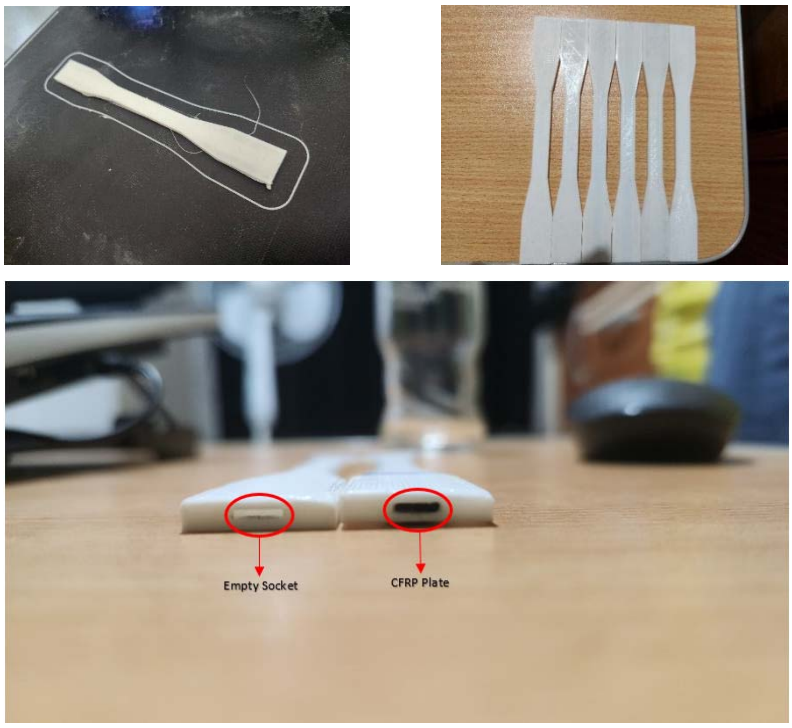


Figure 7: Specimens after printing

3. RESULTS AND DISCUSSION

The comparison between pure PLA and PLA+CFRP in the Izod impact test revealed significant performance differences. The impact strength of the pure PLA specimen was 6.02 kJ/m², whereas the PLA+CFRP composite specimen exhibited an impact strength of 41.85 kJ/m² (Figure 8). This indicates that the impact strength of PLA+CFRP composite material is higher than that of pure PLA, because CFRP reinforcement improved the fracture energy absorption ability of PLA. This improvement is due to the carbon fibre's ability to effectively distribute the impact force and the resulting energy across the PLA matrix. It is well-known that PLA is a brittle material.

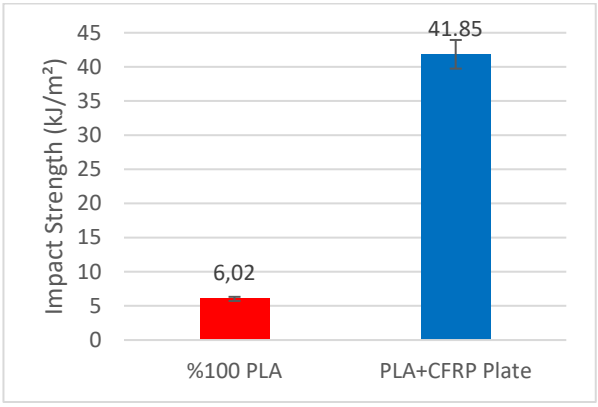


Figure 8: Izod ımpact test results

According to the hardness test results, the Shore hardness value of pure PLA is 62, while the value of the PLA+CFRP composite is 67 (Figure 9). Since CFRP has a harder structure, it increased the hardness of the PLA matrix. This increase in hardness is due to the structural contribution of the carbon fibre, which provides additional support to the PLA matrix.

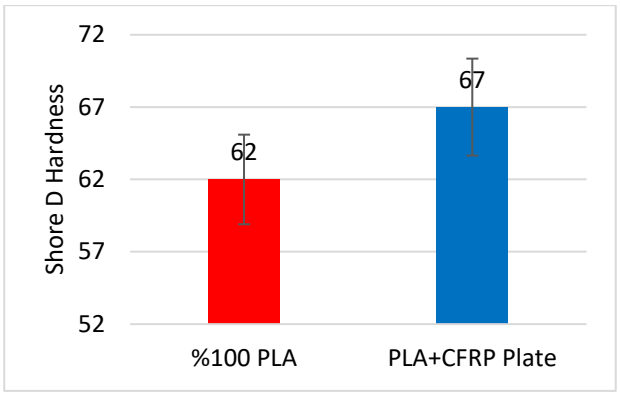


Figure 9: Shore D hardness test results

According to the abrasion test results, the weight loss in the pure PLA sample was 0.13%, while the weight loss in the PLA+CFRP composite was 0.09% (Figure 10). The PLA+CFRP composite sample suffered minimal material loss and exhibited better abrasion resistance. The reinforcement provided by the CFRP prevented rapid surface degradation by resisting the abrasive forces more effectively in the composite sample.

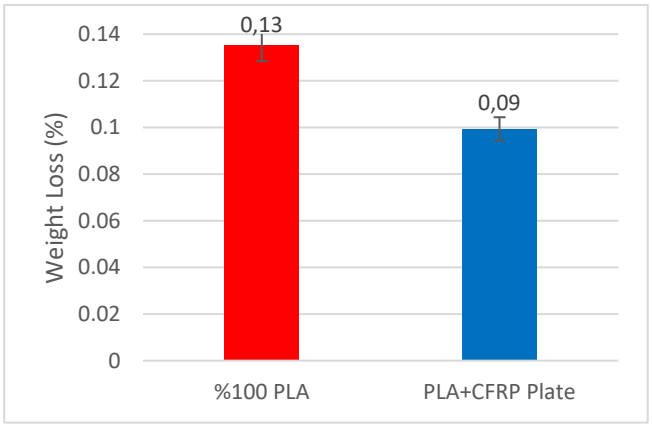


Figure 10: Abrasion test results

The tensile test results revealed a clear difference between the pure PLA and PLA+CFRP samples. While the tensile strength of pure PLA was 20.1 MPa, the tensile strength of the PLA+CFRP composite reached 127.75 MPa (Figure 11). The CFRP reinforcement led to a significant increase in the strength of the pure PLA. In the tensile test, it was observed that only PLA fractured in the PLA+CFRP sample, while the CFRP reinforcement inside did not fracture (Figure 12). This indicates that the adhesion between PLA and CFRP is not very good. If the adhesion were good enough for PLA and CFRP to break together, the tensile strength would have been much higher.

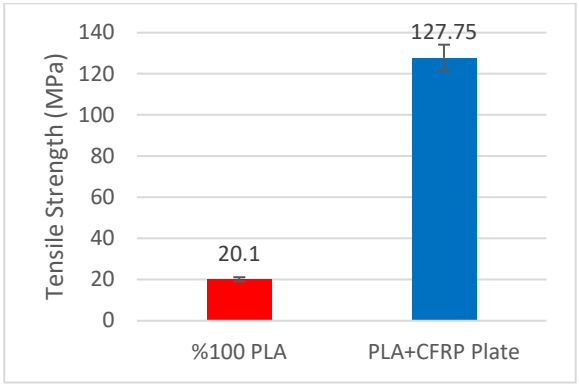


Figure 11: Tensile test results



Figure 12: Breaking shape of the sample in tensile test

According to the 3-point bending test results, there was also a significant difference in flexural strength between pure PLA and PLA+CFRP. While the flexural strength of pure PLA was 50.24 MPa, the flexural strength of PLA+CFRP composite increased by more than threefold to 165.25 MPa (Figure 13). An important point observed during this test was that the PLA+CFRP composite sample exhibited brittle behaviour and the two materials were subjected to fracture together under bending. In the tensile test, PLA peeled away from the CFRP plate and fractured, while in the bending test, PLA and CFRP were damaged together. This indicates that the adhesion between PLA and CFRP plate is strong enough to prevent delamination in terms of resistance to bending and that PLA and CFRP can work together under bending stress.

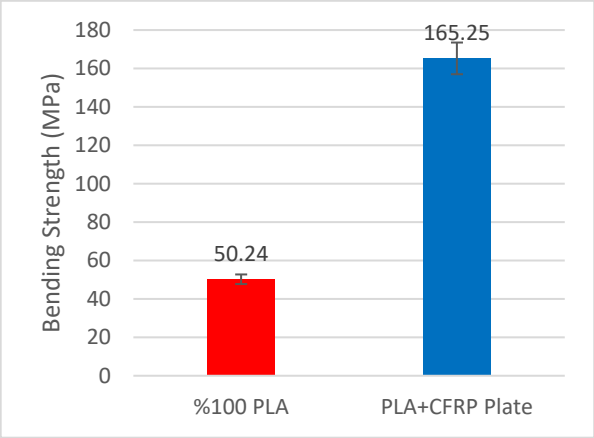


Figure 13: Three-point bending test results

4. CONCLUSION

In this study, the aim was aimed to improve the mechanical properties of PLA produced with a 3D printer by reinforcing it with a carbon fibre reinforced composite (CFRP) plate. The CFRP plates placed inside the PLA samples used in the study provided improvements in mechanical properties. The improved mechanical performance of the PLA+CFRP composite enhances its suitability for challenging mechanical applications. This production method, which increases the tensile, impact, bending and abrasion strengths and hardness of the PLA+CFRP composite sample produced with a 3D printer, can be an effective solution in the production of drone parts where mechanical properties are important and especially in applications requiring lightness and strength.

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TRANSFORMING OFFSET PRINTING WITH DIGITAL TWINS AND AI: INSIGHTS FROM RESEARCH INITIATIVES

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Abstract: *The manufacturing industry has a long tradition in the European Union, being one of the key employers providing jobs for highly skilled and qualified staff. Despite this, the sector is currently facing challenges related to global competition and rising costs, leading to declining profit margins. Additionally, companies are required to meet new environmental initiatives, demanding an ambitious voluntary commitment effort from their side, which has been proven to be difficult to implement. At the same time, manufacturing companies generate vast amounts of unstructured data daily yet struggle to leverage this data for supply chain optimization. This problem is especially noticeable in situations when there are many semi-structured data sources, like the ones found in offset printing operations (images, sensor data, etc.), typically leading to the creation of data silos storage and inefficiencies. Thus, a systematic approach is needed to optimize the process of receiving, combining, and analyzing data, which can, in turn, promote the creation of innovative business models based on manufacturing data. Similarly, the usage of a digital twin in production offers several advantages, primarily enhancing productivity, quality and cost efficiency. This paper presents two use cases illustrating how Digital Twin technologies and the CyclOps platform can be applied to offset printing operations, digitalizing factory processes and enabling AI-driven models, towards achieving Zero-Defect Manufacturing (ZDM), fostering improved efficiency and innovation in the manufacturing process.*

Key words: offset printing, digital twin, artificial intelligence, CyclOps

1. INTRODUCTION

The printing business is among the major manufacturing sectors globally, producing items such as packaging, flyers, books, magazines, and newspapers. The industry is essential to the European economy, producing an annual turnover of over €88 billion in EU GDP and employing over 770,000 individuals. Nonetheless, the industry is also confronting environmental and economic issues that might adversely affect demand and, consequently, the sector's economy. The production of high-quality printing items is intricate and significantly influences the environment because to the substantial consumption of raw resources (such as water, paper, ink, and aluminum) and chemicals that contribute to environmental deterioration (Kalafatelis et al., 2023b).

Contemporary manufacturing environments utilize IoT devices to comprehensively monitor the production chain, generating substantial volumes of data. These data may be employed to enhance the efficiency of printing operations using Artificial Intelligence (AI) and Machine Learning (ML) approaches, hence advancing the industry. Moreover, the use of AI/ML methodologies in manufacturing settings has demonstrated a significant capacity to optimize processes related to automation, waste reduction/prediction, and product quality, advancing towards Zero-Defect Manufacturing (ZDM).

This article presents two separate use cases in Offset Printing designed to improve production processes, utilizing a Digital Twin and the CyclOps platform. This document is organized as follows. Section 2 delineates the use case pertaining to the application of digital twin technology in printing processes. In Section 3, we describe the CyclOps platform and demonstrate its application on the Offset Printing domain. Finally, Section 4 encapsulates and deliberates the use cases.

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2. DIGITAL TWIN FOR OFFSET PRINTING

Digital Twin solutions in the manufacturing sector represent a transformative approach to optimizing production, enhancing efficiency, and driving innovation. A digital twin is a virtual replica of physical assets, systems, or processes, enabling real-time monitoring, simulation, and analysis. By leveraging data from sensors and IoT devices, manufacturers can create detailed models that mirror real-world operations. This allows for predictive maintenance, improved product design, and streamlined supply chain management. Digital twins help manufacturers anticipate issues before they occur, reduce downtime, and increase productivity, ultimately leading to more agile and cost-effective operations in an increasingly competitive market.

2.1 Application of Digital Twin in Offset Printing Manufacturing Use Case

Living in a digital era, a modern and competitive printing company understands that digitalization is key for moving towards the new age of business and commerce. The digitalization process is of paramount importance for an organization to improve its production line. One of the most successful paradigms of digitalization, to be adopted by the printing company, is the Digital Twin. The Digital Twin scheme offers the possibility of creating a digital copy of the physical resources and production line. The process comes with several advantages like being able to simulate facilities in a protected environment, with minimal risks and costs.

In this use case, the company's target is to transform its printing process, which is the main pillar of operations. The printing process lacks real-time decision-making, prevents standardization, and has a significant environmental impact. Monitoring, process optimization, and proactive maintenance will be possible thanks to the transformation of the forenamed process through the Digital Twin experiment. More specifically, the Digital Twin is intended to assist human operators in the difficult machine (line) selection process, which is to send orders to the best available printing line.

Selecting the most suitable machine line to print an order (also referred to as a job) is one of the most important decisions in the production process. In the use case, there are three (3) different lines of printing: one (1) 5-colour printing line, one (1) 8-colour printing line, and one (1) 4-colour printing line. One of the most important decisions of the production process is to select the most suitable machine line for each unique print job (order).

To better understand the process in the use case, the figure above presents the machine line selection activity in a more detailed way. First, the order arrives. Then the production schedule is checked to see which jobs are in priority and if any jobs are currently being printed. The suitable machine line is selected based on the order features that we will present in the following subsection. Finally, the order features and selected machine lines are stored in the company's database, to be used by other departments for other tasks. Figure 1 presents an abstractive illustration of the machine selection process.

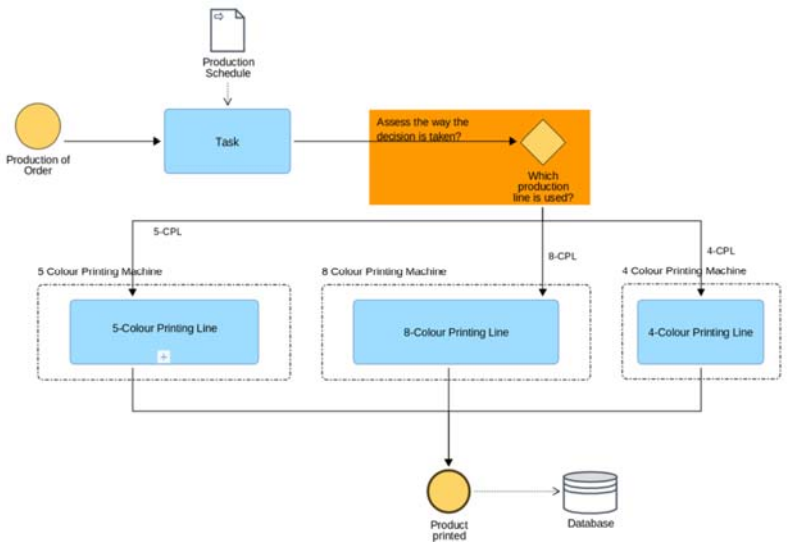


Figure 1: The machine selection process

The following parts have been taking into consideration into design specifications:

1. mapping the digital process landscape, showing all the processes of the physical unit,
2. user stories,
3. design of the experiment,
4. the specific task of machine allocation which will be optimized.

The beginning is the modelling of the Digital Process Landscape. This task is of paramount importance, as it discloses all processes that can be digitized. It should be noted that the Digital Twin experiment is essentially a digitalization step, created to optimize one or more tasks.
Modelling the Digital Process Landscape comes with several steps and advantages:

1. Instantiation and adaptation of process landscape for Customer needs. Each customer may come with different needs, which the enterprise should listen to and follow strictly. As the physical process is adapted to customer needs, so is the digital process.
2. Specification of Digitalization Goals. The enterprise should identify the goals of the digitalization process. In the current experiment, several measurable KPIs have already been specified.
3. Identification of Digitized Processes. In an industrial unit, not all processes can be digitized and further optimized. Furthermore, some processes are much more important for the enterprise, and when optimized, a significantly larger gain is obtained. Finally, there exist processes that are easier to digitize and optimize. All these factors are taken into consideration.
4. Definition of Data and Information Flow of Digitized Processes. The generated data to be used plays a critical role in the optimization task. All the necessary inputs and outputs of all processes in terms of data are required to be defined.
5. Specification of selected Digitalization Processes. Several of the processes will be selected as the digitalization processes to be optimized.

The following Figure 2 presents the complete Digital Process Landscape. This Landscape reveals the most important processes that play a significant role in the printing production line.

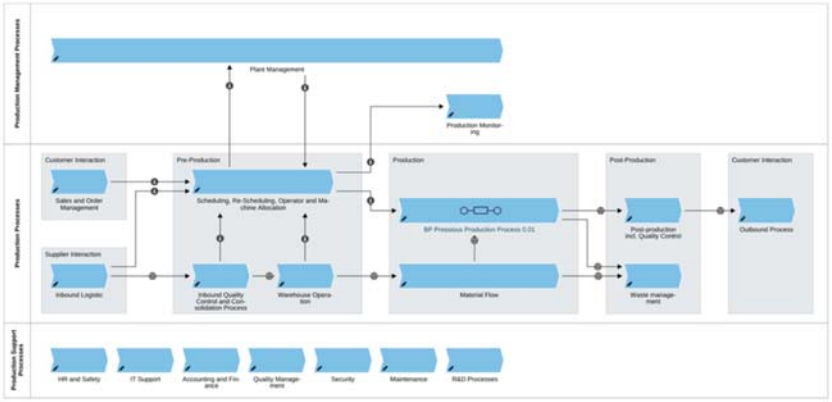


Figure 2: The Digital Process Landscape.

The operators would like to simulate a part of the production process, more specifically the machine line selection.
The economics department would like to know the cost of printing each unique order.
Given a specific order, the operators would like to know which is the optimal printing machine line.
The department that handles scheduling would like to know if an order can be printed on an alternative machine line.
The following Figure 3 is an abstractive high-level illustration of the Digital Twin architecture. On the left side, an abstract illustration of the physical production flow is shown. A customer arrives, giving a specific order. Then the order is passed to the Sales department. Given an order, the Sales department proceeds with the order analysis and outputs the paper type, quantity, size, and format. The total cost is computed by the Finance department and then the order is given to the Production department. Via the sensors, the extraction of important features like accuracy ratio, ink consumption, and colour accuracy is possible. On the right side, the Digital Twin is presented. Older and simulated orders are given for cost computation. Then the ML models can be trained to learn optimal configuration for machine selection. Newly arrived

orders can be given to the trained ML models and via the Digital Twin we have access to the optimal configuration (best machine) for the specific order.

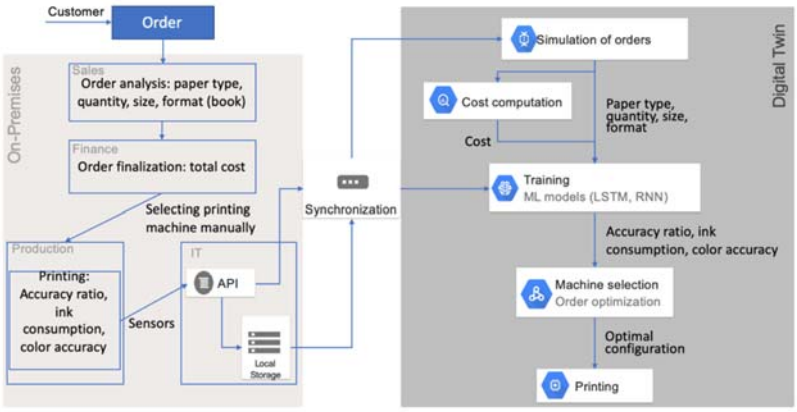


Figure 3: The Digital Twin design

The implementation of business process modelling (BPM) is done with ADONIS, a full-featured business transformation suite created specifically for process management by B.O.C company. The three most important components that we want to model: a) order features that help the operator allocate jobs to machine lines, b) the cost computation of each machine line, and finally, c) the actual decisions that the operators use to select the suitable printing line.
Each order when given by a customer is characterized by several features. Afterwards, the order is enriched with some additional information coming from the customer. The ones that we exploit for the Digital Twin are presented in the Table 1.

Table 1: Dataset for the digital twin

	Description
ID	auto-increment integer identifier of a printing order
Delivery time (days)	the number of days that the order shall be printed and delivered to the customer
Ink Varnish	the ink varnish selection is considered as a boolean attribute with True or False possible values
Colour (4 or >4	This categorical variable denotes the colour requirements of the particular printing assignment. In offset printing, the most requested colour requirement is the 4-colour printing (class 1), followed by 4+1 colour printing (class 2 that involves the use of special / pantone colours, for example gold and/or silver) and grayscale printing (class 3 entailing only black and white colours)
Quantity	the number of paper pieces requested in this specific order. Quantity takes integer values extending to up to large numbers, depending on the type of printing assignment (e.g. newspaper, poster, etc.). Type: Each specific printing order has an associated discrete type of category, also denoting required specifications related to the post-press procedure
Quality	The quality of the paper is associated with the specific printing order. The *Quality* parameter takes string values depending on the properties of the requested paper. The most used ones are 'Velvet' (the most frequently used), 'Uncoated', and 'Illustration/Gloss' paper quality
Job name	each job comes with a small description, mostly including the customer's name, and requested type
Sides	a job may be required to be 1-side or 2-side
Weight (gr)	the weight of the paper to be used in the printing process, measured in grams
Press sheets	it is a larger than-requested sheet that fits multiple smaller printed sheets. For example, a press sheet may include multiple pages of a book, which are then cut to create single pages. Its maximum size may be 70x100 cm
Dimension	the dimensions of a printing order come in the following format: 350x280 mm - 500x280 mm
Cost 4-col	the cost of 4-col line to print the order
Cost 5-col	the cost of 5-col line to print the order
Cost 8-col	the cost of 8-col line to print the order
Machine ID	the machine line to print the order

The next step towards the Digital Twin is to create a digital representation of the decision process, via an interactive diagram. The diagram reflects how the printing company selects a specific printing-machine line for a given order:

1. First, the delivery time is checked. If the delivery date is less than 2 days, the simpler digital printers are selected.
2. The next step is looking at the ink varnish, given by the job order. If the ink varnish selection is True, the order is printed on the 5-colour line. If the ink varnish is false, the algorithm proceeds to the next step.
3. Next, the job colour feature is checked. If the job colour is larger than 4 colours, the 5-colour line is selected. If the job colour is equal to or less than 4 colours, we move to step 4.
4. The next features to be used are Quantity and Printing sheet. If the quantity of printing sheets is less than 500, the 4-colour line is selected to print the order. If the value is equal to or higher than 500, the algorithm proceeds to next step.
5. Next, the paper's weight is checked. Books, journals, newspapers, and magazines fall under the category of weight equal to or less than 170 grams. On the other hand, posters, leaflets, business cards, and folders have a weight higher than 170 grams. If the weight is higher than 170g, the job is to be printed on the 4-color or 5-color lines, depending on the cost. The cost calculation is done by the pre-quotation department. If the weight is less than 170g, we move to step 6.
6. Dimension is the next feature to be taken into consideration. Here, the dimension is transformed to "True 4-col" or "False 4-col". This means that either the job can be printed on the 4-colour line or not. If the value is "True 4-col", a cost comparison between all the lines is performed. In the other case of the dimension being "False 4-col", a cost comparison between the 5-colour and the 8-colour lines is done. The line with the lowest cost gets to print the job.

Before reaching the final step of printing, a comparison with previous jobs on similar lines is made. If no exception arises, the printing process begins. If an exception arises, the job is reallocated to a new machine. In the case of exceptional circumstances, a job can be outsourced to another site.
The following Figure 4 presents the physical process in full detail: features, inputs, outputs, and decision rules. Rectangles represent actions or processes; diamonds represent conditions and lines represent the flow.

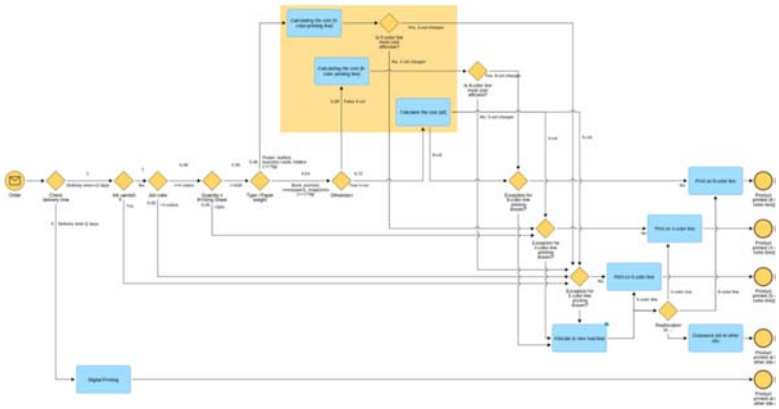


Figure 4: the machine allocation decision diagram, created with ADONIS

3. END-TO-END DATA LIFE CYCLE MANAGEMENT

The ability to cross-reference and integrate heterogeneous data sources is becoming increasingly essential for companies, helping them to gain a competitive advantage. Utilizing these sources, AI-driven applications are transforming vital sectors such as healthcare, manufacturing, and transportation, among others. Within this shift, Data Spaces have evolved as a fundamental framework for facilitating data sharing and exchange, particularly within the context of the European Strategy for Data (European Commission, 2020). This EST seeks to establish a unified data market, augmenting Europe's global competitiveness and data sovereignty (European Commission, 2023).
Despite this progress, the governance of the data life cycle, has not kept pace with technological advances. This gap is especially evident when dealing with semi-structured data from numerous evolving sources,

where manual governance leads to fragmented data silos, making clear the need for a systematic and standardized approach to data ingestion, integration, and analysis to support new data-driven business models and data spaces. Additionally, while current research and development (R&D) efforts focus on specific aspects of the data life cycle (e.g., scalable data management or AI explainability), governance remains largely overlooked. Most organizations still develop their own data architectures, a resource-intensive process that only large tech firms can efficiently manage. Examples include Amundsen (Amundsen, 2019) and Databook (Uber, 2018). Although cloud providers offer layered solutions, data flow design remains ad-hoc, leaving smaller organizations at a significant disadvantage.
To address this challenge, a comprehensive framework is needed to govern the full data life cycle, enabling secure, interoperable, and scalable AI-driven applications for organizations of all sizes. This framework must support large-scale data from diverse, distributed sources to foster efficient data sharing and exchange.

3.1 CyclOps Concept

CyclOps (CyclOps, 2024) aims to redefine the end-to-end data life cycle, enabling organizations to adopt a data-driven culture and utilize data spaces. Achieving this requires automating complex data transformations across large-scale heterogeneous datasets. Currently, this task is handled manually through specialized technologies, making It impractical for large-scale settings. In contrast, CyclOps automates the generation of data processing pipelines, covering the entire spectrum from data consumption to the serving of data, models, and services. In detail, through automated data governance, CyclOps orchestrates the entire data life cycle, ensuring data sharing and exchange in data spaces. A key element of this, is the use of semantically rich metadata, beyond current standards like DCAT, enabling the automation of the components in the data pipeline and content publication. Specifically, utilizing Knowledge Graphs (KGs), CyclOps enables formal models to represent data and metadata, ensuring context and interoperability in line with the FAIR Guiding Principles (Findability, Accessibility, Interoperability, and Reusability) (Wilkinson et al., 2019).
This process is guided by user input and requirements through a Human-in-the-Loop approach, prioritizing a user-centric approach, towards allowing organizations to conduct contextualized analyses, without requiring data management expertise. CyclOps operationalizes the data life cycle through a layered, bottom-up framework composed of five key components, as showcased in Figure 5:

1. DataOps: Automates data management tasks, such as discovery, curation, quality, and integration;
2. AIOps: Offers a decentralized repository of AI algorithms and makes the resulting AI models accessible;
3. Data and Execution Abstraction Layer: Facilitates the development of distributed data preprocessing and analysis;
4. Intent-based Human Interface: Provides a human-centric interface to automatically provide services to exchange, explore, visualize and integrate with data spaces, driving the automatic execution of analytical pipelines;
5. Smart Data Governance and Trust: Acts as a transversal semantic layer that regulates the system, enforces data-related rights, obligations and responsibilities (e.g., GDPR and AI Act compliance), while ensuring interoperability, security and privacy;

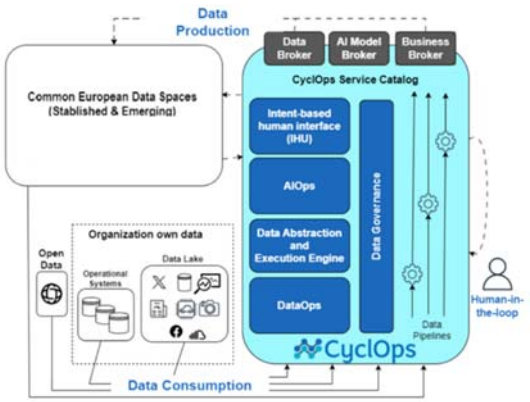


Figure 5: CyclOps conceptual view

3.2 Manufacturing Data Space Use Case

The European printing manufacturing sector plays a pivotal role in employment and skill development, currently facing increasing pressure from global competition, rising costs, and stringent environmental regulations. A significant challenge within the industry is the vast amount of unstructured data generated daily, much of which remains underutilized. Effectively harnessing this data presents an opportunity to optimize production processes, enhance supply chain management, and support the EU's vision for a competitive and sovereign data economy (Kalafatelis et al., 2023a; Kalafatelis et al., 2023b). CyclOps is uniquely designed to address these challenges by transforming unstructured data into actionable insights, enabling manufacturers to meet complex market demands and regulatory requirements more efficiently.

This case study considers a scenario in which two offset printing companies have integrated CyclOps into their operations to tackle persistent issues such as the minimization of their: a) environmental impact, b) frequent product defects, c) machine downtimes, and d) rising production costs. Despite the continuous generation of large volumes of operational structured and un-structured data, these companies have struggled to leverage this information effectively. By adopting CyclOps, they aim to convert their data into valuable insights, optimize production processes, and align with Industry 5.0 principles.

The implementation begins with the DataOps component, which ensures the integration and curation of high-quality data from various factory sources, maintaining data integrity throughout operations. The Data Governance and Trust layer enables secure data sharing, fostering collaboration with partners, suppliers, and research organizations, creating a Manufacturing Data Space environment. This secure environment promotes innovation while ensuring compliance with data privacy regulations. By integrating their data within CyclOps, the companies can utilize the AIOps component to train or utilize existing machine learning (ML) models available on the platform. Meanwhile, the Data and Execution Abstraction Layer manages large-scale data storage and distributed deployment. In scenarios requiring model training, companies can employ Federated Learning (FL) to collaboratively train models on distributed data, such as data collected directly from printing machines, without compromising data privacy. This approach enhances model generalizability, by transmitting only model parameters instead of raw data, thus preserving confidentiality (Sarlas et al., 2023; Angelopoulos et al., 2024). For example, lightweight predictive maintenance models can be trained to monitor printing equipment in real time, proactively identifying potential failures to reduce machine downtime. This predictive capability can minimize costs and enhance productivity by addressing equipment malfunctions proactively (Kalafatelis et al., 2024). Figure 6 showcases the FL training scenario deployed across two printing factories. Additionally, companies can leverage Transfer Learning to adapt pre-trained models to their production line needs, as showcased in Figure 7. This quick adaptation ensures that the benefits of data processing are realized across different machine setups, providing the scalability needed to manage increasing data volumes as the companies expand or modify their printing operations. To enable factory managers and supply chain operators to explore production data in real-time, the Intent-based Human Interface further enhances this scenario setup. By transforming complex datasets into actionable insights, this interface helps identify inefficiencies and guides adjustments to machine settings and workflows. As a result, companies can reduce product defects and material waste, thereby enhancing both operational efficiency and environmental sustainability.

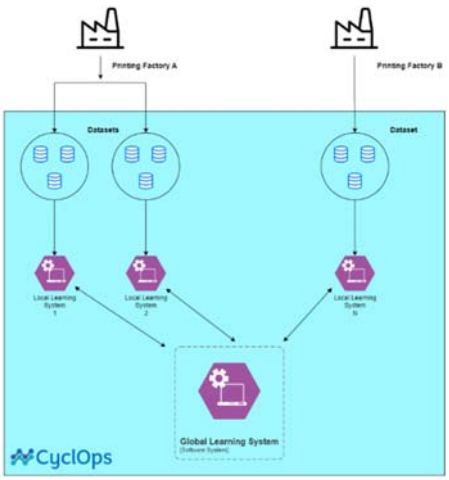


Figure 6: A high-level view of the Federated Learning scheme deployment across two printing companies

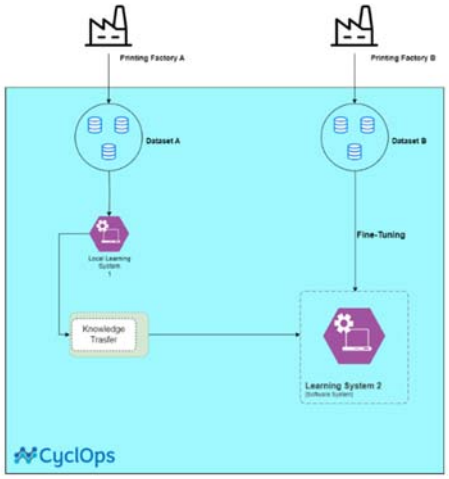


Figure 7: A high-level view of the Transfer Learning scheme deployment across two printing companies

4. CONCLUSIONS

Printing environments exhibit significant unpredictability, making errors an inevitable and prevalent occurrence. These faults can significantly affect several dimensions, from direct economic loss to the environmental consequences of squandered resources. Towards this direction, this study presents two distinct use cases in Offset Printing aimed at enhancing production processes.

The analysis and digitalization process of the printing production line brings many advantages. First, modelling the machine selection process, has enabled the documentation and visualization of real-world decision-making. This process can now be easily simulated in a safe and cost-efficient digital environment, facilitated by a Digital Twin. For new print orders, he simulation accurately predicts the most suitable machine line, allowing operators to input multiple orders and receive optimized recommendations for each. Additionally, past orders can also be checked and validated. The digital model also revealed that some jobs could be processed by multiple machine lines, allowing greater flexibility. Furthermore, the simulation environment provides a platform for parameterizing datasets and fine-tuning configurations related to machine selection. Using ADONIS, different setups can be efficiently tested, enabling informed decision-making with minimal cost. As a result, the integration of new machines into the production line becomes faster and more efficient.

Another important benefit of the Digital Twin is the potential to reduce printing costs. Analyzing a dataset of thousands of orders revealed that, for many, more cost-effective machine lines could have been selected. A comparison between the simulated and actual machine lines demonstrated a cost reduction of approximately 5%, highlighting opportunities for further optimization. Although scheduling conflicts and existing machine utilization may account for some of the inefficiencies, this finding underscores the need for improvements in resource scheduling. In light of this, printing companies are encouraged to explore new ways to optimize efficiency and reduce costs, including partnerships and innovative projects that could address broader challenges within the production line. For instance, digital tools could be employed to automate scheduling and dynamically allocate resources, optimizing both operational costs and human resource management.

Furthermore, the implementation of CyclOps brings transformative benefits to the printing industry by automating tasks such as quality control using ML models, which reduces machine downtime and enhances production efficiency. By leveraging CyclOps, companies can automating routine tasks, enabling workers to focus on higher-value activities, thus reinforcing the human-centric ethos of Industry 5.0. Another notable advantage of CyclOps is its ability to break down data silos through the development of specialized Data Spaces. This fosters greater collaboration with external organizations and suppliers, contributing to a more integrated and competitive data economy, particularly within the EU manufacturing sector.

Concerning future research avenues, this could be focuses on expanding the capabilities of Digital Twins and CyclOps to incorporate real-time ML algorithms that dynamically adjust production strategies based on evolving data patterns. Additionally, investigating the potential for cross-industry collaborations to share data and best practices through enhanced data ecosystems may also yield valuable insights for the broader manufacturing sector. In conclusion, this study demonstrates that digitalization, simulation, and data-

driven approaches can significantly improve the efficiency, sustainability, and flexibility of printing processes. By leveraging technologies like Digital Twins and platforms such as CyclOps, printing companies can not only enhance their operational performance but also contribute to a more sustainable and interconnected manufacturing ecosystem.

5. ACKNOWLEDGMENTS

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AI MODELS FOR PREDICTING VISUAL ATTENTION IN DIGITAL APPLICATIONS: A COMPARATIVE PILOT ANALYSIS WITH EYE TRACKING RESULTS

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Abstract: *The paper presents a comparative pilot analysis of an AI-based visual attention prediction system with the traditional eye-tracking method in the context of UI/UX design. The study assesses the accuracy and reliability of AI-generated attention heatmaps compared to empirical eye-tracking data. The results indicate that AI systems show a strong ability to approximate human attention, achieving ROC-AUC values between 0.75 and 0.84. The study highlights AI's potential in early-stage design iterations, offering a suitable alternative to time-consuming eye-tracking testing sessions, but recommends combining AI tools with traditional methods for critical design decisions.*

Keywords: visual attention, eye-tracking, AI predictions, UI/UX design, ROC, saliency

1. INTRODUCTION

Human attention is an essential cognitive function due to the brain's limited capacity to simultaneously process all incoming visual information (Treue, 2003). Selective attention allows individuals to prioritize only the parts of a visual scene most relevant to their current task or situation, enabling them to respond efficiently in dynamic situations overloaded with visual stimuli (Posner & Petersen, 1990), such as interactions with digital interfaces.
Visual attention encompasses two key mechanisms: exogenous attention, which is reflexively triggered by external stimuli, such as bright objects or unexpected movements, and endogenous attention, which is voluntarily directed by the observer and guided by specific goals and tasks (Corbetta & Shulman, 2002). Understanding these mechanisms of visual attention provides the foundation for developing AI systems that simulate human attention and predict its distribution across visual scenes (Borji & Itti, 2013).
AI-based visual attention prediction relies on data collected through eye-tracking technologies and similar techniques that capture how users naturally distribute their attention (Tatler et al., 2011). The critical components of these systems are saliency and visual priorities. Saliency refers to the characteristics of objects or parts of a scene that make them stand out from their surroundings and attract our attention. These characteristics can be physical (such as contrast, color, and unusual shapes) or semantic (the meaning or relevance of an object in a given context), which together influence the automatic directing of the user's attention (Borji & Itti, 2013). Visual task-dependent priorities help AI models rank scene elements according to their importance.

1.1 Training and evaluating AI models for visual attention prediction

Saliency maps are a main tool for training AI models to simulate human attention mechanisms. They assign values to image points based on their likelihood to attract the user's gaze. These maps are generated through the analysis of both low-level features (e.g., color, intensity, orientation, motion) and high-level features (e.g., semantic information like objects and faces) (Cornia et al., 2018).
That means that AI model training algorithms, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), rely heavily on large-scale datasets collected via eye-tracking technologies, which capture user gaze patterns on various visual scenes (Tatler et al., 2011).
The typical process in these models involves:

- Extraction of visual features: The model analyzes the input image to extract relevant features using computer vision techniques or deep learning methods, such as CNNs that automatically learn significant patterns from data.
- Generation of individual feature maps: For each extracted feature (e.g., color, contrast, orientation), a map is created showing its intensity across the entire image.

ORCID numbers are provided at the end of the paper.

- Combination into a unified saliency map: The individual feature maps are merged through normalization and linear or nonlinear combination to produce a final saliency map that predicts areas of greatest interest.
- Prediction of fixation points: Based on the saliency map, the model predicts the probability that a user will direct their gaze to specific parts of the image, which can be validated against empirical eye-tracking data.

Different AI models apply saliency maps in various ways. Classical models focus on bottom-up processing based on physical scene properties, while deep learning models leverage complex representations of both low-level and high-level features (Kümmerer et al., 2017). Hybrid models incorporate both bottom-up and top-down factors like user intent.
The performance of these models is evaluated using standardized datasets such as MIT300 and CAT2000. The dataset of 300 imaged MIT300, part of the MIT/Tübingen Saliency Benchmark, is used specifically for objective performance assessment because its ground truth data are not publicly available, preventing overfitting (Kümmerer et al., 2018). The accuracy of the saliency maps is assessed through metrics such as AUC-Judd, sAUC, NSS, and CC, which measure different aspects of the model's predictive capabilities (Bylinskii et al., 2019), although Kümmerer et al. (2018) emphasize that a reliable AI model should demonstrate consistently high results across all metrics.

1.2 AI integration in the UI/UX design

AI has become integral to all stages of digital product development and usage, although its integration raises ethical issues (Jobin et al., 2019). One of the primary benefits of AI in UI/UX design is its ability to analyze large datasets. AI algorithms process extensive user data to uncover patterns in behavior and preferences, enabling designers to make data-driven improvements to design and functionality (Davenport & Ronanki, 2018). In addition to that, content personalization in digital applications becomes more achievable as AI predicts user needs based on previous interactions, allowing designers to create tailored experiences (Shneiderman, 2020). AI-driven tools also offer algorithmically generated design suggestions based on defined parameters and suggestions for enhancing accessibility by identifying issues such as poor color contrast (Lazar et al., 2015). Moreover, AI simplifies repetitive tasks by automating processes like resizing images or generating responsive designs, freeing designers to focus on more complex creative challenges. Additionally, AI enhances A/B testing by accurately predicting test outcomes based on previous data, making comparisons between different design elements more reliable (Kohavi et al., 2020). Finally, advancements in AI-based visual attention prediction can assess where users are likely to focus their attention, enable more informed design decisions, and accelerate design iterations (Borji & Itti, 2013).

1.3 Research aim and questions

The usability testing is a fundamental component of UI/UX design, involving the observation of users as they interact with a product to identify areas for design improvement (Nielsen, 1993). Traditional methods like eye-tracking provide valuable insights into user attention by recording eye movements and generating heatmaps that reveal patterns of focus (Duchowski, 2007). However, these methods require specialized equipment and significant time investment for recruiting, testing, and analyzing, making them resource-intensive and less practical during the early stages of design iteration (Moran, 2019).
The AI models offer promising alternatives by simplifying usability testing and predicting user attention without extensive eye-tracking studies (Xu et al., 2014). AI algorithms reduce manual effort while enabling quicker, automated testing cycles. This facilitates large-scale, continuous testing that can adapt rapidly to new data, design variations, and different user scenarios or focus groups.
This study aims to evaluate whether AI can reliably be used during the early stages and iterations of UI/UX design. Specifically, the research focuses on analyzing the performance of a widely used commercial AI system for visual attention prediction in a typical UI/UX design scenario. By conducting a pilot comparative analysis between AI-predicted visual attention maps and actual eye-tracking data obtained from real users, the study seeks to assess the reliability and accuracy of AI-based predictions in the context of UI/UX design.

The research questions of the study are the following:

1. How accurate are AI-based visual attention predictions compared to real eye-tracking data in the context of UI/UX design?
2. What are the key discrepancies, if any, between AI predictions and human visual behavior, and how can these gaps be minimized?
3. Can the AI system's predictions be reliably used to inform design decisions without the need for additional eye-tracking studies?

2. METHODS

2.1 Test samples

Four versions of a desktop application prototype for sharing travel experiences were created, with two featuring banner ads and two featuring native ads, differing only in the ad's position (top or bottom of the page). Banner ads, commonly used in applications, may be ignored by users due to so-called "banner blindness," where users recognize and avoid advertising spaces. In contrast, native ads are organically integrated into the application's content, making them appear more natural and informative to users.

2.2 The AI visual attention prediction

The analysis included six commercial AI tools that utilize attention prediction for evaluating user engagement with visual content. The selection criteria for these tools included the availability of a demo trial, suitability for testing web pages, mobile applications, or UI prototypes, and the availability of information regarding model evaluation. However, only two tools provided demo trials, with one proving unsuitable for analyzing web page content, as it yielded identical results across four test pages.
The remaining AI tool, Attention Insight, uses eye-tracking data from approximately 70,000 individual participants. to train its deep learning algorithms and generate precise visual attention heatmaps, which highlight areas where participants focus when viewing an image. The demography of 70,000 participants is 58% women and 42% men with ages ranging from 7 to over 60, although the majority of participants were between 21 and 30 years old and from the USA and Europe. In conducted eye-tracking studies, participants focused on visual stimuli for an average of 4 seconds.
Attention Insight's heatmap generation is powered by a Convolutional Neural Network (CNN), which mimics biological neural networks. Initially, the CNN's weights are randomized, resulting in inaccurate predictions, but through iterative training cycles, these weights are adjusted to reduce the error between the predicted and actual heatmaps obtained from eye-tracking studies. The model's accuracy continues to improve as new data is incorporated.
Attention Insight’s heatmaps have been tested and validated against the MIT/Tuebingen Saliency Benchmark. After testing with 300 images (MIT300 dataset), the model demonstrated 92.5% accuracy in general image prediction, with accuracy reaching up to 96%.

2.1 Traditional eye-tracking evaluation process

Seventeen participants, with an average age of 26, participated in the eye-tracking study. The Gazepoint device and its accompanying Control and Analysis software were used for calibration, data collection, and subsequent analysis. Prior to the experiment, the device was calibrated individually for each participant to ensure accuracy. Once calibration was complete, participants were instructed to observe the prepared design samples. After viewing each design, a black screen displaying a white cross was presented to reset the participants' gaze before proceeding to the next sample. After eye-tracking data collection, four cumulative heatmaps were generated, summarizing the visual attention of all 17 participants after 5 seconds of viewing each design sample.

2.3 The evaluation metric

When comparing an AI-predicted visual attention heatmap to a ground-truth heatmap obtained from eye-tracking data, selecting the appropriate evaluation metric is crucial. Several specialized metrics have been developed to assess how well a predicted saliency map matches human visual attention patterns. The fundamental tool is the Receiver Operating Characteristic (ROC) curve obtained from confusion matrix components.

A confusion matrix is presented in Table 1 and allows the performance visualization of a classification model by comparing actual values with predicted values. It includes the following components:

- True Positives (TP): Salient areas correctly predicted as salient.
- False Positives (FP): Non-salient areas incorrectly predicted as salient.
- True Negatives (TN): Non-salient areas correctly predicted as non-salient.
- False Negatives (FN): Salient areas incorrectly predicted as non-salient.

Table 1: A confusion matrix for ROC analysis

	Eye Tracking Map (P, positive)	Eye Tracking Map (N, negative)
AI prediction map (positive)	True Positive (TP)	False Positives (FP)
AI prediction map (negative)	False Negatives (FN)	True Negatives (TN)

From the confusion matrix, important metrics such as True Positive Rate (TPR) and False Positive Rate (FPR) can be derived. The ROC curve is a graphical representation that plots the TPR against the FPR at various threshold settings. It illustrates the diagnostic ability of a binary classifier system as its discrimination threshold is varied.
The Area Under the ROC Curve (AUC-ROC) quantifies the overall ability of the model to discriminate between salient and non-salient areas. The AUC value ranges from 0 to 1, where:

- AUC = 0.5 suggests no discriminative ability (equivalent to random guessing),
- AUC < 0.6 indicates poor performance,
- AUC between 0.7 and 0.8 suggests acceptable performance,
- AUC > 0.8 is considered excellent.

3. RESULTS

Table 2 presents the original test pages alongside both the eye-tracking and AI-generated heatmaps for four different advertising setups: banner ads at the top and bottom of the page, and native ads at the top and bottom of the page. Table 3 provides metrics such as the percentage of attention (Area of Interest, AOI) and ROC-AUC values for each test design. Additionally, opacity maps are included in Table 3 to address the potential issue of different color palettes in heatmaps, ensuring consistency and eliminating outlier results from the cumulative heatmaps.
In ROC analysis, 0.5 is typically used as the standard or default threshold for binary classification problems. This means that if the predicted probability of an instance belonging to the positive class is greater than 0.5, it is classified as positive; otherwise, it is classified as negative. Also, AUC- Judd variant of AUC-ROC metric is used which includes all fixations.
Based on the data from Tables 2 and 3, the comparative analysis between traditional eye-tracking heatmaps and AI-generated heatmaps revealed notable insights. For the test page with the banner ad at the top, the area of interest (AOI) accounted for 19.4% of the attention time in the eye-tracking data, while the AI model predicted a lower percentage of 13.4%, with a corresponding ROC-AUC value of 0.79. For the banner ad at the bottom, the eye-tracking data indicated a smaller AOI of 6.8%, while the AI model predicted 8.1%, with a higher ROC-AUC value of 0.84. The native ad positioned at the top showed a significant focus, with 57.5% of attention time in the eye-tracking data, but the AI model estimated a lower 47.8%, with a corresponding ROC-AUC of 0.75. Similarly, the native ad at the bottom reflected 12.7% AOI in the eye-tracking data, with the AI model closely predicting 13.8% and a ROC-AUC value of 0.79. These results highlight the high degrees of alignment between human attention and AI predictions, with relatively strong ROC-AUC values indicating the model's ability to approximate human visual behavior in all four test cases.

Table 2: Heatmaps for test webpages

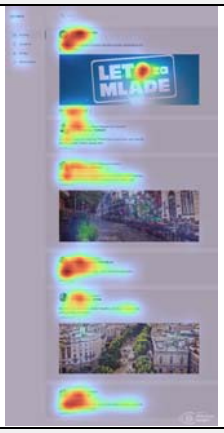
Original Test pages	Eye Tracking heatmap	Attention Insight heatmap
Test page with the banner ad at the top of the page		
		
Test page with the banner ad at the bottom of the page		
		
Test page with the native ad at the top of the page		
		
Test page with the native ad at the bottom of the page		
		

Table 3: Focus maps with metrics – AOI % of attention and ROC-AUC

Original Test pages	Eye Tracking heatmap	Attention Insight heatmap
Test page with the banner ad at the top of the page		
		
% time viewed AOI in the sum time	19.4%	13.4%
ROC-AUC value	0.79	
Test page with the banner ad at the bottom of the page		
		
% time viewed AOI in the sum time	6.8%	8.1%
ROC-AUC value	0.84	
Test page with the native ad at the top of the page		
		
% time viewed AOI in the sum time	57.5%	47.8%
ROC-AUC value	0.75	
Test page with the native ad at the bottom of the page		
		
% time viewed AOI in the sum time	12.7%	13.8%
ROC-AUC value	0.79	

4. DISCUSSION

The primary aim of this study was to evaluate the accuracy of AI-based visual attention predictions compared to real eye-tracking data in the UI/UX design context. By addressing the research questions, we sought to determine the viability of using AI tools for early-stage design iterations and to understand any discrepancies between AI predictions and human visual attention.

Accuracy of AI-Based Predictions (Research Question 1)

The comparative analysis between traditional eye-tracking and AI-generated heatmaps revealed a noteworthy alignment in the percentage values of time spent viewing the AOI (ad). In addition, ROC-AUC values, ranging from 0.75 to 0.84, indicate acceptable to excellent model performance, suggesting that the AI model can approximate human visual attention with a reasonable degree of accuracy.

Discrepancies Between AI Predictions and Human Visual Behavior (Research Question 2)

Despite the overall good alignment, some discrepancies were observed. For the native ad positioned at the top, the eye-tracking data indicated a significant focus with 57.5% attention time, whereas the AI model estimated a lower value of 47.8%. Also, the AUC-ROC values are lower compared to their evaluation with the MIT300 dataset. This variance may stem from the AI model's training predominantly on images that trigger exogenous attention meaning automatic responses to salient stimuli, whereas UX interfaces often require endogenous attention, which is goal-directed and task-oriented.

The discrepancies highlight that while the AI model is effective in predicting general attention patterns, it may not fully capture the nuances of user behavior in task-specific contexts. To minimize these gaps, incorporating UX-specific data into the AI model's training set could enhance its ability to predict endogenous attention patterns more accurately.

Reliability of AI Predictions for Design Decisions (Research Question 3)

The findings suggest that AI-based predictions can be a valuable asset in informing design decisions, especially during the early stages of the design process. The acceptable ROC-AUC values indicate that AI tools like Attention Insight can reliably predict areas of user focus, reducing the need for extensive eye-tracking studies, which are time-consuming. However, for crucial design decisions or interfaces requiring a precise understanding of user interactions, supplementing AI predictions with traditional eye-tracking may be beneficial to capture the full spectrum of user attention.

This study's limitations include a relatively small sample size and a focus on desktop applications with specific advertisement types. The AI model's training on images eliciting exogenous attention may limit its applicability in contexts requiring endogenous attention. Future research should involve more extensive eye-tracking data with more diverse test sets.

5. CONCLUSIONS

The pilot analysis demonstrates that AI attention prediction tools like Attention Insight can effectively approximate human visual attention in UX design contexts. Despite being primarily trained on exogenous stimuli, the AI model achieved acceptable ROC-AUC values, indicating its potential utility in predicting user attention without the need for extensive eye-tracking studies. The ability of AI tools to quickly and efficiently predict user attention areas presents a significant advantage in the iterative design process. While traditional eye-tracking provides precise data on user focus and gaze both order and duration, it requires specialized equipment and more time to conduct. AI predictions offer a practical alternative for rapid assessments, enabling designers to make timely and informed decisions to enhance usability and user satisfaction. A combined approach is recommended for comprehensive analyses and a deeper understanding of user behavior. Utilizing AI tools for initial predictions followed by validation through eye-tracking studies can achieve an optimal balance between speed and accuracy.

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PACKAGING ADDED VALUE



IMMOBILIZATION OF ANTHOCYANINS BY BACTERIAL NANOCELLULOSE IN PRODUCTION OF INDICATORS FOR PH-CONTROLLED SMART PACKAGING

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Abstract: *The main objective of this research was the production and characterization of bio-based indicators for pH-controlled smart packaging. Since pH-sensitive indicators can change color depending on the freshness or spoilage of the food, they can be used to monitor the freshness level and safety of food products. Potato and maize starch without and with the addition of bacterial nanocellulose (BNC) were used as a polymer matrix for the immobilization of pH-sensitive indicators. The natural pigment anthocyanin, extracted from the peels of red onions, was used as a pH-sensing element. In addition, an ultrasound treatment of the extracted anthocyanins was performed to determine the influence of the treatment on the color response of the produced films. The colorimetric and optical differences between the different starch films with ultrasound-treated and untreated anthocyanins were observed. To observe the color response of the prepared indicators when exposed to different pH environment, their optical and colorimetric changes were monitored before and after exposure to altered pH values. The results obtained show the potential for the production of pH-sensitive films immobilized by BNC. In addition, the results will provide the information about the influence of ultrasound treatment during anthocyanin extraction on the optical and colorimetric changes of the pH-sensitive starch-based films.*

Key words: pH indicators, BNC, anthocyanins, UAE, colorimetric properties

1. INTRODUCTION

pH-controlled smart packaging is an innovative approach to maintaining and monitoring the quality of the packaged product through the use of conventional and advanced technologies. This type of packaging can provide real-time information about the quality of the packaged product and the environmental conditions inside the package, helping to ensure freshness and safety, detect spoilage or verify the effectiveness of the packaging. pH-controlled smart elements used in the food packaging industry include various types of indicators and sensors that can be used to monitor the freshness, stability and condition of perishable products (Mustafa & Andreescu, 2020; Rodrigues et al., 2021). In meat or dairy products, for example, spoilage often leads to a drop in pH levels, which can be detected by the color-changing element that provides a clear visual indication to the consumer. In addition, smart packaging systems can provide various safety warnings to ensure that the product remains within a safe pH range throughout its shelf life (Figure 1).

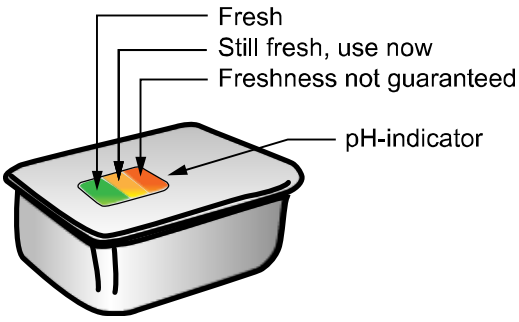


Figure 1: Example of the pH indicator in the packaging container

ORCID numbers are provided at the end of the paper.

pH indicators used in smart packaging to control food safety can indicate spoilage, contamination or degradation of packaged food, allowing timely intervention and better information to consumers. They are mainly composed of natural compounds that are applied to the packaging in the form of labels, films or coatings and change color depending on the pH variations in the packaging. In particular, different types of biodegradable and bio-based materials with natural sensing elements are being researched. Among the various materials, chitosan, starch and alginate composites and their by-products are most commonly used (Zhao et al., 2022). By utilizing the natural properties of starch and combining these properties with advanced technologies, the materials produced offer environmentally friendly ways to monitor and improve the freshness and safety of packaged products. By incorporating pH-sensing elements, produced materials can visually indicate changes in the acidity of the packaged product and alert consumers to possible spoilage.

One of the most interesting natural sensing elements that has recently been widely used in smart packaging is anthocyanins. Anthocyanins are a class of plant phenolic pigments and food ingredients that have various health and other benefits due to their antioxidant and antimicrobial properties (Eng Khoo et al., 2017; Samota at al., 2022; Zhou et al., 2023). In smart packaging, anthocyanins are used as pH-sensing elements responsible for the red, orange, pink and blue colors when exposed to different pH environments. They are very interesting for these applications due to their availability, as they can be extracted from various natural resources such as vegetables (red cabbage, red onions, purple carrots, etc.), fruits (grapes, blueberries, raspberries, etc.) and flowers (butterfly pea, red rose, etc.) (Chayavanich, et al., 2023; Kurek, et al., 2019; Oladzadabbasabadi et al., 2022; Zhao, et al., 2022). Their main advantage in the production of pH indicators is the ability to change color in response to different pH values. On the other hand, by-products and waste from some food crops are cost-effective sources of anthocyanins, which further contribute to sustainable development. pH sensing elements, i.e. anthocyanins, can be embedded in a polymer composite or applied to the packaging material to detect a pH change in the packaging environment and inform the consumer about the potential spoilage of food. There are many methods for extracting anthocyanin pigments from various sources and they are being intensively researched. These include solvent extraction method (SEM), ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), supercritical carbon dioxide extraction (SCDE) and various combined methods (Chesnokova et al. 2021; Tan et al., 2022). Since anthocyanins are highly unstable, all methods aim to preserve the stability and shelf life of anthocyanins, which are directly related to the beneficial properties of these compounds.

Various natural and synthetic polymers can be used to immobilize anthocyanins in a solid material and achieve an improved colorimetric response (Moradi et al., 2019). In this study, bacterial nanocellulose (BNC) was added to the film-forming solution in the production of pH indicators. It has been published that BNC can enhance the absorption of liquids and gases that cause pH change in the production of pH-sensitive films, thus facilitating the color change of the pH sensing element embedded in the BNC network. In addition, BNC has been shown to be useful in protecting anthocyanins from degradation processes and to have a positive effect on their stability, ensuring the excellent barrier properties (Beluhan et al., 2022; Mahović Poljaček et al., 2024; Perdani & Gunawan, 2021; Pourjavaher et al., 2017).

There are a number of publications on the production of various pH indicators for use in smart packaging systems, but the production of pH indicators based on starch matrices with the addition of BNC and anthocyanins from red onions has not yet been reported to our knowledge. The aim of the research was to evaluate the colorimetric and optical differences in the prepared potato and maize starch-based films with UAE treated and untreated anthocyanins and BNC. The prepared films were measured before and after exposure to the environment with different pH values.

2. MATERIALS

In this study, polymeric composites were prepared by dissolving two types of starch in distilled water. A potato starch (extra pure, CAS: 9005-25-8) (Carl Roth, Germany) and maize starch (extra pure, CAS: 9005-25-8) were used. In addition to the starch, glycerol (purity 99.5 %, CAS: 56-81-5) and glacial acetic acid (CAS: 64-19-7) (1 % v/v) were used in varying concentrations to produce a film-forming solutions.

Fresh red onion (Allium cepa L.) for extraction of anthocyanins was supplied from the local market. The anthocyanins were extracted from the peel of red onions (ROA). The peel of red onions was used because the flavonoid compounds, which are mainly responsible for the purple/red color of the onion, are highly concentrated in the outer peel of the onion (Samota et al., 2022). Two methods were used for the extraction. The first was the SEM method, which was performed according to the modified method

described in the publication (Tan et al., 2022), and the second was the combination of SEM and UAE methods. In the extraction, the red onion peels were ground and mechanically mixed within a 96 % (v/v) ethanol solution (Pharmachem, Ljubljana, Slovenia). Extraction was performed at 60°C for 90 minutes, after which the samples were cooled and filtered with Whatman® Quantitative Filter Paper, ashless, grade 40 (Cytiva, USA). Ultrasonic (pre)treatment was performed with an ultrasonic probe (Sonics Vibracell VCX 750) at a power of 350 W for 10 minutes. After one minute of probe operation, a one-minute break was taken. This procedure in combination with a cold water-bath prevented excessive heating of the suspension. The anthocyanin extracts were stored in the refrigerator before use.
BNC was produced from the cellulose-rich biofilm formed after acetic fermentation of apple juice according to the method described in (Lavrič et al., 2020).
Various buffers were used to test the color-changing effect of the films produced: commercially available pH buffers pH 2 - pH 4 [$C_6H_8O_7$ (1-hydrate), NaOH, HCl, H_2O], pH5-pH6 [$C_6H_8O_7$ (1-hydrate) (Gram-Mol d.o.o., Croatia) and additionally prepared buffers: pH 7 - pH 8.05 [Na_2HPO_4, $C_6H_8O_7$] and pH 9.17 - pH 10.5 [Na_2CO_3 - $NaHCO_3$].

3. METHODS

Film-forming solutions were prepared by mixing starch in distilled water on a temperature-controlled hotplate (Tehtnica, Rotamix 550 MMH, Domel, Slovenia) with stirring (DLS Digital Overhead Stirrer, Velp Scientifica Srl, Italy). The films were prepared at different temperatures; the film-forming potato starch solution was heated to 60°C and the maize-starch solution to 80°C. Anthocyanins, glycerol and acetic acid were slowly added to the diluted starch solution at different concentrations. Glycerol was used because it acts as a plasticizer and the incorporation of glycerol into the film-forming solutions increases the flexibility of the films produced and positively influences other film properties (Pounds, et al., 2021). Acetic acid was added to the film-forming solutions to ensure that the branched amylopectin molecules in the starch break into straight-chain amylose molecules. Our previous studies have shown that different amounts of the components are required to obtain compact and stable films. For this reason, a series of tests were carried out to form the films that have optimal properties for the measurements (Mahović Poljaček et al., 2024).
A total of eight samples were prepared, four samples based on potato starch and four samples based on maize-starch. The films were prepared by adding untreated anthocyanins (ROA) in one set of starch-based films and by adding anthocyanins with ultrasound-assisted extraction (ROA-UAE) in another. In addition, the samples were prepared without BNC and with BNC addition. The BNC used was added to the film-forming solutions at a concentration of 50 % (v/v) (dry matter of BNC in a suspension was 0.15 %). The preparation of each starch-based film took approximately 30 minutes. Twenty-five grams of each film-forming solution was poured into a glass Petri dish to obtain a constant film thickness. The films were dried and stored in a ventilated environmental chamber at 25°C and 50 % relative humidity (RH) for ten days. Table 1 contains the films and their ingredients. The amount of ingredients refers to the total amount of film-forming solutions needed to produce the films.

Table 1: Ingredients for film-forming solutions

Produced films	Acetic acid (%)	Glycerol (%)	ROA (%)	ROA-UAE (%)	BNC (%)	Designation of samples
PS starch	15	3	12	/	/	PS_0BNC_ROA
	15	3	/	12	/	PS_0BNC_ROA-UAE
	15	3	12	/	50	PS_50BNC_ROA
	15	3	/	12	50	PS_50BNC_ROA-UAE
MS starch	20	5	12	/	/	MS_0BNC_ROA
	20	5	/	12	/	MS_0BNC_ROA-UAE
	20	5	12	/	50	MS_50BNC_ROA
	20	5	/	12	50	MS_50BNC_ROA-UAE

To observe the influence of UAE on the pigment content in the extracts the total monomeric anthocyanin pigment content was calculated using the pH differential method (Lee et al., 2005). A Shimadzu UV-1280 UV-Vis spectrophotometer (Shimadzu Scientific Instruments, Kyoto, Japan) was used. The method utilises the different absorbance of anthocyanins at pH 1.0 and pH 4.5 at a wavelength of about 520 nm. The

change in absorbance is caused by the structural transformation of anthocyanins between the two pH values. The absorbance spectra of the samples were recorded in the range of 250 to 750 nm, and the anthocyanin pigment concentration, expressed as cyanidin-3-glucoside equivalents, was calculated using Equation (1) (Lee et al., 2005):

$$Anthocyanin\ pigment\ (cyanidin\text{-}3\text{-}glucoside\ equivalents, mg/L) = (A \times MW \times DF \times 1000)/(\varepsilon \times l) \quad (1)$$

where $A = (A_{520\ nm} - A_{700\ nm})_{at\ pH\ 1.0} - (A_{520\ nm} - A_{700\ nm})_{at\ pH\ 4.5}$; MW = 449.2 g moL^{-1} for cyanidin-3-glucoside; DF = dilution factor, l = path-length (cm), ε = 26.900 molar extinction coefficient, in L/mol cm for cyanidin-3-glucoside and 10^3 = factor for conversion from g to mg.
Density of the produced films was measured according to the Equation (2) (Lavrič et al., 2021):

$$Density = m/(d \times S)\ (g/cm^3) \quad (2)$$

where m is the mass of the tested sample, d is the thickness of the film in cm, and S is the area of the sample. Films were cut into pieces of 3×3 cm^2 in size. The thickness was measured with DGTB001 thickness gauge (Enrico Toniolo, Milan, Italy) and weighed on an analytical scale.
The colorimetric and optical properties of the produced films were measured. Samples were measured before immersion in the different pH buffers and after they were exposed to different buffer solutions for 20 minutes. The results are shown as a lightness value (L*) and chromatic coordinates (CIE a*/b*) from CIE L*a*b* color space (Fairchild, 2013). The spectro-densitometer Techkon SpectroDens (TECHKON GmbH, Germany) was used for the measurements. The measurement conditions were set to illuminant D50/2°, M1 filter according to ISO 13655. Calibration was carried out on the integrated absolute white standard and the relative CIE L*a*b* values (with paper as white point) were calculated and presented in the results.

4. RESULTS AND DISCUSSION

4.1 Determination of the total monomeric anthocyanin pigment content

The UV-Vis absorption spectra of red onion extracts at pH values 1.0 and 4.5 are shown in Figure 2. Figure 2a is the absorption spectra of untreated extract (ROP) and Figure 2b extract after ultrasound treatment (ROP-UAE). Table 2 gives the absorbance values of both samples at 520 and 700 nm respectively. According to calculation (Equation 1), the anthocyanin concentration for untreated sample (ROA), expressed as mg of cyanidin-3-glucosides per 100 g of dry peels of red onion, has a value of 13.97, and a value of 14.85 was found for the UAE treated sample (ROA-UAE).

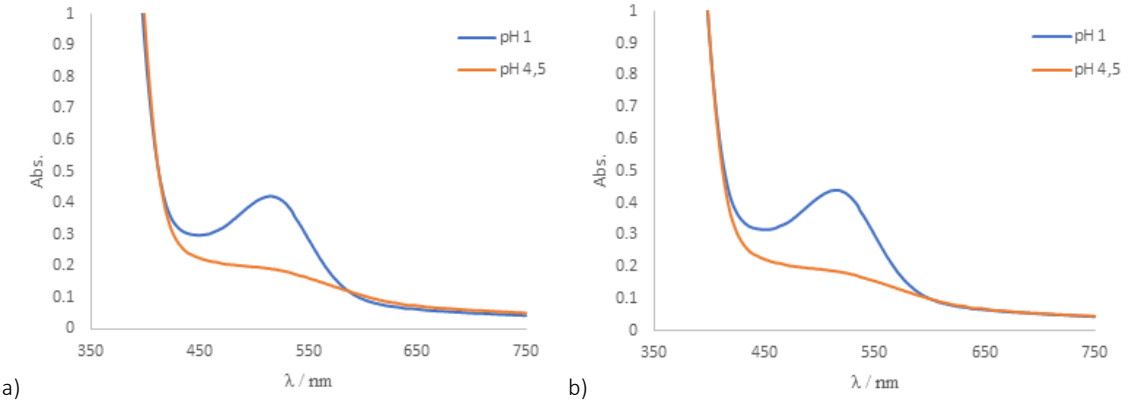


Figure 2: UV-Vis absorption spectra of anthocyanin extracts, a) untreated ROA and b) ultrasound treated ROA (ROA-UAE)

Table 2: Absorbance values of red onion samples at 520 and 700 nm at pH values of 1.0 and 4.5

Absorbance	ROA sample		ROA-UAE sample	
	pH 1.0	pH 4.5	pH 1.0	pH 4.5
A_{520}	0.418	0.187	0.438	0.183
A_{700}	0.051	0.059	0.054	0.053

4.2 Properties of starch-based films

Figure 3 shows the optical properties of the samples measured on dried starch-based films. Figure 3a shows the results of the calculated film density (according to Equation 2) and the results of the measured lightness (L*). It can be seen that the type of starch used has little influence on the density of the films produced. In general, the density value fluctuates between 1.05 and 1.25. Films based on potato starch have slightly higher density values compared to films based on maize starch. The addition of BNC primarily leads to a reduction in density for samples based on potato starch and to a slight increase when BNC was added to maize starch. In addition, it can be seen that samples containing BNC and ROA-UAE anthocyanins have higher density values compared to the samples without BNC. When comparing the lightness results, it can be seen that the samples without BNC addition (PS_OBNC_ROA and MS_OBNC_ROA) measured the lower brightness. The addition of anthocyanins extracted by ultrasonic treatment led to an increase in lightness values for all samples. Figure 3b shows the results of the relative CIE a*/b* color coordinates measured on the films. The films produced have an appearance between red and yellow color coordinates. These results were expected as the peel of the red onion contains flavonoids, which are responsible for the purple/red color of the onion (Samota et al., 2022). Slight differences can be seen between the films produced on the same starch base. Films with different composition based on potato starch show a lower color distribution than samples based on maize starch. Samples without BNC (MS_0BNC_ROA and MS_0BNC_ROA-UAE) show a color shift in the reddish direction and samples with BNC (MS_50BNC_ROA and MS_50BNC_ROA-UAE) show a color shift in the yellowish direction.

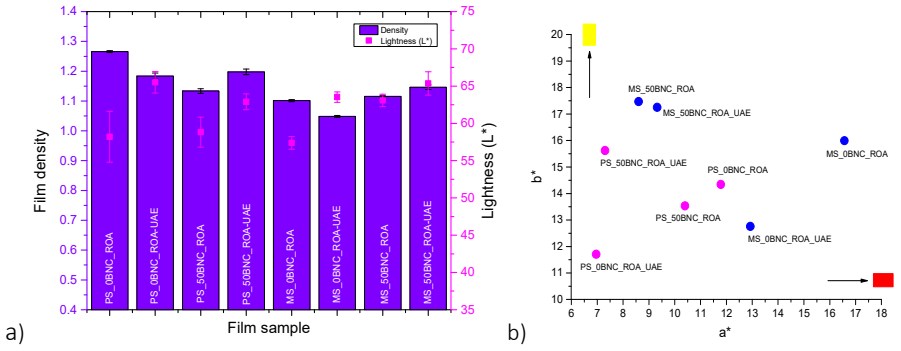


Figure 3a) Film density and CIE lightness (L) values*
and b) CIE a/b* coordinates of the produced starch-based films*

4.3 Visual analysis of starch-based films immersed in different pH-buffers

Figure 4 shows the colour changes of the produced potato-based films after immersion in different buffer solutions (pH 2.0 - pH 10.5). Figures 4a and b show the samples without the addition of BNC (PS_0BNC_ROA and PS_0BNC_ROA-UAE) and Figures 4c and d show the samples with the addition of BNC (PS_50BNC_ROA and PS_50BNC_ROA-UAE).

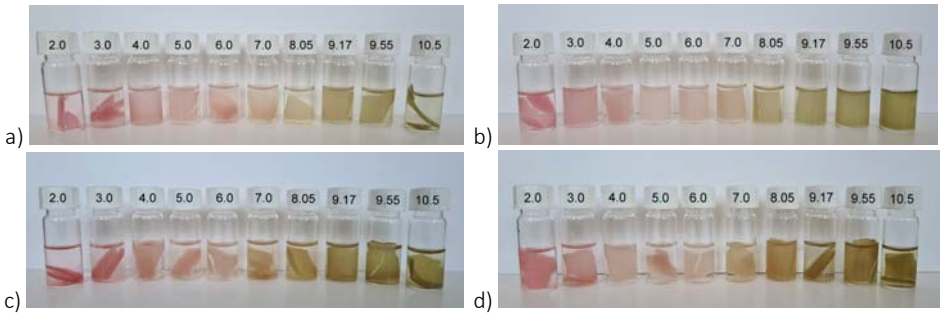


Figure 4: Potato starch-based films immersed in different buffers, (a) PS_0BNC_ROA, (b) PS_0BNC_ROA-UAE,
(c) PS_50BNC_ROA and (d) PS_50BNC_ROA-UAE

All samples show a gradual transition from pink to light pink to light green and brownish. There is a slight difference in colour appearance for the samples containing anthocyanins extracted with ultrasound assistance (Figures 4b and d); it appears that the colours are slightly enhanced across the range of buffers. On the other hand, the addition of BNC (Figures 4c and d) has a visible effect on the colour change. The films in the different buffers show a more pronounced colour transition when BNC is added than the samples without BNC.

Figure 5 shows the colour changes of the produced maize-based films after immersion in different buffer solutions (pH 2.0 – pH 10.5). Figures 5a and b show the samples without the addition of BNC (MS_0BNC_ROA and MS_0BNC_ROA-UAE) and Figures 5c and d show the samples with the addition of BNC (MS_50BNC_ROA and MS_50BNC_ROA-UAE). As can be seen in the images, the colour transition is quite uniform in all samples. The transitions from pink and light pink to green-brownish are clearly visible. Considering the different composition of the films, there are no significant differences in the colour response in the samples. However, it can be seen that the samples treated with ultrasound have a slightly more pronounced yellowish tone in all samples. The colour transitions are least pronounced in sample MS_50BNC_ROA-UAE.

When looking at the images of film samples exposed to different pH buffers, as shown in Figures 4 and 5, overall more pronounced visual and colour responses were observed in films containing maize starch. In addition, corn starch-based films immersed in buffer solutions are visibly stable, while potato starch-based films begin to dissolve in the solutions. This appearance can significantly affect the stability of the pH indicators produced, so further research on this topic is required.

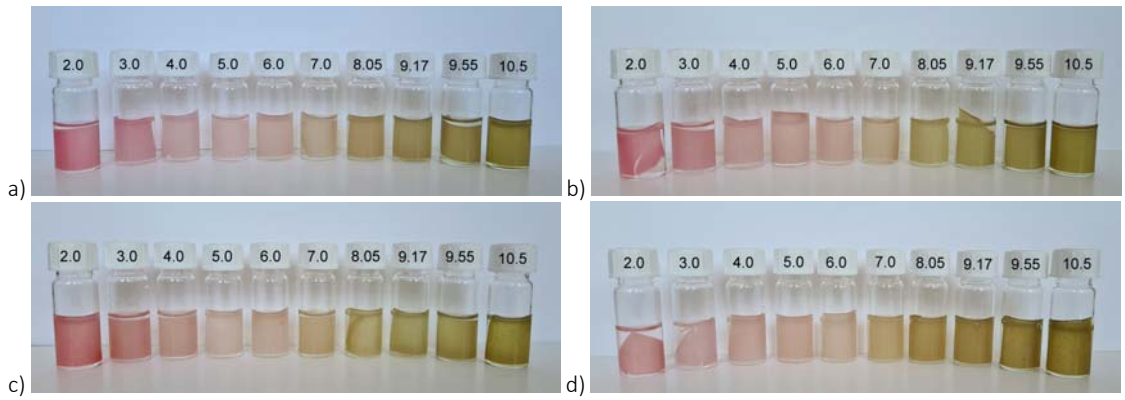


Figure 5: Maize starch-based films immersed in different buffers: (a) MS_0BNC_ROA, (b) MS_0BNC_ROA-UAE, (c) MS_50BNC_ROA and (d) MS_50BNC_ROA-UAE

The visual colour changes observed on potato and maize starch-based films with anthocyanins extracted from red onion peels proved that the films produced can provide information on whether the pH of the food or the pH of the environment varies. According to literature (Sujiwo, 2018), fresh meat must have a pH value in the range of 5.5 to 6.2. If stored improperly, fresh meat begins to spoil and has a pH below 5.3 or rises. It can be seen that all films produced in the pH range between 5 and 6 have a pale pink to pink colour. Lowering the pH leads to a colour shift towards a more pronounced pink and increasing the pH leads to a colour shift towards a greenish brown. These results indicate a positive response in the colour change during the production of pH indicators based on potato and maize starch.

4.4 Colorimetric properties of starch-based films exposed to different pH-buffers

Relative CIE L*a*b* values measured on the films placed on the white paper surface after immersion in buffer solutions (pH 2.0 - pH 10.5) were calculated and presented in Figures 6 to 9 Lightness (L*) was presented separately since previous research (Mahović Poljaček et al., 2024) showed that the addition of BNC affected the films' swelling behaviour, as well as other properties of the films that could directly influence L* values. Furthermore, observing the changes in CIE a* and b* values on a separate diagram can help with the analysis of the shifts in hue range and anthocyanin stability (Mahović Poljaček et al., 2024).

Lightness of the films produced without the UAE of anthocyanins was lower than lightness of the films with UAE-anthocyanins in the pH range between 3 and 10.5 (Figure 6a). However, the addition of BNC, which is not completely optically transparent, disrupted this property of the films produced using UAE

during anthocyanin extraction (Figure 6b). Higher L* values of 50_BNC_ROA-UAE films are observable only in the acidic and neutral pH range and are not consistently higher than L* values of 50_BNC_ROA film samples. The reduction in the lightness of the films containing 50% BNC compared to the films without BNC may be attributed to the optical and physical properties of BNC (Almeida et al., 2023), as well to the interactions of BNC and ROA.

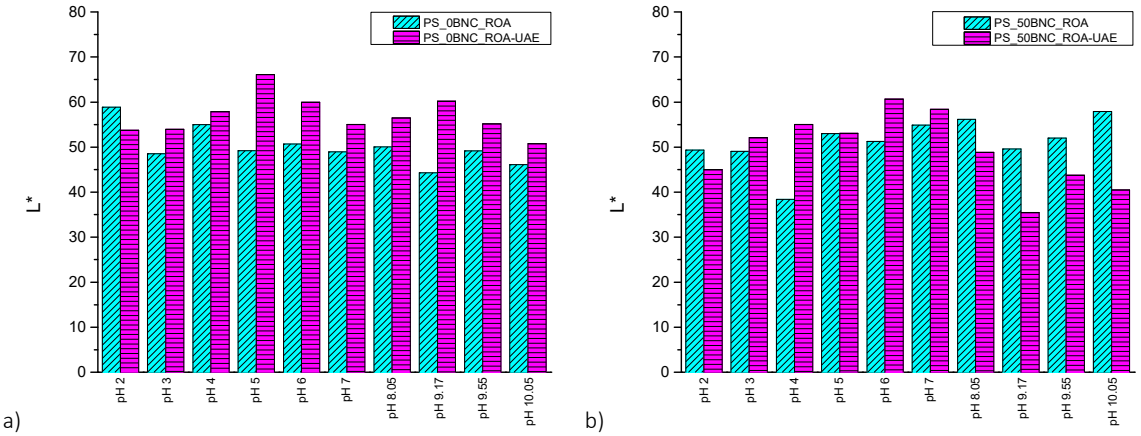


Figure 6: Lightness (L) of potato starch-based films produced without and with UAE, a) PS_0BNC and b) PS_50BNC*

Figure 7a presents the changes in CIE a* and b* values of PS-based films while Figure 7b presents the changes in MS-based films resulting from the changed pH of the environment.

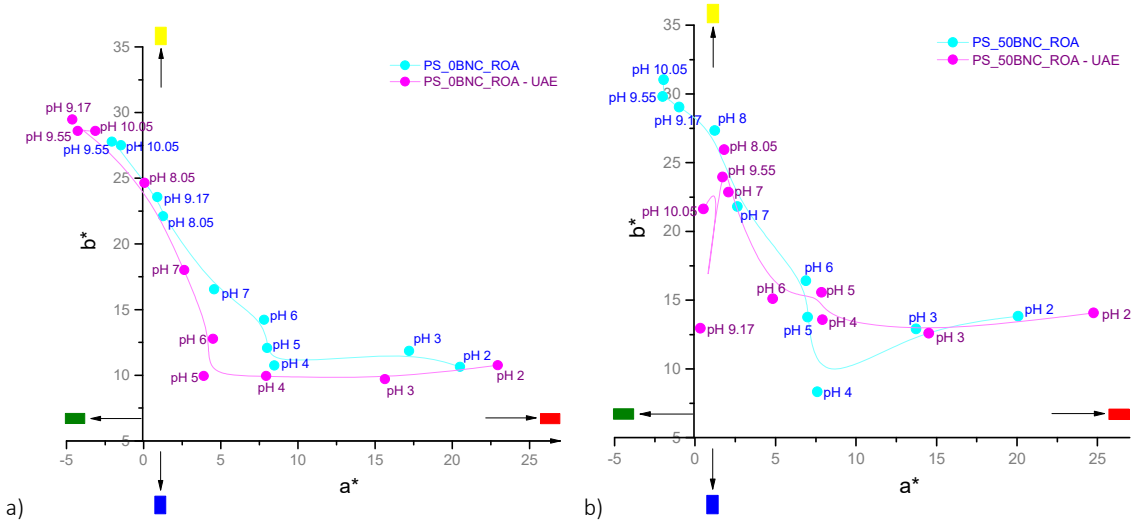


Figure 7: CIE a/b* values for potato starch-based films produced without and with UAE, a) PS_0BNC, b) PS_50BNC*

By observing Figure 7a, it can be seen that UAE caused the expansion of the colour shift range in both a* and b* axis when film samples without BNC were exposed to buffer solutions. This expansion can be linked to the increased concentration of anthocyanins in the film and certainly contributes to the vividness of the film colours after their exposure to varied-pH environments. On the other hand, UAE expanded the colour shift range only in highly acidic environment (pH up to 3) for the film with BNC and UAE (Figure 7b). At alkaline pH levels, colour changes of the films among the neighbouring pH steps remained modest comparing to the colour changes of the films produced without UAE of anthocyanins. It is noteworthy that the L* values of the PS-based films with BNC produced using UAE of anthocyanins significantly decreased in alkaline medium, as well (Figure 6b). This could point to the interaction between BNC and anthocyanins at their higher concentrations, and in alkaline medium. Specifically, when comparing respective a*/b* plots in Figures 7a and b, it is visible that the addition of BNC resulted in more expressed shift to yellow hues for the film without UAE of anthocyanins. As a contrast, the film with

BNC and UAE of anthocyanins did not show such expressed shift to yellow hues at alkaline pH compared to the film without BNC. This occurrence could be both the advantage and disadvantage, depending on the intended range of pH values during the utilization of the films. More expressed colour change with increased pH is certainly easier to notice, but at the same time points to the anthocyanin degradation (Ohno et al., 2021).

L* values of the MS-based films are presented in Figure 8. Contrary to the behaviour of PS-based films, the increased lightness of the MS-based films containing 50% BNC compared to the films without BNC is visible when comparing Figures 8a and b, especially when UAE is included in the film production. The results obtained are consistent with previous research showing that BNC could stabilize and preserve anthocyanins in the pH-sensing films. This is because BNC can form a network that physically protects anthocyanins from degradative factors. Additionally, previous research has demonstrated that incorporating BNC into pH-sensing films resulted in more vibrant and stable colorimetric responses under various conditions, and that maize starch is superior matrix to potato starch for the encapsulation of anthocyanins due to the better and stronger interactions with BNC and anthocyanins (Cao et al., 2023; Mahović Poljaček et al., 2024).

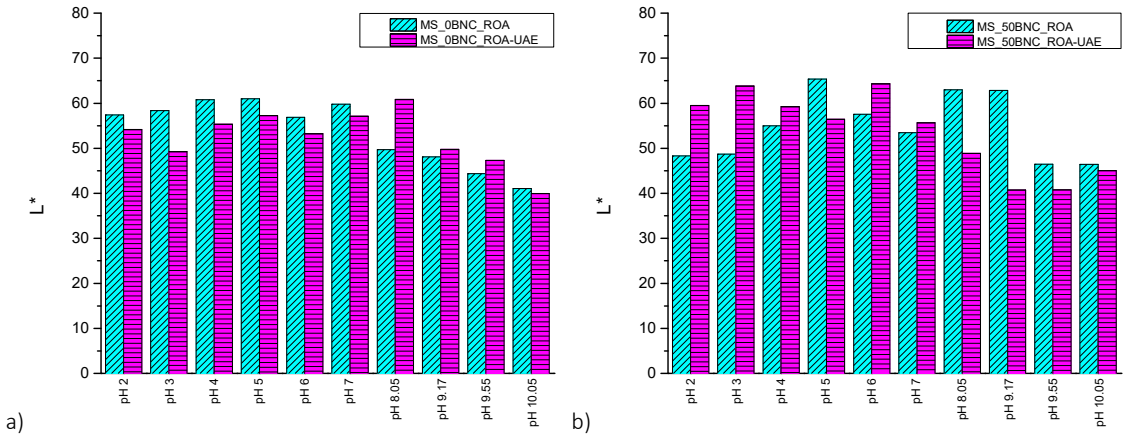


Figure 8: Lightness (L) of maize starch-based films, a) MS_0BNC and b) MS_50BNC*

By observing Figure 9a, it can be seen that UAE caused the expansion of the colour shift range when MS-based film samples without BNC were exposed to buffer solutions, similar to PS-based films. However, this expansion is observable only on a* axis. When BNC was added to the film composition, UAE did not result with the colour shift expansion (Figure 9b). This could be related to the increased stability of the ROA in the starch matrix, due to their interaction with BNC.

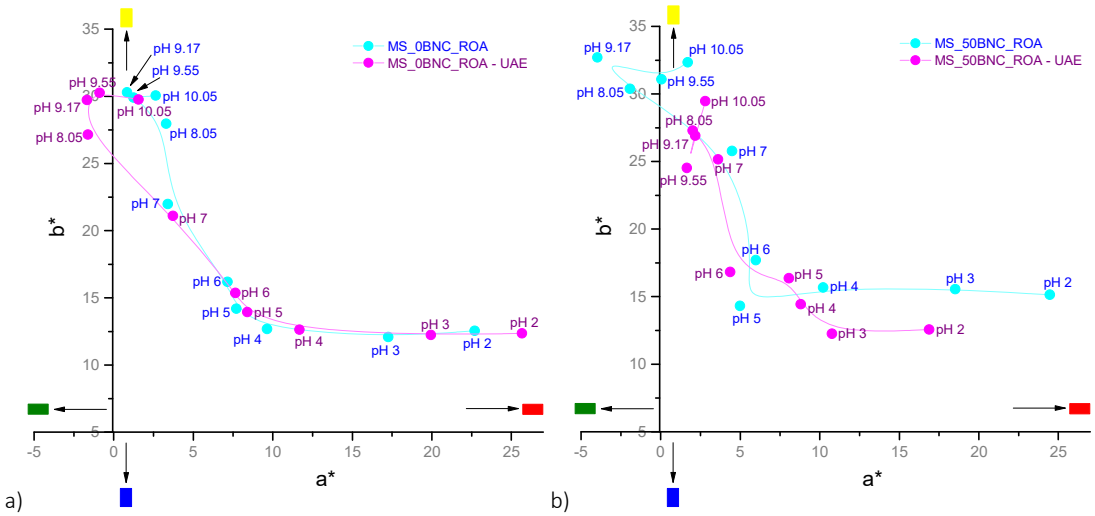


Figure 9: CIE a/b* values for maize starch-based films, a) MS_0BNC, b) MS_50BNC*

When comparing Figures 9a and b, it can be thereby concluded that the addition of BNC expanded the colour shift range only for the films produced without using UAE of the anthocyanins. However, increased L* values of the MS-based films with BNC in acidic and neutral media comparing to the films without BNC contributed to the differences in the colour appearance of the films.
These research findings suggest that adding BNC to starch-based films, especially in the case of MS-based films, offered advantage for applications in indicator systems and smart packaging due to the stabilization of the anthocyanins in the starch matrix. However, depending on the application of such films, the expansion of the colour shift range should be considered. Moreover, the colorimetric measurements, particularly the analysis of CIE lightness (L*) in a separate diagram and the use of CIE a*/b* plots, can help interpret the interactions of different anthocyanins with starch base and additives such as BNC.

5. CONCLUSIONS

In this research, pH indicators with polymeric bio-based matrices, anthocyanins from red onions and bacterial nanocellulose were investigated to observe their potential for use in smart packaging applications. Potato and maize starch were used as matrix for the preparation of films, bacterial nanocellulose was added to immobilize anthocyanins, acetic acid and glycerol were added in film-forming solutions to obtain films with optimal properties for measurements. Ultrasound-assisted treatment of the extracted anthocyanins was performed to determine the influence of the treatment on the colour response of the produced films. To observe the colour response of the prepared starch-based films when exposed to different pH values, their optical and colorimetric changes were monitored before and after exposure to altered pH values.
The research results have shown that it is possible to produce bio-based films that can be used in pH-controlled smart packaging. The pH-sensitive films produced showed a visually detectable colour change when the pH of the environment changed, proving their potential and the use of anthocyanins to produce a pH indicator.
When determining the total monomeric anthocyanin pigment content, ultrasound-assisted extraction was found to cause a slight increase in the anthocyanin content of the extracts. Since pH-sensitive indicators can change colour depending on the pH of the environment, it was found that the addition of bacterial nanocellulose to starch-based films, especially in the case of maize-based films, offers advantages for applications in indicator systems and smart packaging.
The results show that the produced films could be used in smart packaging or as an improved packaging material. Further research on mechanical properties, water barrier properties, antioxidant properties and other interactions with different packaging materials should be conducted to further investigate the effectiveness of the presented pH indicators.

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DEVELOPMENT OF FILMS CONTAINING POLYLACTIC ACID/HALLOYSITE NANOTUBES IN BANANA ACTIVE PACKAGING

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Abstract: *Ethylene plays a significant role in the ripening and aging processes of fruits and vegetables, ultimately reducing their shelf life. Consequently, the presence of ethylene can restrict the marketability and consumer accessibility of certain horticultural products, leading to heightened post-harvest losses and increased food waste. In this study, nanocomposite packaging films with ethylene scavenging activity, which will help preserve freshness during distribution, were developed and tested as packaging for fresh products. Nanocomposite packaging films were prepared by adding different amounts of halloysite nanotubes (HNNTs) to polylactic acid (PLA). Structural characterization of nanocomposite packaging films was performed by FTIR. The thermal properties of nanocomposite packaging films in an inert atmosphere were studied using TGA. The nanocomposite films' surface energies, colours, transparency, and gloss were also measured. The nanocomposite films were printed with gravure and printability parameters were investigated. Finally, the effects of PLA/xHNNTs nanocomposite packaging films on the quality of packaged bananas were also monitored in terms of hardness, colour change, and weight loss. It has been observed that increasing the amount of HNNTs in PLA/xHNNT nanocomposite packaging films improves the storage time of bananas.*

Key words: Active packaging, Protect fresh bananas, Polylactic acid, HNNT

1. INTRODUCTION

Food packaging is crucial in preserving food quality and safety, with plastics being widely used due to their affordability and effective sealing properties. However, petroleum-based plastics pose health risks through toxic residues and contribute to environmental pollution because of their nonbiodegradability. As a result, developing biodegradable alternatives has become a significant research focus, with many studies exploring the use of natural renewable resources such as polysaccharides, proteins, and lipids for innovative food packaging solutions (Zou et al., 2023; Wang et al., 2023; Yang et al., 2022). Polylactic acid (PLA) is a renewable and biodegradable biopolymer derived from resources like corn, making it a promising material for bio-composites and food packaging due to its good biocompatibility, low toxicity, and FDA approval (Boro et al., 2022; Villegas et al., 2017).

A key goal in food packaging is to reduce food loss by extending shelf life and ensuring the safe delivery of fresh, high-quality products. Active packaging, which interacts with the product, offers a promising alternative to traditional methods. These systems not only meet conventional packaging standards but also go beyond removing unwanted molecules, releasing beneficial components, or adjusting the packaging atmosphere. The specific needs of different food types have driven the development of diverse packaging systems to enhance preservation and safety (Alves et al., 2022; Durmaz et al., 2024).

Bananas are popular for their health benefits, containing dietary fibre, vitamins, minerals, phenolic compounds, and carotenoids (Xie et al., 2022; Qin et al., 2024). As a climacteric fruit, bananas undergo postharvest ripening, but harvesting them fully ripe complicates storage and transport due to their short shelf life. To address this, bananas are typically harvested before full ripeness and treated with exogenous stimuli to induce ripening, which shortens the market cycle and enhances their commercial value. While chemicals like calcium carbide and ethylene glycol have been used to ripen bananas, health concerns have led to a shift towards safer methods, such as controlled atmospheres and natural chemicals like ethylene and methyl jasmonate (Tao et al., 2021; Chai et al., 2022). However, ethylene poses safety hazards and can cause over-ripening, leading to significant economic losses (Xiao et al., 2024; Li et al., 2023). Ethylene scavenging is essential for maintaining the quality and shelf life of fruits and vegetables, as ethylene, even at low concentrations, accelerates ripening and deterioration. To address this, ethylene scavengers like potassium permanganate ($KMnO_4$) and metal catalysts, such as palladium, are commonly used in packaging. However, it is only applied in sachets rather than in direct contact with food due to the

ORCID numbers are provided at the end of the paper.

toxicity of $KMnO_4$ (Alves et al., 2022; Janjarasskul & Suppakul, 2018). Other scavengers like activated carbon and zeolite raise safety concerns, particularly regarding accidental ingestion. Polymeric films incorporating ethylene scavengers have been developed as an alternative to sachets to improve safety and reduce costs (Sultana et al., 2023).

Nano clays, particularly halloysite nanotubes (HNNTs), show great promise as fillers in food packaging due to their hollow tubular structure, high aspect ratio, non-toxicity, abundance, and low cost. Widely used in applications like drug delivery and coatings, HNNTs enhance the thermal, mechanical, and barrier properties of polymer composites. Additionally, FDA-approved HNNTs can adsorb ethylene gas, helping to extend the shelf life of fruits and vegetables by improving the gas barrier and ethylene adsorption capabilities of packaging films (Kumar et al., 2023; Boonsiriwit et al., 2020).

In this study, food packaging films were developed by combining HNNTs with biobased and biodegradable PLA. This study aims to develop an environmentally friendly nanocomposite packaging film capable of extending the shelf life of bananas by capturing ethylene gas and regulating gas transfer. To achieve this, HNNTs were incorporated into the PLA matrix at varying concentrations (0-1-3 % wt.).

2. METHODS

2.1 Materials

Polylactic acid (Mw ~60,000) used as a matrix was supplied from Sigma-Aldrich. The raw halloysite nanotubes were provided by ESAN, Eczacıbaşı, Türkiye. All solvents used in the experiments were of high purity and were obtained from Sigma Aldrich. Bananas were obtained from the local agricultural centre in Türkiye.

2.2 Preparation of PLA/HNNTs nanocomposite packaging films

PLA/HNNTs nanocomposite packaging films were produced by solvent casting, which does not need so much effort. HNNTs and PLA pellets were oven-dried under vacuum for 8 h at 80°C before starting the film preparation. For solvent casting, 10 g of PLA pellets were dissolved in 100 ml of chloroform for 4 h at room temperature with stirring at 1000 rpm on a magnetic stirrer. HNNTs were dispersed in a solution of PLA at a ratio of 0 (control film)–1–3 wt.% with a total solid content of 10 wt.% to prepare PLA/HNNTs nanocomposite packaging films. The film formulations to which HNNTs were added were kept in an ultrasonic bath for 30 minutes until the HNNTs became homogeneous. The formulations were cast onto glass Petri dishes (diam. 150 mm) and left to dry at room condition. The dried films were taken, a banana was packaged with each formulation, and the other films for testing were stored in a desiccator. Samples were coded according to HNNTs loading rates. For instance, PLA/1-HNNT represents the packaging film containing 1 wt.% HNNTs. The preparation scheme of PLA/HNNTs nanocomposite packaging films is given in Figure 1.

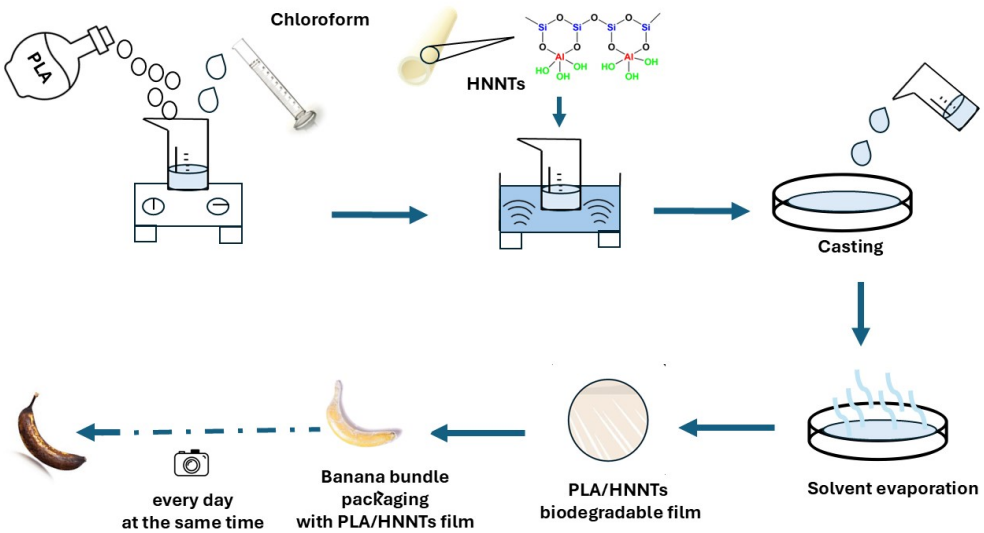


Figure 1: The preparation scheme of PLA/HNNTs nanocomposite packaging film

2.3 Characterization

Fourier-Transform Infrared Spectroscopy (FTIR) analysis was conducted using a Bruker IFS 66/S spectrometer equipped with ATR capability.
Thermal gravimetric analysis (TGA) was performed with a Perkin Elmer STA6000 instrument, with measurements carried out in the temperature range of 30°C to 750°C under a nitrogen atmosphere at a heating rate of 10°C/min.
The colours of the obtained nanocomposite packaging films were measured by X-Rite eXact portable spectrophotometer according to the ISO 13655:2017 standard. The measurement conditions of the spectrophotometer were determined as a polarization filter with 0/45° geometry with a 2° observer angle and a D50 light source in the range of 400-700 nm.
Colour differences were calculated using the CIELab (2000) technique (Equation 1). ISO 11664-6:2014. Calculations were performed by calculating the average of five measurements. Δ_L*, Δ_a*, and Δ_b*: Difference in L*, a*, and b* values between the specimen and target colours, respectively. The lightness is represented by the L* axis, which ranges from white to black. The red area is connected to green by the a* axis, whereas the b* axis runs from yellow to blue.

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (1)$$

Where ΔL*, ΔC*, and ΔH* are the CIEL*a*b* metric lightness, chroma, and hue differences, respectively, calculated between the standard and sample in a pair, and ΔR is the interaction term between the chroma and hue differences. S_L, S_C, and S_H are the weighting functions for lightness, chroma, and hue components. The values calculated for these functions vary according to the positions of the sample pair considered in the CIEL*a*b* colour space. The k_L, k_C, and k_H values are the parametric factors to be adjusted according to different viewing parameters, such as textures, backgrounds, and separations, for the lightness, chroma, and hue components.
The gloss measurements of all nanocomposite packaging films were carried out with the BYK Gardner GmbH micro gloss 75° geometry by ISO 8254-1:2009. The contact angles of nanocomposite packaging films were found on Pocket Goniometer Model PG-X, version 3.4 (FIBRO Systems AB, Sweden).
Surface-free energy was calculated according to the ASTM D5946 standard test method, depending on the water contact angle. The images of droplets were then recorded by using a CCD video camera.
The transparency of the nanocomposite packaging films was examined visually. Gravure prints were made on the obtained films with SEIGWERK ethyl alcohol solvent blue 20 seconds viscosity ink at 1m/s printing speed with RK printing proofer, and the colour properties of the obtained prints were determined by X-Rite eXact portable spectrophotometer according to the ISO 13655:2017 standard.
To examine the storage of fresh bananas using nanocomposite packaging films, bananas were obtained from the local agricultural centre in Türkiye. Fresh bananas were characterized by a green-yellow colour (80 % ripening stage), where unblemished, rot-free, well-formed bananas were selected. Three selected bananas of the same maturity were placed in the middle of the dried nanocomposite packaging film with three different contents. The bananas were tightly wrapped with nanocomposite packaging films. All specimens were stored at room temperature and the same relative humidity and were examined both visually and tactilely daily.

3. RESULTS AND DISCUSSIONS

3.1 Structural characterization of the nanocomposite packaging films

FTIR spectroscopy can be used to characterize the identification of specific functional groups in the nanocomposite packaging films. Figure 2 shows the FTIR spectra of pure PLA, HNNTs, and PLA nanocomposite packaging films with 1, and 3, wt.% HNNTs. For pure PLA films and nanocomposite PLA films with 1, and 3, wt.% HNNTs, the representative bands were detected at 2800-3000 cm^{-1} from CH_2 asymmetric stretching, at 3400–3000 cm^{-1} for the O–H stretch, and 1750 and1180 cm^{-1}, which belong to the C=O stretching and the C–O–C stretching. Looking at Figure 2, the FTIR spectrum of HNNTs can be seen. HNNTs have specific absorption bands at 3600 and 911 cm^{-1} due to O-H stretching and Al-O-OH bending. Moreover, the specific planar stretching vibration at 1091 cm^{-1} and 1034 cm^{-1} seen in HNNTs is due to the presence of Si–O–Si. The peak characteristic of Si–O–Si bonds became more pronounced with

the increasing HNNT content in the nanocomposite packaging films, which can be attributed to the silicon and oxygen composition of the HNNTs.

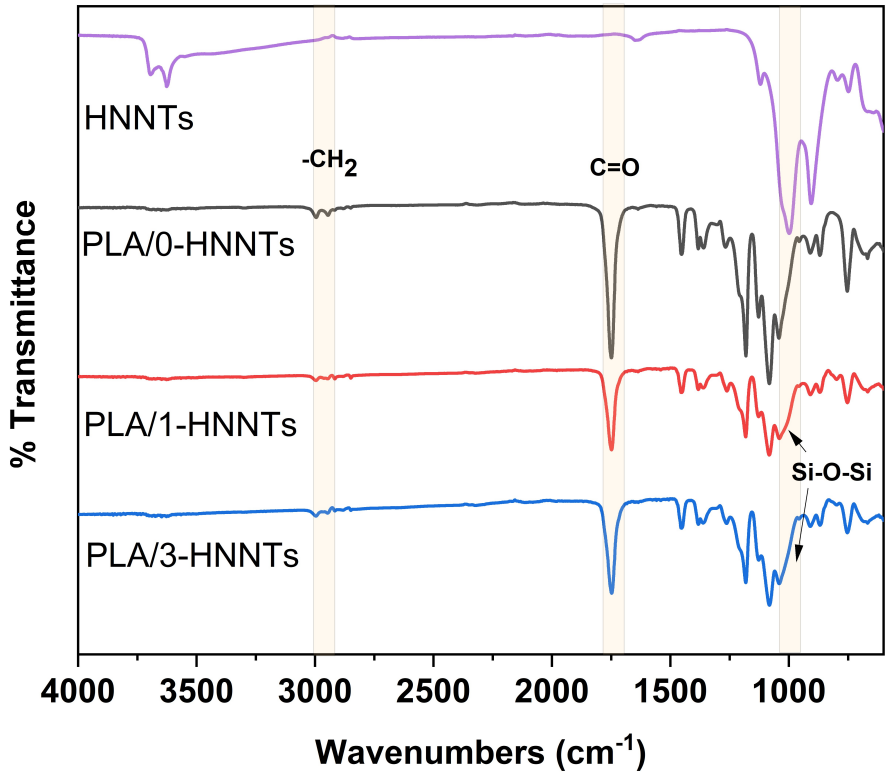


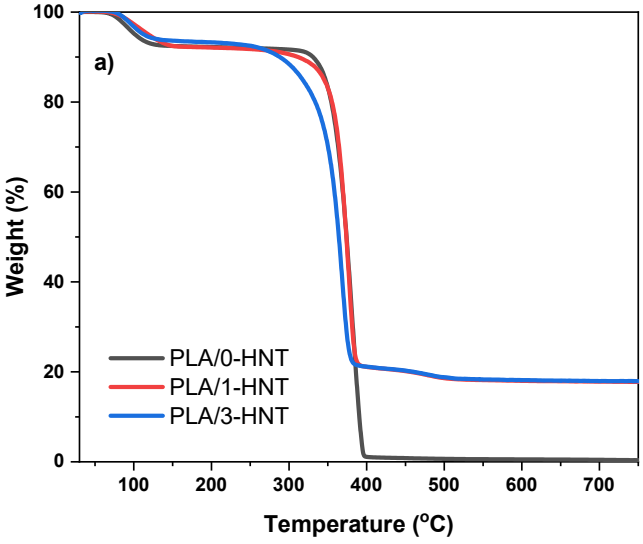
Figure 2: FTIR spectra of PLA/HNNTs nanocomposite loaded with 0, 1, and 3, wt% HNNTs. The spectrum for HNNTs is shown for comparison

3.2 Thermal characterization of the nanocomposite packaging films

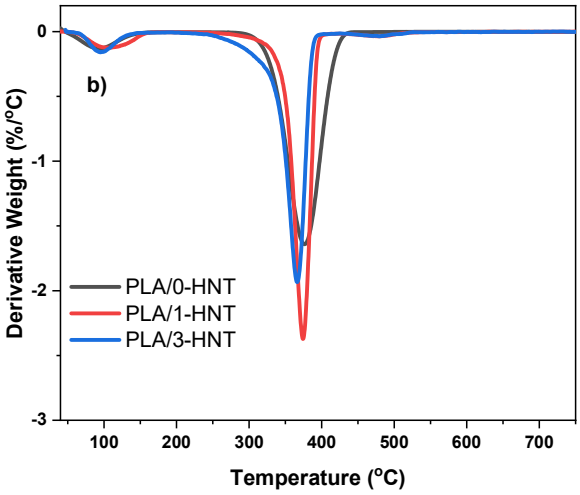
Figure 3 shows the TGA curves of the nanocomposite packaging films (PLA/x-HNNTs). The TGA results are summarized in Table 1. The maximum degradation temperature of PLA films without HNNTs is 377 °C. The thermal decomposition of PLA is mainly due to chain depolymerization (Lim et al., 2019). The results indicate that increasing the loading amount of HNNTs into PLA gradually decreased the degradation temperature, which was reduced from 377 °C (PLA/0-HNNTs) to 364 °C for the film containing 3% HNNTs. The incorporation of HNNTs into the nanocomposite packaging films did not enhance their thermal stability. This is attributed to the lower insulation efficiency of HNNTs in comparison to other silicate nanolayers, primarily due to their tubular structure. Consequently, at low loading ratios, they fail to effectively stabilize the polymer matrix (Du et al., 2006). As expected, the % char content at 750 °C of nanocomposite packaging films increased with the loading amount of HNNTs. The char yield of the nanocomposite films containing 0%, 1%, and 3% HNNTs was determined to be 0.3%, 17.74%, and 17.83%, respectively.

Table 1: TGA results of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films

	T_5 (°C)	T_{max1} (°C)	T_{max2} (°C)	Char
PLA/0-HNNTs	98	94	377	0.3
PLA/1-HNNTs	114	106	374	17.74
PLA/3-HNNTs	108	97	364	17.83



a)



b)

Figure 3: a) TGA curves of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films, b) DTG curves of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films

3.2 Colour properties of the nanocomposite packaging film

A simple naked-eye investigation of these images reveals that the transparency and colour characteristics of the pure PLA films were highly transparent and glossy. However, HNNTs were added to the formulation, and nanocomposite packaging films became semi-transparent and slightly yellow. Despite this change, the texts can still be read. Table 2 shows the colour L*a*b* coordinate values, the colour difference (ΔEab*), and glosses of the PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films.

Table 2: Colour properties of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films

	L	a	b	Delta E	Glos
PLA/0-HNNTs	90,29	1,89	-6,85	Reference	86,6
PLA/1-HNNTs	88,40	1,84	- 4,12	2,54	57,1
PLA/3-HNNTs	85,10	1,57	-1,521	5,63	45,5

When the colour values in Table 2 are analyzed, it is seen that there is not much change in the (green and red) value of the nanocomposite packaging films with HNNTs added compared to the pure PLA film (PLA/0-HNNTs), and the biggest difference is in the b (blue and yellow) value. This difference shows itself as a shift towards yellow. The reason for this shift towards yellow is due to the titaniferous content in the HNNTs. When the colour differences are analyzed, it is determined that PLA/1-HNNTs "does not have a noticeable colour difference" (Delta E is less than 3), but the colour difference of PLA/3-HNNTs increases with the addition of more HNNTs, and "the two colours are not the same colour" (Delta E is less than 5). As a result, the colour changes towards yellow as the amount of HNNTs increases. When the gloss values are analyzed, it is determined that the pure film has a very high gloss, the surface roughness increases with the addition of HNNTs, and accordingly the light is scattered and the gloss decreases. The results are supported by the literature. (Rojas-Lema et al., 2020; Trezza et al., 2001).

3.3 Surface properties of the nanocomposite packaging film

The contact angles and surface energies of the produced nanocomposite packaging films were investigated and shown in Figure 4. When Figure 4 was examined, the contact angle of the PLA/0-HNNTs nanocomposite packaging film was measured as 74.9°. This is a very close result to the contact angle values in the literature (Silva et al., 2014). A decrease in the contact angle (PLA/1-HNNTs: 72°, PLA/3-HNNTs: 64.9°) can be seen with the addition of HNNTs into the PLA packaging film. This is thought to occur because of the increase in surface energy by the hydroxyl groups of HNNTs increasing the polarity of the film. This decrease becomes a little more pronounced as the amount of HNNTs increases in the two concentrations in this study. In the literature, it is stated that when higher HNNT ratios are studied, the decrease in surface energy due to surface roughness dominates the polarity, therefore the contact angle starts to increase after 7 wt.% HNNTs ratios. The relevant results are consistent with the literature (Alakrach et al., 2018).

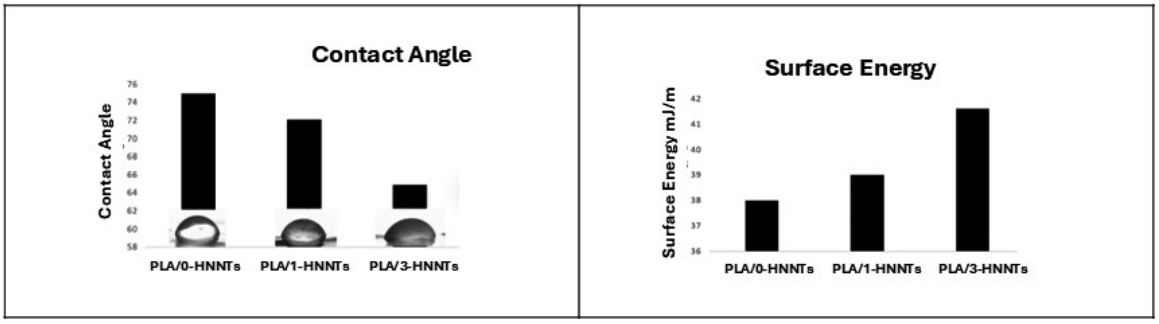


Figure 4: Contact angles and surface energies of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films

As illustrated in Figure 5, translucent, flexible nanocomposite packaging films were produced by solvent casting method. PLA/0-HNNTs (only PLA) nanocomposite packaging films are fully transparent. HNNTs ingredient PLA films are semitransparent and contains of whitish macroscopic spots. This situation is tough due to the nucleating effect of HNNTs and could resemble the 'micro-nano binary' structure the same line as that Liu et al noticed for polypropylene/HNT composites (Liu et al., 2010).

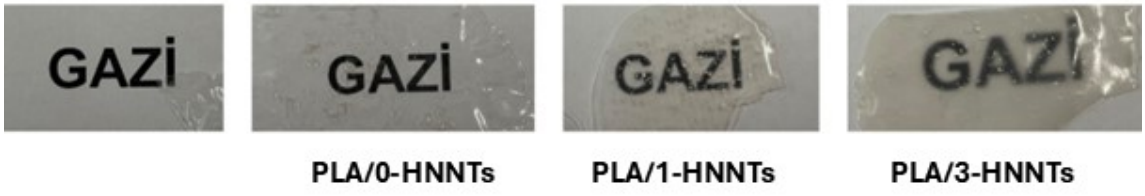


Figure 5: Images of PLA/0-HNNTs, PLA/1-HNNTs, and PLA/3-HNNTs nanocomposite packaging films

3.4 Printability properties of the nanocomposite packaging film

Prints were successfully made with blue ink on the three different nanocomposite packaging films obtained. No viscosity problems were experienced during the prints. The results of the adhesion test with the tape after the prints dried revealed that the adhesion was high for commercial ink, as there was no ink residue on the tape. The colour properties of the prints obtained are given in Table 3. When Table 3 is examined, it can be concluded that the addition of HNNTs shifted the colour of the nanocomposite packaging films to yellow, and the prints shifted slightly to yellow with the shift in the b-axis. This yellow shift in colour is due to the titaniferous compounds found in the chemical content of HNNTs. However, the colour change (delta e) is below 3, which means it is quite difficult to perceive by eye. As the amount of HNNTs in the nanocomposite packaging films increased, the yellow shift in the print and the amount of delta e increased, but there is no correlation between the increment. The results are compatible with the literature (Rojas-Lema et al., 2020).

Table 3: Colour properties of printed nanocomposite packaging films

	L	a	b	Delta E	Image
PLA/0-HNNTs	47	-10	-42	Reference	
PLA/1-HNNTs	45	-8	-40	1,90	
PLA/3-HNNTs	44	-8	-38	2,19	

3.5 Storage studies of the nanocomposite packaging film

As a climacteric fruit, bananas continue to undergo the ripening process after harvesting due to the release of ethylene gas. Considering this phenomenon, the impact of ethylene release on the browning and decay of fresh bananas was evaluated through photographic documentation after a 12-day storage period. Figure 6 presents photographs of bananas packaged in nanocomposite films over a 12-day period. Among the packaging films tested, PLA/3-HNNTs nanocomposite films exhibited the highest ethylene scavenging ability, followed closely by PLA/1-HNNTs nanocomposite films. As illustrated in Figure 6, bananas packaged in pure PLA began to darken after 8 days. In contrast, the bananas packaged in PLA/3-HNNTs and PLA/1-HNNTs films retained a closer resemblance to their initial appearance. While the bananas wrapped in PLA/1-HNNTs films began to show signs of darkening, those packaged in PLA/3-HNNTs films maintained their initial appearance and remained undecayed for the entire 12-day period at room temperature.

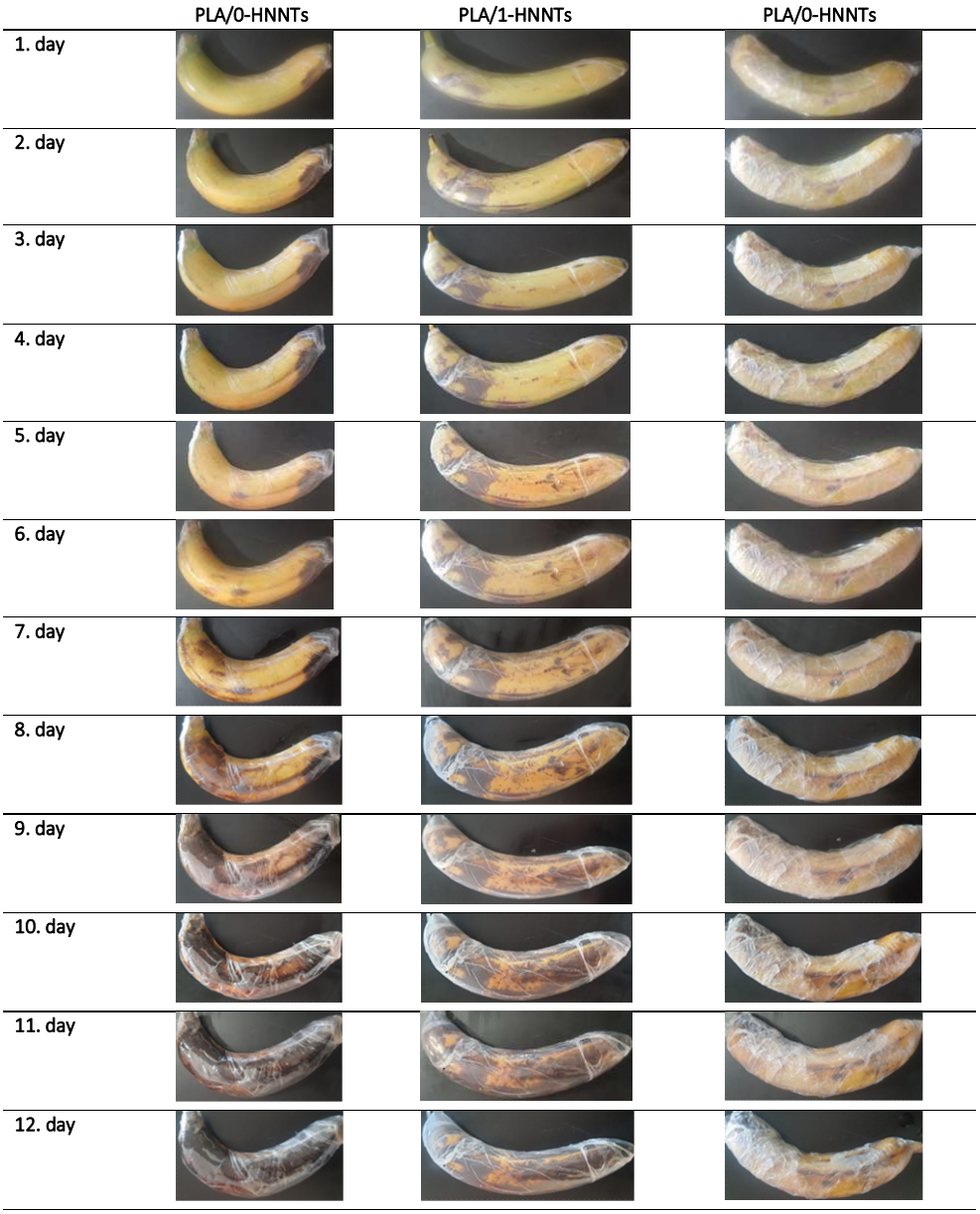


Figure 6: Effects of PLA/HNNTs nanocomposite packaging films

5. CONCLUSIONS

In this study, HNNTs-reinforced PLA nanocomposite packaging films were developed as potential eco-friendly, ethylene-scavenging active packaging materials for bananas. The nanocomposite packaging films were prepared by solvent casting, which is an easy production method. The impacts of HNNTs content were investigated on the structural, thermal, printability properties, surface properties, and ethylene scavenging ability of the nanocomposite packaging films. The incorporation of HNNTs was found to enhance the ethylene scavenging ability of PLA. It was concluded that the produced nanocomposite packaging films were transparent and semi-transparent and that the addition of HNNTs shifted the film colour slightly to yellow. It was determined that all of the obtained *nanocomposite packaging* films were printed with commercial ink without any problems and had good printability characteristics. Finally, the effects of the films on bananas were examined, and it was determined that films containing 3 wt.% HNNTs are suitable as packaging materials for bananas. Considering their physical and functional properties, PLA/3-HNNTs nanocomposite packaging films exhibit considerable potential as a viable alternative to synthetic packaging materials and as effective ethylene scavengers for fresh fruit packaging.

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https://doi.org/10.24867/GRID-2024-p50 Review paper

NATURAL SUBSTANCES AS PROTECTIVE AGENTS AGAINST PHOTODEGRADATION

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Abstract: *This study explores the use of natural substances as resources in the development of UV protective coatings, offering an environmentally sustainable alternative to toxic and synthetic materials, mostly organic compounds used as UV stabilizers in various industrial and commercial applications. Therefore, the focus of this study is on different natural sources possessing protective properties. To ensure adequate protection, it is necessary to carefully consider and properly blend various substances that possess protective properties against UV radiation and free radical formation. UV radiation poses a constant threat to materials, promoting oxidative stress that can cause serious damage. In this context, UV stabilizers play a crucial role in protecting materials from degradation caused by solar radiation. Their ability to absorb or reflect UV radiation is crucial for preserving the physical and chemical properties of polymeric materials, coatings, inks and coloration. On the other hand, antioxidants are additives that protect against oxidative stress by neutralizing free radicals - reactive compounds that are formed under the influence of UV radiation and can cause material damage. UV stabilizers, in synergy with antioxidants, often result in optimal material protection, ensuring durability and preservation of the aesthetic and functional properties of products. Therefore, a formulation that includes carefully selected UV stabilizers and antioxidants, is crucial for achieving a high level of protection against the harmful effects of UV radiation and free radicals. This integrated approach not only ensures material durability but also contributes to sustainability. This study emphasizes the need for further research aimed at developing new technologies that could enhance the interaction between UV stabilizers and antioxidants to achieve optimal material protection.*

Key words: UV radiation, antioxidants, natural resources, sustainability

1. INTRODUCTION

Durability of polymeric materials have made them indispensable in various applications, from packaging, arts to construction. However, when exposed to environmental factors, these materials are not immune to degradation. Sunlight, in particular, plays a significant role in triggering chemical reactions that weaken polymers, compromising their performance over time. Understanding the mechanisms of polymer degradation, particularly under outdoor conditions, is crucial for developing materials that can withstand harsh environments and maintain their integrity for longer periods. Polymers and organic materials exposed to sunlight undergo photo-oxidation, through various mechanisms involving UV radiation, oxygen, temperature, and humidity, leading to the degradation of their physical properties (Rosu, Varganici & Rosu, 2016). To maintain their functionality in outdoor environments, polymers require the addition of stabilizers like antioxidants and UV absorbers. Photodegradation is the most efficient form of abiotic degradation occurring in the environment. When polymeric materials are subjected to outdoor conditions such as weathering, aging, and burial, they may undergo various transformations—mechanical, light-induced, thermal, and chemical. This exposure alters the biodegradability of the polymers as well. In most cases, abiotic factors weaken the polymer structure, facilitating undesirable changes (Lucas et al., 2008).

To protect against UV light, various substances, known as UV filters, are used in products exposed to solar radiation, such as coatings, plastics, and cosmetics. They are increasingly included in personal care items like sunscreens and lipsticks due to the rising awareness of sun-related health risks, including skin cancer (Chen, Hu & Wang, 2012; Saewan & Jimtaisong, 2015). UV filters protect by either reflecting UV light, as with inorganic pigments like TiO_2, or by absorbing it using organic compounds. Since no single compound can cover the entire UV spectrum (280–400 nm), combinations of filters are typically used for full protection.

The ultimate goal of industrial processes is to create a more sustainable world where the products we use in our daily lives are safe for people and the planet. By replacing toxic compounds with natural ones, we

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can significantly reduce the risk of disease, preserve biodiversity, and ensure a healthy future for everyone. This concept requires an interdisciplinary approach, where science, technology, functional design and traditional knowledge work together to develop innovative products and processes that are in harmony with nature. Natural compounds found in waste materials, plants and other sources from nature represent a sustainable and safe alternative.

2. MECHANISM OF PHOTODEGRADATION

Materials exposed to sunlight absorb energy from a wide spectrum, including UV radiation, visible light, and infrared radiation. UV radiation (280 nm and 400 nm) is an important factor causing photodegradation of polymers resulting in breaking of the polymer chains, free radical production and reducing the molecular weight, causing deterioration of mechanical properties in unpredictable time (Rabek, 1996). UV radiation is categorized into three distinct bands based on decreasing wavelength and increasing energy: UVA (320–400 nm), UVB (290–320 nm), and UVC (200–290 nm). Each band of UV radiation, with its specific wavelength and energy, has unique effects on materials. UVC, despite the fact that it possesses the highest energy, is effectively filtered by the ozone layer. Solar UVB and UVA levels reaching the Earth's surface are influenced by latitude, altitude, season, time of day, cloud cover, and the ozone layer. UVA can pass through window glass (Korać & Khambholja, 2011).
When UV radiation acts on the surface of a polymer, it can cause the formation of reactive species such as free radicals, peroxides, and ozone, leading to the degradation of the polymer. The mechanism of the formation of these reactive species can be divided into several steps. Polymer molecules on the surface absorb energy from the UV radiation. Absorption occurs in a single step, where a photon's energy is either fully absorbed or rejected, depending on the specific wavelength. When UV radiation is absorbed by a molecule, electrons in molecule enter an excited state, and if the absorbed energy exceeds the bond energy, it can cause degradation. This principle highlights that molecular changes only occur if enough energy is absorbed to break chemical bonds (Wypych, 2020).
Depending on the wavelength of the UV radiation and the structure of the polymer, certain bonds within the polymer matrix may become excited. The absorbed energy causes the molecule to transition from the ground state to an excited state. In this state, chemical bonds, especially covalent bonds in the main chain or side groups of the polymer, become destabilized. High-energy radiation can cause the breaking of chemical bonds within the polymer, creating free radicals. These radicals are highly reactive because they have unpaired electrons and seek to react with other molecules to achieve stability. After photolysis, free radicals can react with oxygen from the air and form peroxides or superoxide anions. Oxygen can react with free radicals to create ozone or hydroxyl radicals, which are very aggressive oxidants. These reactive species can further destabilize polymer chains, leading to further degradation. Once free radicals are formed, they can initiate chain reactions in which free radicals are continuously generated. This oxidative degradation results in changes to the physical and chemical properties of the polymer, such as reduced elasticity, discoloration, or the appearance of microcracks.

2.1. UV stabilization

Recent attention has focused on polymer photostabilization to effectively inhibit photochemical degradation. Additives are incorporated to enhance polymers' performance, as well as their mechanical and thermal properties. These additives function as stabilizers, fillers, plasticizers, lubricants, colorants, flame retardants, blowing agents, crosslinkers, and UV absorbers (El-Hiti et al., 2022). UV stabilizers, in particular, help slow the rate of polymer photooxidation.
UV absorbers act as protective additives that prevent polymer damage caused by ultraviolet (UV) radiation. They function by absorbing the energy of UV radiation and converting it into less harmful thermal energy, thus preventing UV radiation from causing chemical changes in the polymers.
UV absorbers have the ability to absorb UV radiation within a specific wavelength range (usually between 280 and 400 nm, where UV radiation most significantly damages polymers). These absorbers are designed with chemical groups that can absorb high-energy UV light. After absorption of UV radiation, the absorbers convert that energy into heat, which is then dissipated throughout the material. Since thermal energy is much less harmful to the polymer than UV radiation, this reduces the risk of photooxidative damage. UV absorbers act as polymer stabilizers by preventing the breakdown of polymer bonds that would otherwise be attacked by UV radiation. In this way, they help maintain the mechanical and optical properties of the polymer, thereby extending the material's lifespan.

Chemical compounds that are often used for UV stabilization of polymers include: organic UV absorbers (benzimidazoles, benzoates, benzophenones, benzotriazines, benzotriazoles, benzoxazoles, camphor derivatives, cinnamates, cyanoacrylates, dibenzoylmethanes, epoxidized oils, malonates, oxalanilides, salicylates), carbon black, inorganic screeners (TiO_2, ZnO), fibers, hindered amine light stabilizers (HALS), while the most common additives used recently for research include Schiff bases and organometallic complexes (Wypych, 2020; El-Hiti et al., 2022).
Benzotriazole UV stabilizers (BUVs) are emerging contaminants of concern due to their widespread use in consumer and industrial products (Khare et al., 2023; Zhou et al., 2023). These compounds have been detected in water, soil, and sediments, as well as in biological samples (Zhou et al., 2023). BUVs exhibit persistent organic pollutant-like properties and have been classified as substances of very high concern (Khare et al., 2023). Their bioaccumulation potential and toxicity raise concerns about human and environmental health impacts (Zhou et al., 2023). The widespread occurrence of BUVs in the environment, coupled with limited data on their properties, exposure levels, and effects on organisms, poses challenges for policymakers and regulatory bodies in developing effective management strategies (Khare et al., 2023).
In formation of protective coatings and films, UV absorber do not exist in polymeric material alone, but it is dispersed within the matrix. It is therefore pertinent that there is a competition for incoming radiation between UV absorber and other components of the mixture (Wypych, 2020).

2.2. Reduction of oxidative stress

Antioxidants act as protectors of polymers in the degradation process caused by UV radiation. They interrupt the chain reactions that lead to the formation of reactive species such as free radicals, peroxides, and hydroxyl radicals. There are several key mechanisms through which antioxidants work. Antioxidants can react with free radicals before they manage to damage the polymer chains. In this way, antioxidants neutralize free radicals by donating an electron or a hydrogen atom, thus preventing further degradation. This halts the chain reaction of generating new free radicals. Some antioxidants, such as peroxide decomposers (peroxide stabilizers), can break down hydroperoxides formed by the reaction of free radicals with oxygen. Hydroperoxides are inherently unstable and can further decompose into even more reactive species, but antioxidants deactivate them before that reaction occurs (Chen, Hu & Wang, 2012; Deng et al., 2012). UV radiation can lead to the formation of singlet oxygen, a highly reactive form of oxygen. Antioxidants such as tocopherols or carotenoids can deactivate singlet oxygen, preventing its reaction with polymers. Antioxidants prevent the initial stages of oxidative degradation of polymers by absorbing energy from UV radiation or stabilizing molecules that could become reactive.

3. NATURE AS INSPIRATION

UV (ultraviolet) light also strongly affects all living organisms such as plants, animals, and humans. Plants have withstood varying levels of UV radiation since the beginning of their existence by developing a range of protective mechanisms. These include the production of UV-absorbing compounds. Thus, plants should be the inspiration when designing UV protective films and materials. When exposed to UV radiation, plants accumulate UV-absorbing compounds in their epidermal cells. These compounds, along with antioxidants protect plants by reducing UV transmittance in leaves. Enzymes further prevent oxidative damage. Some plants, adjust their UV protection throughout the day, regulating the amount of UVB they absorb. This dynamic response is crucial for plants' acclimation to varying UV environments (Wypych, 2020).
Antioxidants play a crucial role in photoprotection by neutralizing reactive oxygen species generated from both endogenous and exogenous sources, including ultraviolet radiation (Chen, Hu & Wang, 2012). An antioxidant is a type of molecule or compound that can slow down or prevent oxidative stress or damage to cells caused by oxidizing agents. These compounds work by neutralizing free radicals, typically by donating an electron. Due to the stability of their chemical structure through resonance, antioxidants are able to disrupt the oxidation process. Additionally, certain molecules demonstrate antioxidant properties by influencing transcription factors (Lizárraga-Velázquez et al., 2020). In recent years, the use of natural antioxidants (AOXs) in sunscreens and skincare products has been considered to replenish the skin's natural reserves (Table 1) (Korać & Khambholja, 2011; Chen, Hu & Wang, 2012).

Table 1: Properties and general applications of antioxidants (Catoni, Peters & Martin Schaefer, 2008; Korać & Khambholja, 2011; Chen, Hu & Wang, 2012; Deng et al., 2012)

Antioxidant	Properties	Application
Vitamin C	Powerful antioxidant, supports the immune system, improves iron absorption, involved in collagen synthesis	Dietary supplements, cosmetics (for skin radiance and health), pharmaceuticals, prevention of oxidative stress
Vitamin E	Protects cells from oxidative damage, improves skin health, supports the immune system	Cosmetics (skin care and anti-aging products), dietary supplements, pharmaceuticals, functional foods
Vitamin A	Supports vision, skin health, and immune function, essential for reproductive health	Dietary supplements, cosmetics (anti-aging and regenerative products), pharmaceuticals
Carotenoids	Precursors of vitamin A, antioxidant properties, support eye and skin health	supplements, functional foods, cosmetics (skin and hair protection products)
Polyphenols	Anti-inflammatory and antioxidant properties, reduce the risk of chronic diseases, protect cardiovascular health	Food (teas, wine, fruits), cosmetics, pharmaceuticals, dietary supplements
Anthocyanin	Potent antioxidant, gives red, purple, and blue colours to fruits, has anti-inflammatory and anticancer properties	Food (juices, functional drinks), dietary supplements, cosmetics (for skin brightening, anti-aging)

Polyphenols, a class of antioxidants with over 8,000 identified phenolic structures in plants, are notable for their high potency and low toxicity at reasonable doses. They are among the most abundant and effective natural antioxidants (Brito et al., 2021). According to Brito et. al., the enhancement of the antioxidant properties of polymer films used in food packaging or biomedical applications, antioxidant moieties can be incorporated into the polymer matrix. The strength of interactions between polyphenols and the polymer can influence the release of polyphenols into different media and impact both the antioxidant activity and the physical properties of the materials (Brito et al., 2021).

4. CIRCULARITY AND GREEN CHEMISTRY

Circularity, green chemistry, and the Sustainable Development Goals (SDGs) are key to building a sustainable future, especially when we consider that new sources of materials should increasingly come from discarded materials. Circularity promotes the recycling and reuse of resources, turning waste into valuable raw materials, which reduces the need for extracting new resources. Green chemistry supports this by developing environmentally friendly processes that enable safe and efficient transformation of waste into new products, reducing toxicity, energy use and price. Together, these approaches help achieve SDGs related to responsible production, climate action, and environmental protection. In practice, this means industries should prioritize using waste materials, rather than relying on virgin resources. By applying green chemistry, the conversion of these discarded materials into new, high-quality products becomes more feasible and safer for the environment. In addition, it can be more cost-effective, which should be an incentive for industry to turn to green chemistry and circular economy. This concept reduces landfill waste and pollution and creates a closed-loop system where resources remain in use, aligning with the principles of circularity and sustainability (Ncube et al., 2023). The production of active components from various types of waste, primarily derived from agro-industry, facilitates the utilization of materials that would otherwise be discarded, without addressing ethical considerations related to the use of substances intended for human consumption.

4.1. Waste as a source

Every year, large amounts of agricultural waste, such as peels, pomace, seeds, leaves, resin, and other residues, are generated and often improperly disposed of, leading to serious environmental pollution. However, these residues represent a significant and cost-effective source of antioxidant compounds,

including terpenes, phytosterols, phenolic substances, and peptides, which can have beneficial applications across various industries (Table 2) (Lizárraga-Velázquez et al., 2020).

Table 2: Residues as a source of antioxidant compounds (Yen et al., 2005; Deng et al., 2012; Lizárraga-Velázquez et al., 2020)

Waste type	Active compound
Fruit peels (orange, lemon, apple, banana	vitamin C and polyphenols
Grape seeds and skins	resveratrol
Vegetable peels (carrot, potato, cucumber)	carotenoids and flavonoids
Coffee grounds	polyphenols and other
Olive oil production residues	Polyphenols (hydroxytyrosol and oleuropein)
Cocoa production waste	flavonoids
Nut shells	phenolic compounds
Tomato and pepper skins	lycopene and carotenoids

In recent years, the application of innovative or eco-friendly extraction methods for obtaining antioxidant compounds from agricultural waste has grown significantly. These approaches aim to maximize the value of such waste by producing high-quality extracts, while minimizing environmental impact. They also prioritize safety, reduce energy use and solvent consumption, and enhance the efficiency and yield of the final product. This shift towards sustainable extraction technologies helps to better utilize plant by-products and create valuable outcomes (Lizárraga-Velázquez et al., 2020).

5. CONCLUSIONS

Integration of circularity and green chemistry is essential for developing sustainable industrial processes that protect both human health and the environment. By prioritizing the use of waste materials as alternative sources for new products, we reduce the reliance on virgin resources and minimize environmental degradation. This approach, inspired by nature's inherent resilience, aligns with the Sustainable Development Goals and promotes innovative solutions for photodegradation and material protection. Drawing from natural mechanisms, such as plants' ability to adapt to UV exposure, we can design durable, eco-friendly materials that extend product lifecycles while preserving biodiversity and reducing pollution. Combining scientific innovation with traditional knowledge allows us to create safer, more sustainable products for future generations. The future research should examine the potential of using natural UV stabilizers ad antioxidants in formation of durable polymer materials.

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PACKAGING AS A PART OF ENERGY EFFICIENCY STRATEGIES IN FOOD COLD SUPPLY CHAINS

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Abstract: *Cold supply chains are an important part where perishable food can be transported and kept fresh until it reaches the desired destination. The lack of these systems which provide the necessary temperatures can lead to large food loss, which has multiple consequences from hunger to increased environmental impacts in the form of waste of invested greenhouse gases during production. The strategies of keeping the food under a certain temperature can be achieved by active, passive and hybrid systems combining electrical components (coolers and freezers) and packaging materials in the form of insulating materials. The energy consumption of the cooling devices is running in many cases on fossil fuel sources and requires energy efficiency to achieve decarbonization efforts. On the other hand, certain passive packaging systems are made from materials which are not yet fully recyclable on the scale throughout the EU. In the paper, an overview of potential energy efficiency strategies combining hybrid systems (electric and packaging) are presented with possible savings in energy and carbon footprint values.*

Key words: cold supply chain, insulating packaging, energy efficiency, carbon footprint

1. INTRODUCTION

Food loss is a significant global issue, with nearly one-third of all food produced annually being lost or wasted. This not only represents a loss of valuable resources such as water, energy, and labour but also contributes to environmental problems like methane emissions from decomposing food in landfills (U.S. Food and Drug Administration, 2024). Food is both an essential aspect of life and a considerable source of greenhouse gas (GHG) emissions. The agriculture sector is responsible for nearly half of methane (CH_4) emissions, two-thirds of nitrous oxide (N_2O) emissions and 3% of carbon dioxide (CO_2) emissions from human activities worldwide (Ivanovich et al., 2024). Packaging plays a crucial role in mitigating food loss. Proper packaging can protect food from mechanical damage during transportation and storage, preserve its quality under various environmental conditions, and extend its shelf life. For instance, adequate packaging can shield food from extreme temperatures, humidity, and contamination, ensuring that more food reaches consumers in good condition (Beltrami, 2019). By optimizing packaging, we can significantly reduce the amount of food lost along the supply chain, particularly in developing countries where losses are more prevalent before food reaches consumers. If we investigate the food types which contribute to GHG emissions (Figure 1), a large portion of them need to be cooled or chilled during the postharvest and transportation stage (Center for Sustainable Systems, 2024).

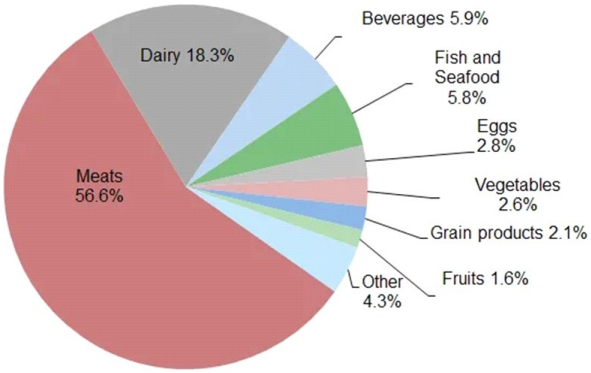


Figure 1: Greenhouse Gases Contribution by Food Type in Average Diet

The average temperature of the Earth is rising and the last year was the warmest one (if we compare the global average surface temperature) in several decades according to the NOAA (Figure 2).

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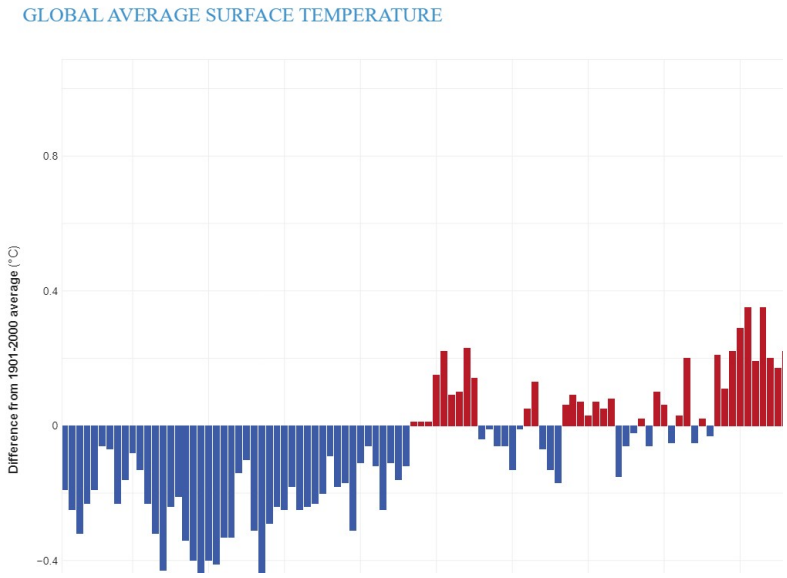


Figure 2: Average global surface temperature

According to the 2023 Global Climate Report from NOAA National Centers for Environmental Information (National Centers for Environmental Information, 2023), every month of 2023 ranked among the 7 warmest for that month, and the months in the second half of the year (June-December) were each their hottest on record. In July, August, and September, global temperatures were more than 1.0°C (1.8°F) above the long-term average—the first time in NOAA's record any month has breached that threshold. Although the warming has not been uniform across the planet, the upward trend in the globally averaged temperature shows that more areas are warming than cooling. According to NOAA's 2023 Annual Climate Report, the combined land and ocean temperature has increased at an average rate of 0.11° Fahrenheit (0.06° Celsius) per decade since 1850, or about 2° F in total. The rate of warming since 1982 is more than three times as fast: 0.36° F (0.20° C) per decade. So, there is data on the rising temperatures on the surface which will increase the food loss due to this temperature rise. Hotter countries appear to have more food waste per capita in households, - increased consumption of fresh foods with substantial inedible parts and lack of robust cold chain. Higher seasonal temperatures, extreme heat events, and droughts make it more challenging to store, process, transport, and sell food safely, often leading to a significant volume of food being wasted or lost. From the GHG point of view, food loss and waste generate 8-10 per cent of global greenhouse gas (GHG) emissions – almost five times the total emissions from the aviation sector (UNEP 2024 Food Waste Index Report).

To mitigate this food loss during the postharvest period and transportation cold supply chains are used. On the other hand, the food cold chain is responsible for about 4% of global greenhouse gas emissions1. This includes emissions from refrigeration technologies and the energy used to power them. In 2017, emissions from food loss and waste due to inadequate refrigeration were estimated at around 1 gigatons of CO_2 equivalent, roughly 2% of total global emissions (United Nations, 2022). Cold chains require a significant amount of energy to maintain low temperatures throughout the supply chain. This energy consumption often relies on fossil fuels, further contributing to carbon emissions (The Food and Agriculture Organization, 2022). Another challenging issue is the refrigerants. Many active refrigeration systems use hydrofluorocarbons (HFCs), which are potent greenhouse gases. Efforts are being made to phase out HFCs in favour of more environmentally friendly alternatives (UN Enviroment Programme & The Food and Agriculture Organization, 2022) To mitigate these impacts, there is a push towards developing sustainable cold chain technologies. This includes improving energy efficiency, adopting renewable energy sources, and using low-global-warming-potential refrigerants1. There are some researches regarding multi-dimensional optimization (Arabsheybani, Arshadi Khamseh & Pishvaee, 2024) but they overlook the environmental components in more depth but focus on food safety and profitability. Some work has been done on the Life Cycle Analysis (LCA) of cold food chains by (Meng et al., 2023) where their study conducted a comparative environmental impacts analysis of two food cold chain packaging systems using LCA, for ice cream transportation. The reusable vacuum insulated panel (VIP) box packaging system demonstrates superior environmental performance when compared to the disposable expanded polystyrene (EPS) box

packaging system across all evaluated impact categories. The result of the study suggests that conclusions regarding lower environmental impact cannot be exclusively based on the choice of insulation material. The weight of the packaging and the transportation distance also exert a significant influence on the overall environmental performance of the systems in terms of environmental impact calculation.
While these efforts are partially mitigated through technology design in the cooling industry, overall standardization and mitigation are just in their beginnings. For example, a standardized way of defining cold food supply chains has just a recent standard in the form of the: ISO 23412:2020 Indirect temperature-controlled refrigerated delivery services – Land transport of parcels with intermediate transfer. This basic standard mainly defines the basic terminology and splits the food types into two large groups (chilled and frozen) – positive and negative service transport temperature delivery. The positive systems maintain temperatures between 0°C and 15°C and are used for products that need to be kept cool but not frozen, such as fresh fruits, vegetables, dairy products, and certain beverages. Refrigerated trucks, cold storage rooms, and refrigerated display cases in supermarkets are typical system components. The negative temperature delivery systems maintain temperatures below 0°C. They are essential for products that have to be kept frozen to prevent spoilage, such as ice cream, frozen meats, and seafood. Typical parts in the cold supply chains are freezer trucks, deep-freeze storage facilities, and frozen food sections in supermarkets. The typical temperatures needed for different kinds of food transports (mixed loads) are presented in Table 1 (Australian Food and Grocery Council, 2017).

Table 1: Recommended thermostat setting used for mixed loads

Thermostat setting	Frozen food -18^{0}C or less	Chilled food 0 ^{0}C to + 4^{0}C	Fresh food +5^{0}C to + 7^{0}C	Confectionery App. +15^{0}C	Ambient goods +15^{0}C to 30^{0}C
+15^{0}C (all runs)				x	x
+5^{0}C (all runs)			x	x	x
+2^{0}C (run> 2hr) +4^{0}C (metro run)		X	x	x	x
+4^{0}C (all runs)		X	x		
-22^{0}C (all runs)	X	X			x

These values follow the main principle of the "never the warmer rule": All products must be kept at temperatures never warmer than the manufacturer or producer's recommended maximum temperature. In most cases, chilled foods need to be kept at a temperature between 0°C and +4°C to ensure the product temperature is never warmer than +5°C, For frozen foods and ice creams in most cases, the temperature must never be warmer than -18°C (Australian Food and Grocery Council, 2017).

2. PACKAGING IN THE FOOD COLD SUPPLY CHAINS

Cold supply chain packaging materials are crucial for maintaining the integrity of temperature-sensitive products during transport and storage. They can be categorized as passive components as they do not use any active coolants like electric drive ones or ice packs with different phase change materials. The typical materials due to their lightweight structure and good thermal insulation properties are expanded polystyrene (EPS), and polyurethane (PUR) which on the other hand do not have a very high recycling ratio. There have been some recent efforts to use corrugated boards (Thermoboxes from Smurfit Kappa), different kinds of cellulosic foams (Liao et al., 2022) and even wool (WoolCool, 2024). All these materials are, also sometimes used as single-use products during the storage and transport of food their carbon footprints need to be considered for decarbonization efforts.
The calculation of heat transfer into an insulated container can be expressed as (Equation 1) (Russell & Crespo, 2004):

$$Q = n\,x\,L = A\,(T0 - Tb)/R \quad (1)$$

Where: n = rate at which the coolant melts (e.g. lb/hr)
L = latent heat of coolant (e.g. Dry Ice = 246 BTU/lb)
A = area of container walls
T0 = coolant temperature
Tb = temperature outside the container
R = resistance to heat flow (R-value)

The type of material is normally selected in cold chain design based on cost and thermal performance. Thermal performance is typically referred to as "R-value." The term R-value is predominantly used in the building industry to rate the insulative properties of construction materials and building. The SI unit for the R-value is K·m²/W. The R-value describes thermal insulating products including heat being transferred by all three mechanisms -- conduction, radiation, and convection. R-value should also not be confused with the intrinsic property of thermal resistivity and its inverse, thermal conductivity. The SI unit of thermal resistivity is K·m/W. Thermal conductivity assumes that the heat transfer of the material is linearly related to its thickness. All values presented in Table 2 are approximations, based on the average of the values (Russell & Crespo, 2004). We have also included the eCO_2 values per packaging material for 1kg.

Table 2: Insulation packaging material R values (per cm thickness) and eCO_2 values per 1kg

Material	R-Value (per cm)	eCO_2 (kg CO2e per kg)
Expanded Polystyrene (EPS)	1.42 - 1.65	3.5 - 4.0
Polyurethane Foam	2.36 - 2.56	2.5 - 3.0
Extruded Polystyrene (XPS)	1.97 - 2.17	4.0 - 4.5
Vacuum Insulated Panels (VIP)	9.84 - 11.81	8.0 - 10.0
Fiberglass	1.14 - 1.50	1.0 - 1.5
Cellulose Foam	1.38 - 1.57	1.5 - 2.0
Corrugated Board	0.39 - 0.47	0.5 - 0.7
Wool	1.38 - 1.57	0.2 - 0.5

From Table 2 we can see that the EPS and PU as well as XPS foams have a good R-value but due to the density of materials like corrugated board can be lighter and equalize the initial eCO_2 values which are achieved in the production phase of the basic packaging materials. In determining the right choice both values need to be considered of course with the no more than the temperature rule.

3. CASE STUDY

So, considering many different aspects involved in the cold supply chain and cooling of food a proposal for new ways of energy efficiency can be established by covering the missing link between the active cooling system driving and the passive packaging in the refrigeration units for example in the supermarkets. According to the International Institute of Refrigeration, 7.8 per cent of GHG emissions can be attributed to the heating, ventilation, air-conditioning and refrigeration (HVACR) sector (IIF-IIR, 2017). While direct emissions from refrigerants account for around 35 per cent of emissions from cooling systems, the remaining 65 per cent are caused by indirect emissions from electricity consumption. The proportion of indirect and direct emissions varies according to leakage rates, the Global Warming Potential (GWP) of refrigerants and electricity grid emission factors. Supermarkets consume approximately 3-4 per cent of the annual electricity production in industrialized countries and usually have one of the highest specific energy consumptions of commercial buildings (energy consumption per sales or total area) (Funder-Kristensen, 2024). Refrigeration systems consume 30-60 % of this total (depending on the climate, social habits and other factors) (EU, 2024). So by using the interactions of both systems (passive and active) and intelligent monitoring of the active cooling system and food monitoring (intelligent) packaging the energy consumption and thus electricity consumption can be reduced. If renewable energy were to be used this decarbonization would have a greater effect on savings and with the right food amount can decrease both losses in food and other natural resources (Figure 3).

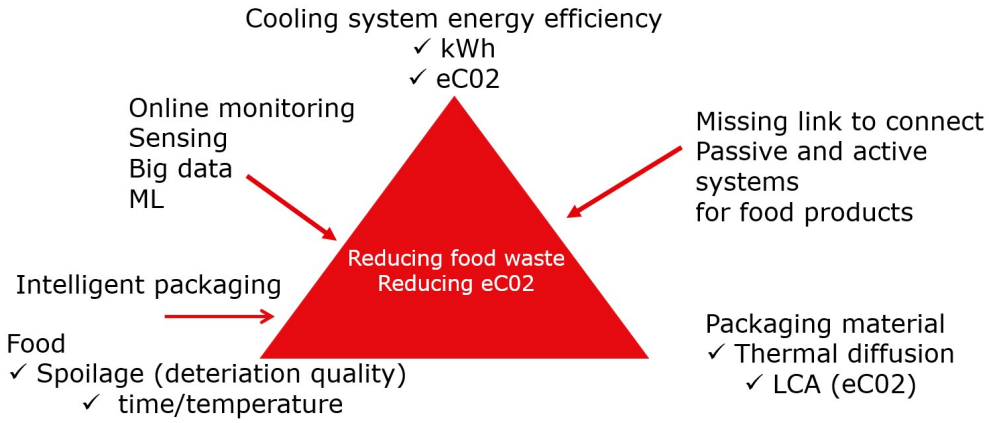


Figure 3: Proposed framework for passive and active cooling calculation

If we investigate the data (Evans, Scarcelli & Swain (2007) (which is not easily accessible to the wider public) to which extent the energy efficiency varies (Figure 4). It is obvsious there are lot of saving potential not just by upgrading to newer better cooling systems, but also more intelligently using the passive systems without compromising food safety.

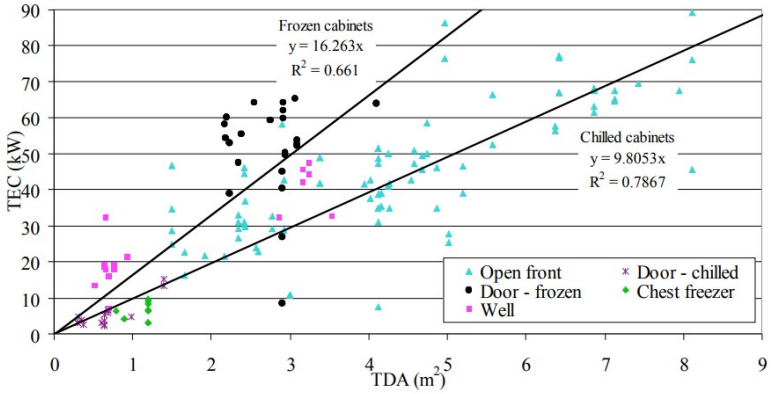


Figure 4: Relationship between total display area (TDA) and the total energy consumed (TEC) for all chilled and frozen cabinets (Evans, Scarcelli and Swain, 2007)

If we presume a display area of 2 m^2 for a chilled cabinet with a higher TCE of around 3000 kWh/year, what energy could be saved by intelligently switching off the electricity on certain time frames and using passive packaging systems? If we set the typical time limits without cooling could be 24 hours in appropriate insulated packaging of the right thickness. The food would be displayed in a appropriate insulated container, where the staff would cover it at the end of the last shift before the store closes down.
The average normal consumption would be 3000 kWh/year (24/7 running loop) in a non-leap year we have 24x365=8760 hours. Sunday (as a typical non-working day in some EU countries) is for non-leap year 52 and that would bring 1248 hours when the chiller is off. This would bring the reduction of electricity from 3000kW to around 2573, or 427 kWh per year would be saved, which would mean around 14% of energy or 17 days of working chiller. For example, the newer generation of home refrigerators consumes 300-800 kWh per year, so if we would use 2 chillers, we could save 1 home refrigerator per year. These time limits can vary based on factors such as the initial temperature of the food, the external temperature, and the specific design of the packaging. If we turn it off for 4-6 hours for chilled food (at a safe temperature without chilling at room temperature), then approximately 4,45 days of chiller working could be spared with 106,82 kWh. As the average eCO_2 per 1kWh in the EU (different energy source mixes can change this a lot) is 275g eCO_2 we can assume for every Sunday shut we could decarbonize by 117,43kg eCO_2 and by the 6-hour shut-off regime it would be 29,38 kg eCO_2 saved in decarbonization efforts. For this of course we could subtract the eCO_2 of the packaging (1kg of EPS -4 kg of eCO_2) so the overall decrease for 24/6 hour shut down every year would be 113,43-25,38 kg eCO_2. In this case, the reuse of the material would be

mainly polymer-based as due to moisture fluctuations during the shutoff and refreezing the cellulose-based materials could have a decrease in mechanical properties which could hamper long-term reuse. To ensure any potential hazard to human health cold chain sensors as a part of the intelligent packaging could be applied to these bulk display systems (and reducing a per product application of these sensors).

4. CONCLUSION

Cold supply chains are an important part of providing basic human needs, by providing bacteria-free fruits in the regions otherwise prone to potential hazards and food loss to spoilage. The active cold chain systems employ electric energy which is still mainly derived from fossil fuels. The importance of using the right active system and passive systems (regarding $eC0_2$ values – production, use and end-of-life stages) with possible intelligent systems which can actively monitor the temperature so some kW/h can be spared, which can further help the overall decarbonization efforts and lowering the outside temperatures which are again interconnected with the cooling systems. The importance of right supply chain decisions, with the right tracking technology and the use of artificial intelligence and machine learning algorithms can provide energy savings needed for a more sustainable future. This applies to all food chain steps from transportation to storage and display. Small behavioural changes with the right technology can have a larger impact on the food packaging (and food waste) than focusing on just single changing of materials to a more sustainable one.

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STUDY OF EFFECT OF SILVER NANOPARTICLES SYNTHESIZED USING EXTRACT FROM SIDERITIS SCARDICA, INCORPORATED INTO WATER-BASED AND UV COATINGS

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Abstract: *In this work, we present an efficient and rapid green method for silver nanoparticles synthesis by using extract from Sideritis Scardica and direct sunlight irradiation. The synthesized nanoparticles were characterized by UV-Vis spectroscopy and Transmission Electron Microscopy (TEM). Then, the as obtained silver nanoparticles were mixed with water-based varnish, which is widely used for paperboard packaging in the food industry, pharmaceutical industry and others. Evaluation of the results of a microbiological study showed that water-based varnish with incorporated silver nanoparticles exhibited antibacterial activity against Escherichia coli K12 NBIMCC 407 bacteria and Bacillus subtilis NBIMCC 3562 bacteria. From the results obtained it is clear that these water-based and UV coatings with incorporated silver nanoparticles could find industrial applications in medicine and food industry as packaging with antibacterial properties.*

Key words: coatings, antibacterial coatings, packaging, silver nanoparticles, green synthesis, antibacterial activity

1. INTRODUCTION

Silver nanoparticles are increasingly used across various fields due to their unique physical and chemical properties. Because of these specific properties, they find applications in a number of areas, including catalysts, in electronics, optics, and especially in medicine as a bactericidal and therapeutic agent (Zhang et al., 2016). They also exhibit strong antimicrobial properties, which are believed to be due to the action of the Ag^+ ions released by these particles (Yin, 2020). The biological, also known as 'green,' synthesis of nanoparticles is attracting great attention as a reliable, sustainable, and environmentally friendly approach for synthesizing a wide range of nanomaterials, including metal and metal oxide nanomaterials, hybrid, and biomaterials. In this method, biomolecules replace traditional stabilizers and reducing agents. In biological techniques, silver nanoparticles are typically obtained using various plant raw materials, molds, or bacteria (Alaqad et al., 2016; Sharma et al., 2009). Different plants contain varying amounts of phytochemicals. The main phytochemicals present in plants are flavones, terpenoids, sugars, ketones, aldehydes, carboxylic acids, and amides, which are responsible for the reduction of silver ions (Prathna et al., 2010). The synthesis of metallic nanoparticles using plant extracts generally occurs in three stages. The first one involves the reduction of metal ions to metal atoms. During the second stage, coalescence of small adjacent nanoparticles into larger particles takes place, and during the third stage, the growth process is halted while the final shape of the nanoparticles is imparted (Dikshit et al., 2021). The size and shape of the silver nanoparticles synthesized using plant extracts vary depending on the concentration of the plant extract, reaction time, temperature, pH, and the ratio of the metal ions to the reducing agents available in the extracts (Jose et al., 2014). Extracts obtained from Sideritis scardica are rich in flavonoids and phenols—substances with numerous pharmacological effects, such as antioxidant, anticancer, and antiviral properties (Ververis, 2023). The active components (flavonoids, terpenoids, phenols) present in S. Scardica play an important role due to their anti-inflammatory, antioxidant, and antimicrobial properties. The application of coatings to printed and packaging production is used to improve various properties such as: optical properties, physical and mechanical properties, barrier and antibacterial properties (Bozhkova et al., 2017; Bozhkova et al., 2015). In the present study, the two types of coatings were chosen. Both two types of coatings are built up to be applied in-line in printing presses using anilox cylinders with different transfer, depending on the specific conditions, used materials and quality requirements. The aim of the

ORCID numbers are provided at the end of the paper.

present experiment is to improve the antibacterial properties of the coatings, along with the optical and barrier ones.

2. METHODS

2.1 Silver Nanoparticles Synthesis

To prepare the extracts from *Sideritis scardica*, 5 grams of the dried herb were combined with 100 mL of distilled water. The mixture was stirred using a magnetic stirrer with heating, set at 500 rpm. Once the solution reached temperature around 80°C, stirring was continued for an additional 10 minutes. Afterward, the extracts were cooled to room temperature and filtered using a vacuum filtration system. An accurate concentration of silver nitrate was prepared by dissolving $AgNO_3$ (> 99.8 %, Sigma-Aldrich) in distilled water under vigorous magnetic stirring (Boeco MMS-3000, Germany) at room temperature. Preliminary experiments indicated that the most reliable results were achieved with $AgNO_3$ concentrations of 5 and 7 mmol/L. To the aqueous $AgNO_3$ solution, 60 µL of the prepared plant extract was added dropwise under vigorous stirring. The resulting mixtures were then exposed to direct sunlight, with continuous stirring, for 10 minutes. The synthetized silver nanoparticles were analyzed by UV-Vis spectrophotometer (T60, PG Instruments Ltd., U.K.). The samples morphology was observed by Transition Electron Microscopy (TEM) on a JEOL JEM 2100, 80-200 kV (Jeol Ltd. Japan).

2.2 Mixing Silver Nanoparticles with two types of coatings

In this study, two types of coatings were utilized: water-based (Actega Terrawet G9 Food Safe) and UV-curable (Actega Terragloss). Silver nanoparticles, synthesized using a 7 mmol/L $AgNO_3$ solution, were incorporated into each varnish at two volume percentages: 20% and 30%. The total volume of each mixture was 50 mL. After adding the nanoparticles, the dispersions were thoroughly homogenized by stirring.

2.3 Antibacterial experiments

Liquid and solid (agar) medium, Luria Bertani (LB) for E. coli K12 and Nutriant Broth (NB) for B. subtilis 3562, both from HiMedia Laboratories were prepared for the bacteria. The strains were obtained from the Bulgarian National Bank of Industrial Microorganisms and Cell Culture. The cultures were incubated in Shaker ES-20/60. Sterile filter paper discs (6 mm in diameter) by HiMedia Laboratories were used for the antibacterial experiments. The antibacterial activity of the two types of Varnish was evaluated against facultative anaerobic Gram-negative E. coli K12 and aerobic Gram-positive B. subtilis 3562 by using the agar disk diffusion test. The cultures were grown, sub-cultured and maintained in LB and NB solid medium and stored in the fridge at 4°C. For the experiments a single colony of each organism was inoculated into 50 ml LB and NB broth and incubated overnight (24 h) at 37°C and 30°C for E. coli K12 and B. subtilis 3562 respectively with shaking at 220 rpm. A 100 µl of bacterial suspensions with concentration of 0.5 McFarland (comparable to a bacterial suspension of 1.5 x 108 CFU/ml) were seeded on agar plates with solid medium-LB or NB respectively by the pour plate technique. Sterile paper discs were impregnated with 5 µl of the varnish samples, and placed on the surface of the agar plate. A disc with the equal amount of distilled water was used as a control. The presence of a clear zone (restricted bacterial growth) is an indication of antibacterial activity for the obtained materials. Inhibition zones were measured edge to edge across the zone of inhibition over the center of the disk according to the Kirby-Bauer Disk Diffusion Susceptibility Test Protocol after incubation overnight at the appropriate temperature for each strain (Hudzicki, 2009). Mean values of the inhibition zones were determined by performing the experiments in triplicate.

3. RESULTS

3.1 Silver nanoparticles

When exposed to sunlight, the initially colorless aqueous solutions of silver nitrate and 60 µL of plant extract undergo a visible color change to yellow or yellow-brown within approximately 10 minutes. Figure 1 shows the UV-Vis absorption spectra obtained during the characterization of the solutions synthesized using *Sideritis scardica* extract after 10 minutes of direct sunlight exposure. The observed peaks, with maxima around 448 nm, correspond to the characteristic surface plasmon resonance of spherical silver nanoparticles.

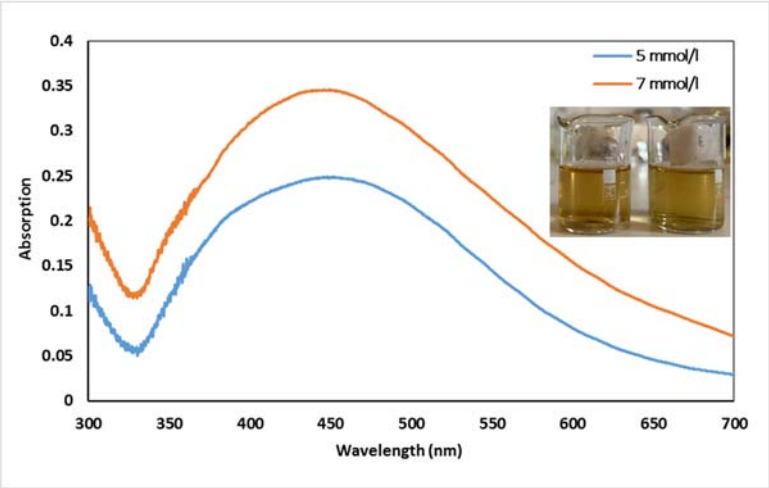


Figure 1: UV-Vis spectra of silver nanoparticles synthesized with 5 mmol/l and 7 mmol/l aqueous solution of silver nitrate and extract from Sideritis scardica *for 10 minutes under direct sunlight*

In Figure 2, TEM images at different magnifications revealed spherical particles ranging from 10 nm to 100 nm. The electron diffraction patterns showed concentric rings, confirming the crystalline structure of the nanoparticles.

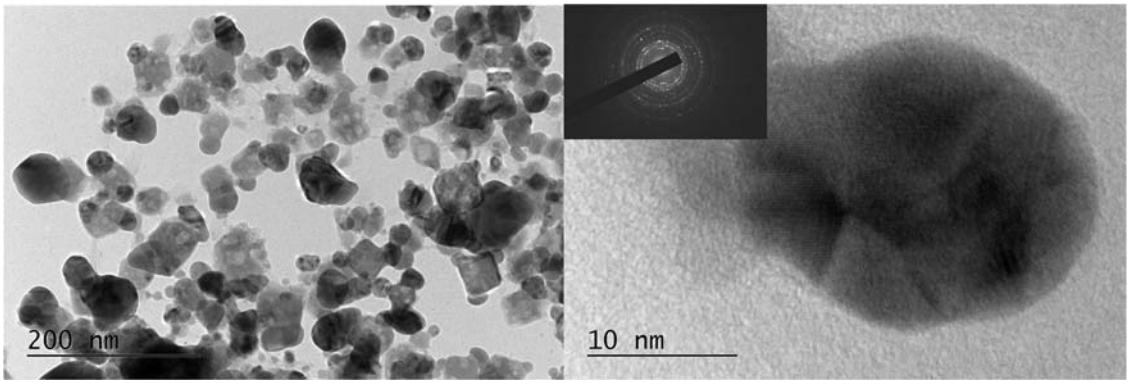


Figure 2: TEM images and the corresponding electron diffraction patterns of silver nanoparticles obtained with Sideritis scardica extract

3.2 Antibacterial activity

In Table 1 are presented the results from the agar disk diffusion test. Coating 1 (water-based varnish) and Coating 2 (UV varnish) were tested at two volume concentrations of the antibacterial agent: 20 vol% and 30 vol%. The inhibition zones are measured in mm.

Table 1: Antibacterial test results of Varnish 1 and 2 samples against B. subtilis 3562 and E. coli K12

Bacterial strain	Coating 1 (water based)		Coating 2 (UV)	
	20 vol%	30 vol%	20 vol%	30 vol%
	Inhibition zone (mm)			
B. subtilis 3562	18.3	18.0	14.5	0
E. coli K12	0	9.5	8.5	9.33

Both samples showed antibacterial activity which was more pronounced against the Gram- positive strain. AgNPs have exhibited significant antibacterial effect against multiple bacteria. However, the exact mechanism of growth inhibition has not yet been fully explained (Bruna T, 2021). Many studies have demonstrated that NPs have greater effectiveness against Gram-positive bacteria than Gram-negative bacteria. This is due to the cell wall of Gram-negative bacteria, which is composed of lipopolysaccharides,

lipoproteins, and phospholipids, which form a penetration barrier that allows the entrance of only macromolecules. In contrast, the cell wall of Gram-positive bacteria includes a thin layer of peptidoglycan as well as teichoic acid and abundant pores that allow foreign molecules to penetrate, resulting in cell membrane damage and cell death (Wang L, 2017). A maximum inhibition zone of 18.3 mm was observed for the Varnish 1 sample (20%). According to our results, the last mentioned is a stronger antibacterial agent than Varnish 2. No inhibition was observed against the *E. coli K12* strain when a smaller amount of the antibacterial agent was added.

4. CONCLUSIONS

Experiments were conducted to explore the "green" synthesis of silver nanoparticles using Sideritis scardica extracts, utilizing direct sunlight and continuous stirring with a magnetic stirrer. This approach is energy-efficient, stable, and straightforward, requiring no advanced technology, and results in the formation of well-defined nanoparticles. Sunlight facilitates a cost-effective and rapid synthesis process, minimizing the risk of particle agglomeration. UV-Vis spectra revealed distinct peaks characteristic of well-formed nanoparticles. Transmission electron microscopy (TEM) analysis confirmed the presence of spherical silver nanoparticles with sizes ranging from 10 nm to 100 nm.

The integration of silver nanoparticles into two types of coatings (water based and UV) was investigated to assess whether the resultant products exhibit antibacterial activity. Microbiological tests were conducted using two bacterial strains. The results demonstrated that both types of varnish exhibited antibacterial activity, with a more pronounced effect against the gram-positive strain. The water-based varnish sample showed a maximum inhibition zone of 18.3 mm.

The results obtained from the conducted experiment shows that the addition of silver nanoparticles obtained by the “green” synthesis to different types of coatings increases their antibacterial activity. Improving the antibacterial properties of coatings is important from a scientific and applied point of view, due to the great possibilities for practical application in the field of packaging of foods, medicines, etc. Refinement of the concentrations of silver nanoparticles, expansion of the types of researched coatings in the field of packaging is pending. A number of experiments will be conducted with applying of variety of quantities and different anilox rollers, on papers and cardboards in order to study their antibacterial properties and practical application of this method.

5. ACKNOWLEDGMENTS

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ADDITION OF ALLANTOIN TO THE WATER DISPERSIVE VARNISH FOR CARDBOARD PACKAGING

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Abstract: *Due to its good properties, paper and paper-based materials are significant substrates in the visual communication industry. With the increased concern about plastic materials usage and their influence on the environment, the use of paper and cardboard increases. Cardboard packaging is often used as secondary packaging, and it carries visual information about the product but must have certain mechanical properties to protect the product. As cardboard deteriorates with age, it must be protected to maintain its basic function. This paper aims to investigate the influence of allantoin in addition to the water-dispersive varnish to protect cardboard during accelerated thermal ageing. For the research, the coatings including allantoin were prepared and applied onto cardboard prints. The prepared prints were characterized by their optical and mechanical properties before and after exposure to accelerated thermal ageing. Results of this research showed that the application of coatings including allantoin do not significantly influence cardboard prints, but at the same time do not provide protection in the accelerated thermal ageing. It could be concluded that including allantoin in the water dispersive varnish will not provide higher protection of prints compared to the one without allantoin.*

Key words: allantoin, water dispersive varnish, cardboard, accelerated thermal ageing

1. INTRODUCTION

Regardless of the grim predictions, the graphic industry is still growing industry. The industry's growth is dominantly due to the packaging industry, which in the period of 2023 – 2028 has predicted annual growth of 4% (Metsa board, n.d.). Even more, due to the environmental concerns and regulations (EU Commission, 2018) about plastics, paper and paper-based materials are more present in the packaging industry. Packaging has different roles including protection of goods during transport and storage. At the same time, packaging plays significant role in marketing as it has strong influence on purchasing decisions (Hurley et al., 2013). There are various methods to make packaging more attractive, consequently more appealing to customers. One of those methods is coating. Coating makes the packaging surface more appealing by making glossy or matte effect, can be spot applied or covering the whole image. Beside visual influence on the printed image on packaging, coating is also used to protect the printed image from mechanical or chemical damages caused by exposure of packaging to light, moisture, rubbing, etc. The coating should not influence the visual message of the packaging design, but studies have confirmed that there is change of the reproduction of colour due to different types of coatings (Cigula, Hudika & Donevski, 2022).
To make functional coatings, which will provide even more positives for the basic material, some additional compounds are mixed into the basic coating. In this case it is important to include compounds which will not influence the health and environmental standards of packaging, or to impact on the recycling and/or biodegradation potential of the packaging after use. For that purpose, using compounds of natural origin is of interest to researchers and producers (Fierascu, Fierascu & Chican, 2021). Having that in mind, the goal of this research is to investigate influence of allantoin onto prints coated with the mixture of commercial water dispersive varnish and various weight ratios of allantoin.
Allantoin is a compound which has origin in plants and animals and is often used in various skincare products (Martin, 2022). This compound has moisturizing effect onto skin and therefore has the potential in keeping moisture in paper and paper-based products. Moisture in paper has significant role in keeping its flexibility (Alava & Niskanen, 2006), enabling cardboard packaging formation and keeping its shape on storeshelf.

2. MATERIALS AND METHODS

For the purpose of this research samples of gloss coated cardboard with grammage of 305 gm^{-2} (UPM Finesse white gloss) were printed on a four-color offset printing press (KBA Rapida 105). Printing inks used

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for printing were standard process offset printing ink Novavit Supreme Bio (Flintgroup). To enable colour change detection, patches with different tone values from 0 – 100% percent with the step of 10% were defined and placed on the test print.
The coatings were prepared by dispersing allantoin particles in a commercial water dispersive varnish (Terra High Gloss Coating G9/285 by Actega). Four coatings were prepared by altering added allantoin amount to achieve weight ratio of 0, 0.25, 0.5 and 1%. The coatings were prepared by mixing water dispersive varnish with allantoin for 15 minutes by magnetic stirrer at room temperature and 1000 rpm at room temperature. Coating of the prepared prints was performed by K control coater, model 202 with the use of coating rod Nr. 3 – defined wet film thickness of 24 µm (RK Printcoat instruments, n.d.). After coating process, samples were left air dry. In the end the samples were exposed to thermal accelerated ageing for 72 hours at 105°C in a Memmert UNB400 oven. Accelerated thermal ageing is often used to simulate paper ageing and detect changes due to degradation (Małachowska, Pawcenis & Dańczak, 2021).
The prepared samples (at the beginning, after coating and after accelerated thermal ageing) were characterized by determining CIE L*a*b* colour coordinates and calculating colour change ΔE_{ab} (Mokrzycki & Tatol, 2011). For the colour measurements spectrophotometer SpectroDens (Techkon) was used. The measuring unit settings were as follows: measuring conditions M1, D50 illuminant, 2° standard observer and without polarization filter activated. Mechanical characterization of samples was performed by measuring bursting strength - Mullen test (measuring unit Lorentzen & Wettre Bursting Strength Tester SE 181) and bending stiffness according to Taber (measuring unit Lorentzen & Wettre bending tester, code 160). All measurements were performed at standard room conditions.

3. RESULTS AND DISCUSSION

Figure 1 shows influence of applied coatings on colour of prepared prints. As a reference for the colour difference (ΔE_{ab}) calculation print before coating process was used.

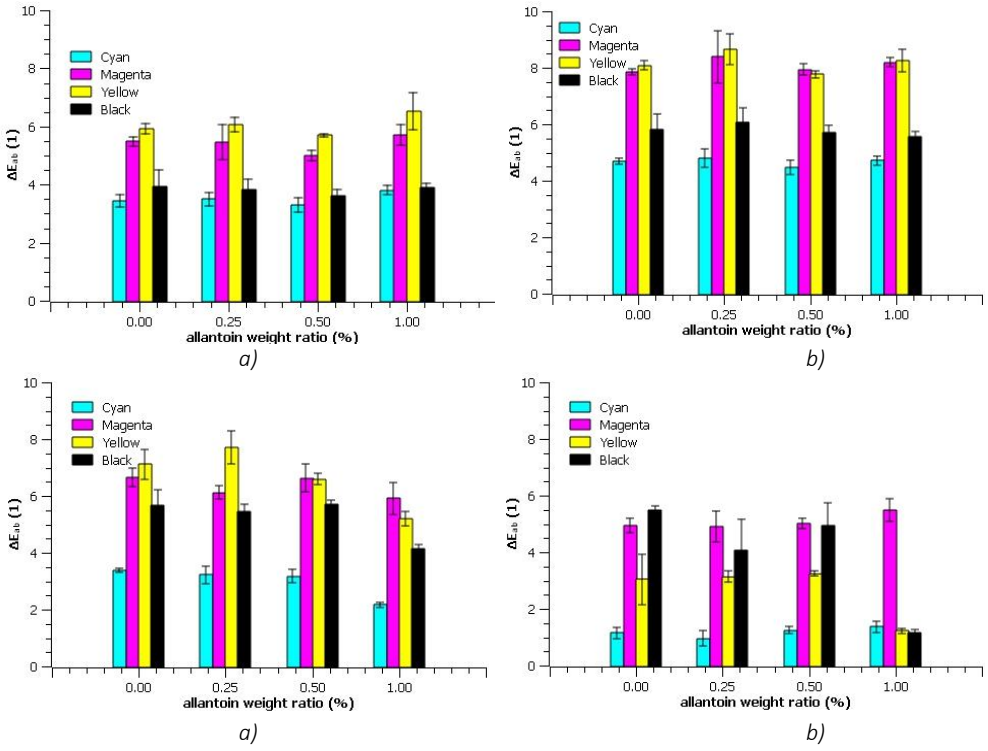


Figure 1: Colour difference on coated samples at: a) low tone value (20%), b) middle tone value (50%), c) high tone value (80%) and d) full tone

It is visible that coating process has the lowest influence on full tone of process colours while the highest colour differences are in the middle tone value (Figure 1). Furthermore, there is no influence of the allantoin weight ratio in prepared coating to the resulting colour difference.

The observed colour difference after coating process was expected as applying coating leads to darker appearance of colour (Cigula, Hudika & Donevski, 2022). Additionally, the middle tone values are the most sensitive for reproduction and often achieve the largest optical differences due to the light interaction on the surface with nearly equal ratio of surface with and without an ink film on the printing substrate. This fact is also noted in the printing standard, where middle tone values are allowed higher tolerances compared to lower and higher tone values (ISO standard, 2013).
As previously mentioned, allantoin is often used in cosmetics due to its moisturizing effect in skin care (Talakoub et al., 2008). It is expected to see a higher influence of prepared coatings on the mechanical properties of the coated cardboard. In Figure 2 and 3 one can see the results of stiffness and burst strength of prepared samples before and after accelerated thermal ageing. Please note that on the x-axe, REF means reference print, i.e. the one which was not coated.
On can see that coating process is leading to small increase of Taber stiffness, which further increases with the increase of the allantoin weight ratio (Figure 2). After the accelerated thermal ageing all samples, including the uncoated one (REF) have increased stiffness with keeping the same trend, i.e. the sample coated with the highest allantoin weight ratio having the highest Taber stiffness.

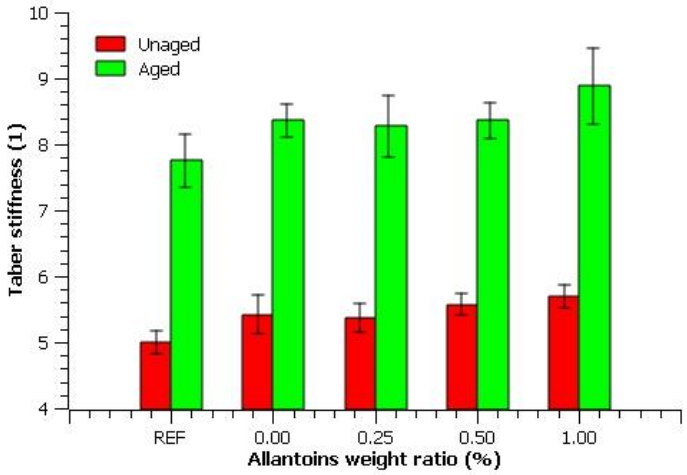


Figure 2: Taber stiffness of samples before and after accelerated thermal ageing

During thermal ageing the paper substrate is losing moisture (Alava & Niskanen, 2006) and therefore becoming more rigid, which can cause problems in packaging of products.

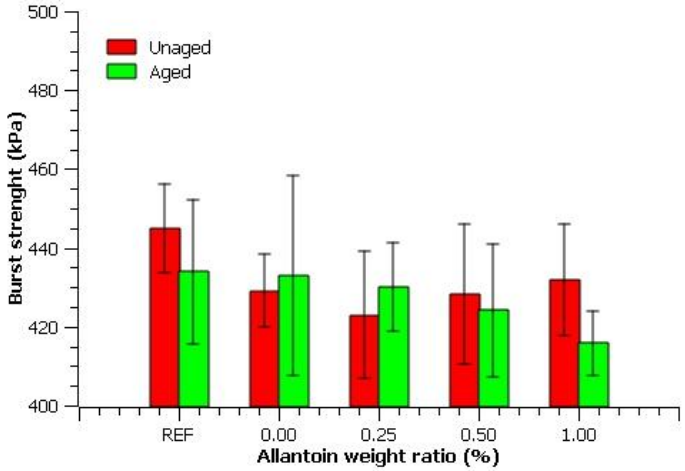


Figure 3: Burst strength of samples before and after accelerated thermal ageing

Bursting strength of samples (Figure 3) decreases with the application of coating on the surface of the print. Nevertheless, the addition of allantoin in the water dispersive varnish does not influence the burst strength. Opposite to the stiffness of the samples, accelerated thermal ageing causes decrease of the burst strength.

Although standard deviations of measurements are relatively high, it could be noted that increase of the allantoin weight ratio will lead to the decrease of the burst strength after accelerated thermal ageing. These results indicate that the coating with allantoin did not improve preservation of moisture in the paper as lower moisture in a paper material will make it more brittle (Lin et al., 2022).
In Figure 4 one can observe colour change of the paper and the process colours due to the accelerated thermal ageing. The highest colour change is on the paper and the lowest in black. The results also showed that applied coatings did not influence colour change on samples.
These results are probably caused by paper yellowing, which is common when exposed to thermal degradation (Aleksić et al., 2023) which is also confirmed by lower colour difference in yellow, while black is opaque and therefore masking the colour change of paper.

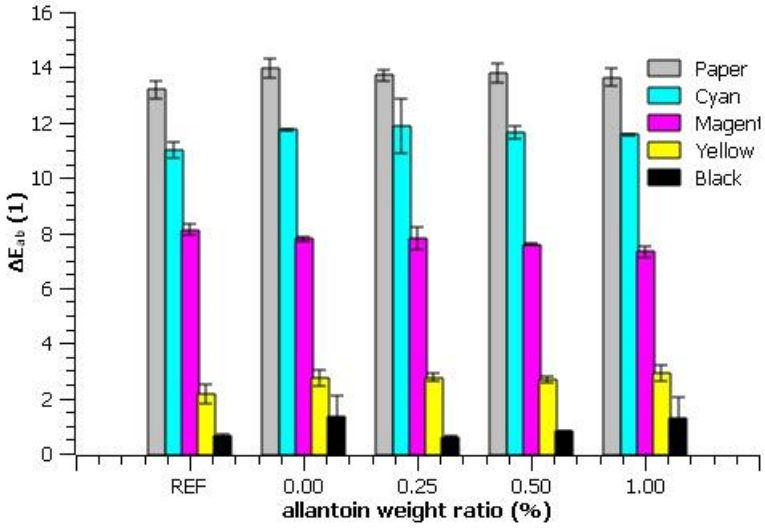


Figure 4: Colour difference of paper and full tone on coated samples after accelerated thermal ageing

The colour change of tone values aligned to the behaviour shown in Figure 4, i.e. the difference was higher in lower tone values (less surface of the paper is covered by printing ink) and lower in higher tone values. Colour difference according to the nominal tone value for black colour is shown in Figure 5. The curves are similar for other colours, although with higher differences.

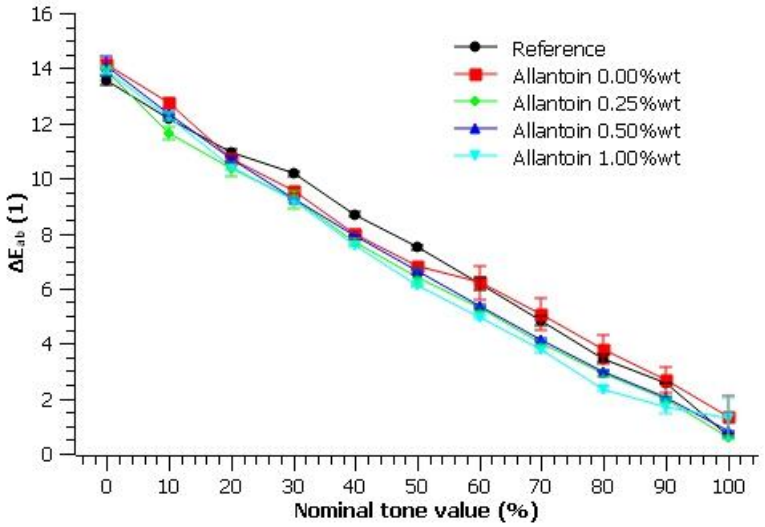


Figure 5: Black colour difference after accelerated thermal ageing depending on nominal tone value

4. CONCLUSIONS

This research was conducted to determine the influence of allantoin addition on the protective properties of water dispersive varnish applied on cardboard prints.
Results of this research showed that the application of coatings including allantoin do not significantly influence cardboard prints, but at the same time do not provide protection in the accelerated thermal ageing.
It could be concluded that including allantoin in the water dispersive varnish and applying it as an overprint varnish on the cardboard print will not provide higher protection of prints compared to the one without allantoin.

5. ACKNOWLEDGMENTS

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IMPROVING PACKAGING ERGONOMICS THROUGH PUFF-ENHANCED SCREEN PRINTS

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Abstract: *Effective ergonomic packaging ensures efficient and intuitive product handling, providing easy access and a secure grip, thereby enhancing user experience. Achieving this involves optimizing packaging size, shape, and material. This study investigates the application of screen printing with puff-enhanced ink to improve packaging ergonomics. Puff-enhanced ink augments surface roughness, thereby enhancing tactile perception and grip security. This research utilized objective measurements and subjective evaluations to assess the impact of tactile properties on manual pulling force. Building on prior work where the mesh count of 120 l/cm was investigated, this study explores prints created using a screen with a mesh count of 63 l/cm. Three substrates were used: bulky paper, paperboard, and matte-coated kunstdruk paper, with the amount of added puff base varied between 0%, 10%, 20%, and 30%. The findings reveal that surfaces with increased roughness not only enhance grip and increase the manual pulling force but also suggest how different substrates and mesh counts impact the ergonomic properties of packaging. This contributes to a better understanding of the optimal conditions for effectively applying the puff base in the packaging industry.*

Key words: packaging, ergonomics, screen printing, puff base

1. INTRODUCTION

Tactile perception and interaction with objects are essential parts of our daily lives, shaping how we engage with the world. The skin on our palms is particularly sensitive, allowing us to feel textures and receive feedback from the things we touch (Striano & Bushnell, 2005). Touch is a primary way we communicate with our environment, helping us handle objects and assess their tactile qualities (Darden & Schwartz, 2015). Haptic perception refers to our ability to recognize the tactile features of different materials. People often use a rich vocabulary to describe how materials feel, which shows the complexity of our interactions (Meyer, 2001; Kawazu et al., 2000). However, Hollins has identified two main aspects of this perception: hardness (from hard to soft) and roughness (from smooth to rough) (Hollins, 1993). Friction between our skin and the surfaces of objects is crucial for safe handling, giving us confidence when we interact with various items (Veijgen, Masen & Van Der Heide, 2012; Veijgen, Van Der Heide & Masen, 2010; Derler & Gerhardt, 2012). However, there is still much to learn about slipperiness and its effects on grip safety (Bergmann Tiest, 2010). While some studies have looked at how the shape and surface of objects affect grip when lifting them (Kinoshita et al., 1997; Jenmalm, Goodwin & Johansson, 1998), they often overlook how materials can be improved and how psychological factors play a role. The challenges in measuring friction between skin and materials highlight the need for more research to understand what makes a grip feel secure (Derler et al., 2009; Bergmann Tiest, 2010). One innovative approach is screen printing with a puff base added to the ink. When the printed material is heated during the drying process, the puff base expands, creating a raised appearance on the surface of the print. This technique not only creates a three-dimensional effect but also enhances the texture of prints, potentially influencing how consumers interact with and perceive the products. By exploring these advancements, we can improve the tactile experiences and enhance the ergonomic properties of products intended for manual use, such as packaging. In the context of handling products, surface roughness plays an important role. Greater roughness can lead to a more secure grip, making it easier to handle and manipulate items effectively.

2. METHODS

The experimental phase of this research aims to test the hypothesis that incorporating a puff base in manual screen printing can enhance the ergonomic features of packaging. This study evaluates how the addition of a puff base in the ink affects comfort and manual pulling forces, with higher detected forces indicating samples with better ergonomic characteristics. The research involved an experiment followed by

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a survey. The experiment assessed the maximum pulling forces required to handle objects with printed samples, based on the premise that tactile properties influence comfort and usability. Fourteen participants (7 males and 7 females, ages 25 to 35) took part in the study. The experiments were conducted in a controlled environment with a temperature of 23±2°C and relative humidity of 50±2%. The methodology was informed by prior research conducted by Seo et al. (2008) and Bošnjaković et al. (2023).

2.1. Test samples

The test samples were created using manual screen printing on a Centropapir carousel machine (model no. S.6S4T.B). All prints were produced in black with water-based Teflex ink, incorporating Teflex's puff base at three different percentages: 0%, 10%, 20%, and 30%. Different percentages of puff base were used to create prints on various paper materials, leading to changes in characteristics like surface roughness. A screen mesh count of 63 l/cm was employed. After printing, the samples were dried at 133°C. The prints were applied to various substrates, including bulky paper (164-180 g/m²), matte-coated kunstdruk paper (257-300 g/m²), and paperboard (250 g/m²). Each print was rectangular (135 x 30 mm) with full coverage. In total, 12 distinct print variations were produced (Table 1). It's worth noting that the tactile characteristics of these exact prints on textile materials were analyzed in a previous study (Bošnjaković et al., 2022).

Table 1: Categorization of test samples

Test sample	Substrate	The added amount of puff base in the ink
vol-63-0	bulky paper (164-180 g/m^2)	0 %
vol-63-10	bulky paper (164-180 g/m^2)	10 %
vol-63-20	bulky paper (164-180 g/m^2)	20 %
vol-63-30	bulky paper (164-180 g/m^2)	30 %
pol-63-0	paperboard (250 g/m^2)	0 %
pol-63-10	paperboard (250 g/m^2)	10 %
pol-63-20	paperboard (250 g/m^2)	20 %
pol-63-30	paperboard (250 g/m^2)	30 %
kun-63-0	matte-coated kunstdruk paper (257-300 g/m^2)	0 %
kun-63-10	matte-coated kunstdruk paper (257-300 g/m^2)	10 %
kun-63-20	matte-coated kunstdruk paper (257-300 g/m^2)	20 %
kun-63-30	matte-coated kunstdruk paper (257-300 g/m^2)	30%

2. 2 Experimental apparatus, survey, and procedure

Participants entered the measurement room individually and received clear instructions. They could adjust their position in front of the experimental apparatus based on their dominant hand (Rowson & Yoxall, 2011; Peebles & Norris, 2003). The experimental setup (Figure 1) featured a Shimadzu Compact Tabletop Testing EZ-LX machine, equipped with a 2.5 kN measuring cell and operating at a speed of 0.1 mm/min. Maximum manual pulling force values were recorded in newtons (N) using TrapeziumX software. To measure the pulling force accurately, a tool coated with the printed samples was used.



Figure 1: Experimental apparatus and participant testing the samples

The tool's height was customized for each participant to ensure optimal comfort. Participants were instructed to grip the tool using their fingertips, with their thumb on one side and the other fingers securing the sample on the opposite side (both sides were coated with the same printed sample). Their task was to pull the coated tool downward with maximum force. The measurement ended as soon as they felt the sample slip through their fingers. After the pulling force measurements, participants completed a survey. everyone had the task of evaluating samples based on two criteria: pleasantness to the touch and ease of manual pulling, which reflects stability and grip security (1 - lowest grade, 10 - highest grade). To provide subjective feedback based on tactile perception, participants gently ran their fingertips over each sample, following established methodologies (Wongsriruksa et al., 2012; Bergmann Tiest, 2010; Srinivasan, Whitehouse & lamotte, 1990; Hollins et al., 2000; Chen & Ge, 2017). This survey facilitated the collection of subjective ratings and allowed participants a brief respite to rest their hands, muscles, and nerves. The same systematic approach was employed for each sample until all variations were evaluated.

3. RESULTS

Figure 2 presents the findings from the subjective tactile evaluations conducted on various test samples. The samples vol-63-20, kun-63-10, and kun-63-30 received the highest ratings for pleasantness to the touch. In terms of ease of manual pulling, the samples printed with vol-63-30, pol-63-30, and kun-63-30, each containing a puff base composition of 30%, achieved the most favorable ratings.

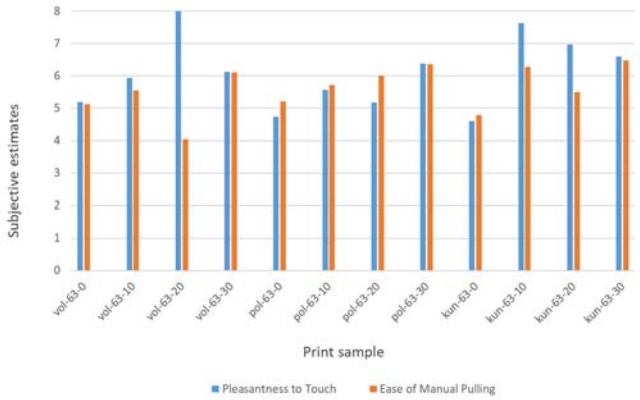


Figure 2: Graphic representation of the results of subjective estimates of printed samples by 14 participants

The mean values of manual pulling forces and standard deviations are given in Table 2. The normal distribution function was utilized to calculate the normal distribution based on the specified mean values of manual pulling forces and standard deviation (Figure 3).

Table 2: Mean values of manual pulling forces and standard deviations

Test sample	N	Mean	SD	Coefficient of variation
vol-63-0	14	68.883	29.073	0.422
vol-63-10	14	79.492	31.691	0.399
vol-63-20	14	72.847	27.983	0.384
vol-63-30	14	81.923	34.531	0.422
pol-63-0	14	62.674	26.213	0.418
pol-63-10	14	69.995	23.652	0.338
pol-63-20	14	72.473	29.599	0.408
pol-63-30	14	77.159	26.499	0.343
kun-63-0	14	67.729	29.154	0.430
kun-63-10	14	79.216	37.871	0.478
kun-63-20	14	75.503	31.361	0.415
kun-63-30	14	87.308	29.338	0.336

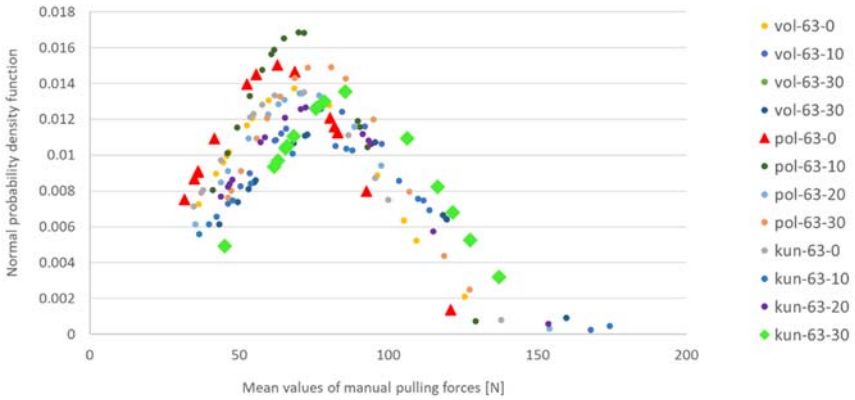


Figure 3: The normal distribution function for every printed sample

Figure 3 illustrates two key curves: one representing the manual pulling forces for the sample that exhibited the highest forces (marked by green rhombus symbols for sample kun-63-30), and the other showing the printed sample with the lowest forces (identified by red triangle symbols for sample pol-63-0). The standard deviations indicate a lack of significant deviations from normality. Notably, the curve for the kun-63-30 sample displays a clear rightward shift in the normal distribution, suggesting advantageous characteristics for manual pulling forces. A one-way repeated measures ANOVA was conducted to assess the effect of the printed sample on forces achieved by manual pulling. Mauchly's test of sphericity, which examines the assumption that the variances of the differences between all possible pairs of within-subject conditions are equal, was evaluated: $x^2(65)=101.220$, $p=.009$. Due to a violation of the sphericity assumption, the Greenhouse-Geisser correction was applied. The main effect of the printed sample was found to be statistically significant, $F(4.861, 63.196)=5.761$, $p<.001$, $\omega^2=0.038$ indicating a significant difference in forces achieved by manually pulling across the levels of printed samples. Post-hoc pairwise comparisons using Holm correction revealed significant differences between specific levels of printed samples. The results indicate that maximum manual pulling forces were significantly higher for samples with an added puff base compared to those without it. Comparing the maximum pulling force results on the same substrate, post hoc tests using Holm's method show a statistically significant difference in pulling forces between the sample pol-63-0 ($p=.027$) and the sample pol-63-30. Additionally, there is a statistically significant difference in pulling forces between the sample kun-63-0 ($p<.001$) and the sample kun-63-30. However, no statistically significant differences in pulling forces were observed between the samples on bulky paper.

4. CONCLUSION

Ergonomic packaging is designed to facilitate efficient, effective, and intuitive handling of products, ensuring a secure grip that enhances the user experience. This study explores the potential of screen printing with an added puff base to improve the grip properties of packaging materials. The puff base increases the roughness of the printed surface, which is essential for achieving a secure grip and effective manipulation. The research methodology involved an experimental setup followed by a survey to assess the maximum manual pulling forces of the printed samples. The results showed that varying combinations of printing parameters led to different subjective evaluations regarding pleasantness to the touch and ease of pulling. Ratings for pleasantness indicated a wide range, suggesting that the type of substrate significantly affects print characteristics. Furthermore, samples with a higher amount of added puff base generally received better ratings for ease of pulling. Differences in recorded pulling forces were also noted between samples containing a puff base and those without it. A comparison of maximum pulling forces on the same substrate revealed significant variations among certain samples, particularly between the pol-63-0 and pol-63-30 samples, as well as between the kun-63-0 and kun-63-30 samples. However, no notable differences were observed among samples printed on bulky paper. These findings imply that specific printing parameters can enhance pulling performance, while the type of paper substrate consistently influences the results. Further research may be warranted to delve deeper into these relationships. Nonetheless, the observed differences in pulling forces likely stem from several factors. The addition of the puff base enhances the roughness and texture of the printed surface, which in turn improves grip and

friction. Additionally, the visual depth and texture created by the puff base may positively affect users' perception of grip, suggesting that incorporating this technique in screen printing could greatly enhance the handling of packaging products.

5. ACKNOWLEDGMENTS

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THE INFLUENCE OF COLOR ON CAPTURING CUSTOMER ATTENTION IN ONLINE PURCHASES OF ORGANIC COSMETICS CASE

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Abstract: *This study examines the effect of colour on users in the context of online sales of organic cosmetics. The primary goal is to identify which colours most effectively capture attention and drive engagement, ultimately influencing purchasing behaviours for organic cosmetic products. Through the use of eye-tracking technology, participants' attention and focus were monitored as they observed products displayed in various colours on screens. Key metrics such as Time to First View and Time Viewed were analyzed to gain a comprehensive understanding of how participants' attention and engagement were impacted by the recommended colour tones, particularly concerning their perception of organic cosmetics. The analysis revealed that lighter tones are detected more rapidly than darker tones, with statistical analysis supporting the finding that lighter colours more effectively attract immediate attention. Additionally, stimuli in lighter tones were viewed for longer periods compared to those in darker tones. This study provides a preliminary exploration of how colour tones influence the attention and engagement of e-commerce users. The findings offer valuable insights into the emotional and cognitive dimensions of consumer engagement, enhancing our understanding of how colour affects purchasing behaviour.*

Key words: Impact of colour, online sales, organic cosmetics

1. INTRODUCTION

Humans are inherently visual beings, perceiving the world through colours and shapes, a process deeply embedded in human nature. Light, as it enters the eyes and reaches the brain, is converted into visual signals that facilitate rapid and intuitive decision-making. In this intricate process, colours play a pivotal role in our interpretation of the surrounding world. As a core element of visual design, colour possesses the power to evoke strong associations and significantly influence both our emotional and cognitive responses. It has the capacity to inspire, calm, or provoke action. The ability of colour to communicate with our inner world and trigger a range of emotional reactions forms a complex network of associations and meanings, thus playing a crucial role in shaping our experiences and perceptions (Demirbilek & Sener, 2003). This communication is further enriched by diverse cultural and social contexts, where the associations and meanings of colours vary globally, influenced by historical, social, and cultural factors. For example, perceptions of colour differ between men and women (Ellis & Ficek, 2001). These differences are also evident across various age groups, with adults and children reacting differently to specific colours (Casas & Chinoperekweyi, 2019). These variations underscore the complexity of colour use in design, while also highlighting its potential to create powerful visual and emotional experiences that are tailored to users and their distinct experiences.

Packaging design, a fundamental aspect of branding, significantly impacts the purchasing process, especially in situations constrained by time. An effective packaging design must be informative, functional, and aesthetically appealing, with colour serving a pivotal role in capturing attention and shaping consumer emotions and decision-making (Reimann et al., 2010). This interplay can be critical in forming a strong initial impression and ultimately influencing the final purchase decision.

In the context of organic cosmetic product packaging, colour is employed not merely to draw attention but also to communicate the product's inherent values and attributes. The choice of colours is meticulously crafted to reflect the product's naturalness, purity, and ecological consciousness. For instance, green and brown hues are commonly associated with natural and organically sourced ingredients, while beige and cream tones evoke a sense of simplicity and sophistication. Colours used in organic product packaging help consumers identify items that align with their ecological values, thereby enhancing the product's visual identity and reinforcing its positioning as a sustainable choice (Mohebbi, 2014).

Packaging colour holds significant importance in the domain of digital promotion, particularly within the context of online stores and their catalogues, which function as primary channels of communication between consumers and products. In an environment where purchasing decisions are increasingly driven by visual impressions, the strategic selection of packaging colour can be instrumental in capturing attention

ORCID numbers are provided at the end of the paper.

and distinguishing a product amidst a sea of alternatives. Since online catalogues often serve as the first point of contact with a product, careful selection of packaging colour is crucial for attracting potential customers. In these reduced-scale product displays, colour stands out as one of the most influential visual elements capable of captivating users' interest and encouraging further exploration (Purwati, 2011). The organization of products within catalogues, combined with thoughtful use of brand-reflective colours, not only enhances the product's visual identity but also increases its likelihood of being noticed and remembered. This approach helps products stand out on crowded digital shelves, capturing consumer attention—a crucial factor for success in a competitive market.

Considering the importance of understanding how participants visually respond to and associate packaging colours with organic cosmetics, particularly in the context of online shopping, this experiment utilized eye-tracker technology for its ability to provide precise insights into real-time visual processes. The key metrics analyzed were Time to First View—indicating how quickly a colour (stimuli) is noticed—and Time Viewed, which measures the duration of attention given to specific stimuli. These metrics reveal where participants focus their attention, how long they engage with particular visual elements, and which colours capture their notice first.

2. METHODS

The study was organized into three main phases, details are described below.

Based on the market research conducted (review of websites of organic cosmetics manufacturers and sellers, around 50, i.e. Herbalia (https://herbalia.rs/)), to assess the recognition of organic cosmetics within a wide product range, colours typically recommended for organic cosmetic products were chosen as reference stimuli (Figure 1), alongside the identification of colours generally endorsed for the cosmetics industry (Figure 2). CieLab and HSB values for the reference stimuli are shown in Table 1, and those for the non-reference stimuli are in Table 2. The minimalistic packaging stimuli, with colour-based design, were created in the next phase, for newly designed organic cosmetic brand named "Avelis" and a hand cream was chosen as the representative product.



Figure 1: Representation of reference stimuli (S1, S2, S3, S4, S5)

*Table 1: Representation of the CIE L*a*b* and HSB coordinate values of the reference stimuli*

stimuli	CIE L*a*b*	HSB
S1	(48.78, 10.95, 21.57)	(26.00°, 45.00%, 57.00%)
S2	(68.34, 10.48, 33.69)	(32.00°, 48.00%, 80.00%)
S3	(86.14, -0.27, 32.39)	(43.00°, 35.00%, 93.00%)
S4	(59.16, 23.54, 54.38)	(31.00°, 79.00%, 79.00%)
S5	(36.20, -16.79, 17.72)	(101.00°, 39.00%, 36.00%)



Figure 2: Representation of non-reference stimuli (S6, S7, S8, …, S19)

The second phase involved creating five reference stimuli and fourteen non-reference stimuli using the previously mentioned recommended colours associated with both organic and general cosmetic products. These stimuli were organized into five groups, each containing a total of fifteen stimuli, with one reference stimuli per group (an example of one stimuli group is shown in Figure 3).

*Table 2: Representation of the CIE L*a*b* and HSB coordinate values of the non-reference stimuli*

Stimuli	CIE L*a*b*	HSB
S6	(81.17, -23.79, 73.22)	(65.14°, 78.42%, 82.84%)
S7	(79.22, 9.47, 78.68)	(43.85°, 90.80, 96.94%)
S8	(44.64, 52.89, 41.57)	(7.12°, 79.90, 75.37%)
S9	(31.84, 48.64, 27.99)	(356.19°, 81.99%, 57.4%)
S10	(72.18, 29.81, 7.59)	(353.67°, 33.03%, 91.49%)
S11	(50.42, 61.39, -17.93)	(322.14°, 66.96%, 79.14%)
S12	(44.98, 21.32, -20.64)	(279.84°, 32.55%, 55.29%)
S13	(29.1, 22.16, -23.68)	(273.54°, 45.66%, 41.34%)
S14	(26.29, 42.37, -14.49)	(318.69°, 75.48%, 43.61%)
S15	(82.48, -13.71, -5.86)	(183.01°, 21.39%, 84.57%)
S16	(70.21, -41.37, 16.65)	(150.12°, 53.18%, 74.69%)
S17	(70.81, -34.26, -12.26)	(181.46°, 72.83%, 76.24%)
S18	(47.22, 5.22, -42.86)	(213.56°, 68.89%, 72.2%)
S19	(25.53, 7.12, -27.47)	(222.24°, 59.68%, 40.05%)



Figure 3: Representation of a group of stimuli

The third phase focused on preparing the stimuli and equipment for the experiment. Initially, each participant was positioned at a specified distance of 65 cm from the EIZO ColorEdge CG241W monitor to allow the Gazepoint GP3 eye-tracker device (positioned in front of the monitor) to detect their eye movements during content observation. The setup of the monitor, eye-tracker, and participant positions is illustrated in Figure 4. Each group of stimuli was displayed for ten seconds, during which gaze tracking recorded the Time to First View and Time Viewed for each participant.
The analysis of data collected from the study were focusing on key metrics obtained through eye-tracking technology. The statistical methods employed included a one-way between-groups analysis of variance.

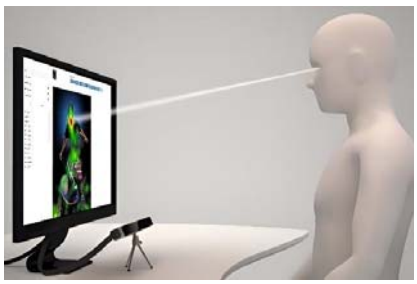


Figure 4: Participant's position relative to the monitor and eye tracker setup

3. RESULTS AND DISCUSSION

3.1. Demographic Profile of Respondents

Within the demographic profile of respondents, there were 180 participants in total, comprising 130 (72%) women and 50 (28%) men (Figure 5).

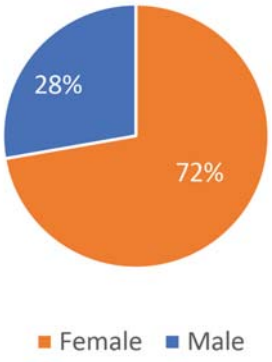


Figure 5: Graphical representation of gender distribution

The largest proportion of respondents, 97%, regardless of gender, falls within the age of 20- 24 years, (Figure 6).

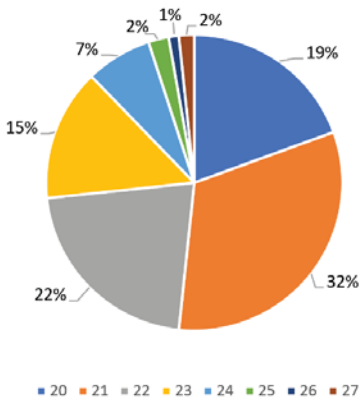


Figure 6: Graphical representation of age distribution

3.2. Analysis of Participant Interaction Metrics

The key metrics analyzed were Time to First View, which measures how quickly a stimuli is noticed, and Time Viewed, indicating the duration of attention given to specific stimuli. According to the Time to First View results, stimuli 3 was detected the fastest among all reference stimuli, followed by stimuli 2 and stimuli 5 (Figure 7). Stimuli 4 performed better than stimuli 1 in terms of detection speed (Figure 7). Regarding Time Viewed, stimuli 2 and 3 held participants' attention for the longest durations, with stimuli 1 following closely (Figure 8). In contrast, stimuli 4 and 5 had the shortest observation times (Figure 8). The analysis of these metrics provides valuable insights into participants' focal points of attention, the duration of their engagement with specific visual elements, and which colours initially captured their notice. These observations reveal a complex relationship between Time to First View and Time Viewed. For example, although stimuli 3 attracted attention the fastest, it did not retain the observer's attention as long as stimuli 2, which took more time to be noticed but held attention for a longer period. Additionally, stimuli 1 and 4 were detected around the midpoint of the total display time (10 seconds) and, although they required slightly more time to be noticed compared to stimuli 5, they exhibited longer viewing durations than stimuli 5.

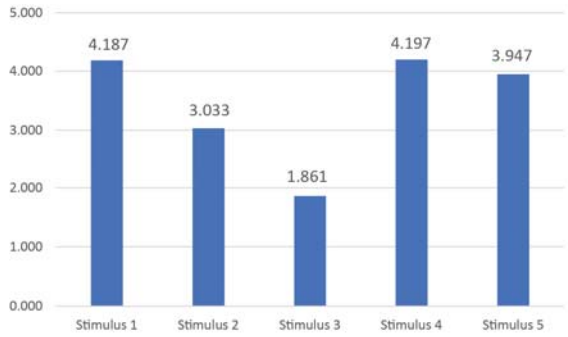


Figure 7: Graphical representation of Time to First View (sec)

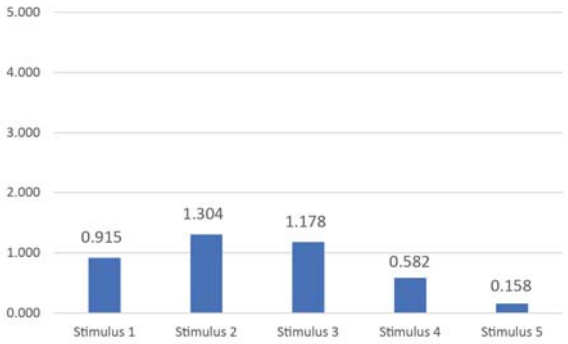


Figure 8: Graphical representation of Time Viewed (sec)

Accordingly, in the correlation graph (Figure 9), it can be observed that the value of the correlation coefficient, indicates a moderate correlation between the time required to detect the stimuli and the time spent observing it. This suggests that while certain stimuli may capture attention quickly, this does not necessarily lead to longer viewing durations. Various factors appear to influence both recognition and engagement levels, highlighting the complexity of the relationship between how quickly a stimuli is noticed and how long it retains attention.

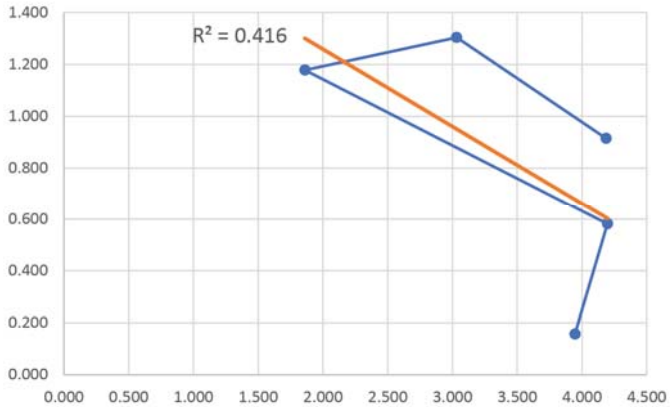


Figure 9: Correlation graph between Time to First View and Time Viewed

Table 3 presents the Time to First View values for non-reference stimuli, organized into two groups based on whether they were noticed before or after the reference stimuli. The results show that the recognition of reference stimuli among the non-reference stimuli largely aligns with the order established among the reference stimuli (Figure 7). Specifically, the reference stimuli with the shortest Time to First View in Figure 7 also exhibited the shortest Time to First View among all non-reference stimuli (Table 3).

Table 3: Comparison of reference and non-reference stimuli based on Time to First View

Reference stimuli	Non-reference stimuli with shorter Time to First View	Non-reference stimuli with longer Time to First View
S1	All Remaining (8/14)	S19 ,17 ,7 ,13 ,6 ,9
S2	S16 ,18	All Remaining (12/14)
S3	-	All (14/14)
S4	All Remaining (8/14)	S11 ,7 ,14 ,8 ,18 ,13
S5	S7 ,16 ,6 ,9 ,17	All Remaining (9/14)

Table 4 presents the Time Viewed values for non-reference stimuli, also organized into two groups, indicating whether they were observed for a shorter or longer duration compared to the reference stimuli. With the exception of stimuli S4, all other reference stimuli had the longest Time Viewed compared to the non-reference stimuli. This suggests that the reference stimuli generally held attention for a longer period than the non-reference ones.

Table 4: Comparison of reference and non-reference stimuli based on Time Viewed

Reference stimuli	Non-reference stimuli with shorter Time Viewed	Non-reference stimuli with longer Time Viewed
S1	All (14/14)	-
S2	All (14/14)	-
S3	All (14/14)	-
S4	All Remaining (11/14)	S6 ,15 ,16
S5	All (14/14)	-

Figures 10 and 11 present two heatmap visualizations for randomly chosen two participants, further supporting the previous observations. These visualizations demonstrate that, although stimuli S5 (Figure 11) had the shortest viewing time among the reference stimuli, it was still significantly recognized within the non-reference group. In contrast, this pattern is not observed with stimuli S4 (Figure 10), where greater attention was directed toward non-reference stimuli S6, S15, and S16.
This highlights the varying degrees of recognition and attention across different stimuli, reinforcing the complexity of how both reference and non-reference stimuli capture attention.

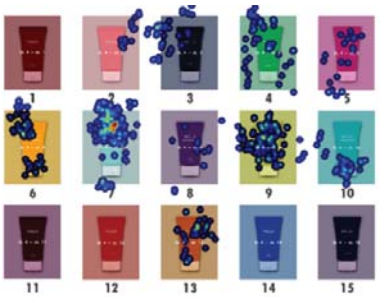


Figure 10: Heatmap of participant 63 with reference stimuli S4 (position 13)

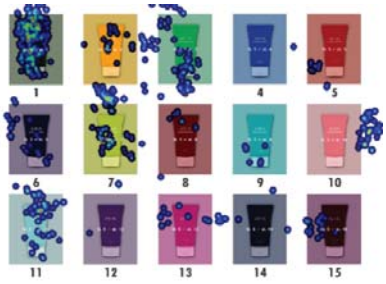


Figure 11: Heatmap of participant 32 with reference stimuli S5 (position 1)

3.3. Statistical Analysis of Participant Interaction Metrics

A one-way between-groups analysis of variance (one-way ANOVA) was performed to examine the impact of different stimuli on the parameter Time to First View. The results presented in Table 5 reveal a statistically significant difference in the parameter Time to First View among the stimuli (S1, S2, S3, S4, S5): $F(4, 895) = 51.611$, $p < 0.001$. The substantial difference between the mean values of the stimuli is indicated by an eta-squared value of 0.187, reflecting a large effect size.

Table 5: ANOVA results for Time to First View

ANOVA					
Time to first View					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2347.696	4	586.924	51.611	.000
Within Groups	10177.988	895	11.372		
Total	12525.683	899			

Since the Homogeneity of Variances test indicated that homogeneity was not confirmed, the Dunnett T3 Post Hoc test was conducted. As shown in Table 6, a statistically significant difference in Time to First View was found in all comparisons except between stimuli S1 and S4, where no significant difference was observed.

Table 6: Dunnett T3 results for Time to First View

Multiple Comparisons							
Dependent Variable: Time to first View							
	(I) S	(J) S	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Dunnett T3	S1	S2	1.5744556*	.3392655	.000	.619022	2.529889
		S3	2.7947167*	.3346474	.000	1.852287	3.737146
		S4	-.5331333	.3515682	.749	-1.523247	.456981
		S5	-1.8131667*	.3692477	.000	-2.853198	-.773135
	S2	S3	1.2202611*	.3361461	.003	.273609	2.166913
		S4	-2.1075889*	.3529951	.000	-3.101714	-1.113464
		S5	-3.3876222*	.3706065	.000	-4.431464	-2.343780
	S3	S4	-3.3278500*	.3485589	.000	-4.309507	-2.346193
		S5	-4.6078833*	.3663836	.000	-5.639886	-3.575881
	S4	S5	-1.2800333*	.3819009	.009	-2.355583	-.204483

*. The mean difference is significant at the 0.05 level.

A one-way between-groups analysis of variance (one-way ANOVA) was conducted also to assess the impact of different stimuli on the parameter Time Viewed. The results, as shown in Table 7, reveal a statistically significant difference in viewing time among the stimuli (S1, S2, S3, S4, S5): $F(4, 895) = 23.152$, $p < 0.001$. Despite this significant difference, the eta-squared value of 0.093 indicates a medium effect size.

Table 7: ANOVA results for Time Viewed

ANOVA					
Time Viewed					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	155.754	4	38.938	23.152	.000
Within Groups	1505.238	895	1.682		
Total	1660.992	899			

Similar to the case with the Time to First View parameter, homogeneity was not confirmed, which is why the Dunnett T3 Post Hoc test was conducted. Additionally, Table 8 shows that significant differences were found in all pairwise comparisons except between S1 and stimuli S2, S3 and S4 as well as between stimuli S2 and S3, where no significant differences were detected. This suggests variability in how different tones

are perceived in terms of viewing time. That may indicate that the viewing time is firstly influenced by the lightness of the stimuli, rather than the tone of the stimuli since S2 and S3 are lighter stimuli in comparison to S4 and S5.

Table 8: Dunnett T3 results for Time Viewed

Multiple Comparisons							
Dependent Variable: Time Viewed							
	(I) S	(J) S	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Dunnett T3	S1	S2	-.3885278	.1613813	.153	-.843174	.066118
		S3	-.2624444	.1542207	.606	-.696839	.171950
		S4	.3328111	.1265134	.085	-.023576	.689198
		S5	.7571278*	.1009329	.000	.471466	1.042789
	S2	S3	.1260833	.1740467	.998	-.364080	.616246
		S4	.7213389*	.1500463	.000	.298286	1.144392
		S5	1.1456556*	.1292118	.000	.779829	1.511482
	S3	S4	.5952556*	.1423165	.000	.194118	.996393
		S5	1.0195722*	.1201491	.000	.679434	1.359710
	S4	S5	.4243167*	.0815930	.000	.193498	.655136

*. The mean difference is significant at the 0.05 level.

4. CONCLUSION AND FURTHER RESEARCH

This study focused on understanding how colour tones used in organic cosmetics packaging influence participants' attention and engagement, particularly in the context of online shopping, by analyzing two key metrics—Time to First View and Time Viewed.

The results demonstrate that lighter tones, such as light yellow and light brown, are detected more swiftly than darker tones, including dark brown, dark orange, and dark green. Statistical analysis supports these findings, revealing significant differences between lighter and darker tones in terms of detection speed. Additionally, lighter-toned stimuli (stimuli 2 and 3) were observed for longer periods than darker-toned stimuli (stimuli 1, 4, and 5).

The study also highlighted that the time required to detect a stimuli (Time to First View) does not necessarily correspond to the duration of time spent viewing that stimuli (Time Viewed). While there is a moderate correlation between these two metrics, it is not strong enough to suggest a significant relationship, indicating that various factors influence viewer engagement.

This is further confirmed by instances where stimuli that attracted attention more quickly did not always result in longer viewing times. This research offers an initial exploration of how colour tones affect attention and engagement in e-commerce users. To validate these findings more conclusively, future research should include a broader range of tones and brightness levels. Such an expanded study would provide deeper insights and enhance the understanding of how different colour tones and brightness levels impact consumer perceptions and behaviour, particularly when viewing organic cosmetic packaging on e-commerce platforms.

5. ACKNOWLEDGMENTS

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IMPLEMENTING ARTIFICIAL INTELLIGENCE IN THE PACKAGING DESIGN FOR THE TASTE IMPRESSION

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Abstract: *This study examines the ability of the artificial intelligence (AI) generator to create packaging with taste impression. Influence of packaging design on taste impressions is well researched and achieved through transfer effects of symbolic associations from the visually perceived packaging to the products taste. The experiment was conducted by generating packaging designs with gradation in the strength of taste by AI image generator. This was done for sweet, sour, bitter, salty taste and feeling of hotness for spicy food. Afterwards participants were asked to grade packaging designs on their perception of the presumed product taste. Results indicate that AI image generator was able to generate packaging designs with recognizable strength of taste, although limited, as fine gradation of the presumed taste perception was not achieved.*

Key words: Packaging design, artificial intelligence, perceived taste

1. INTRODUCTION

Visual appearance of the product is one of the most important factors for purchasing decision of the food products (Crilly et al., 2004; Fenko et al., 2010). In the category of the food products packaging is often conveying the characteristics of the product. So packaging, rather than the product itself, can steer purchasing decision through its design (Creusen et al., 2005; Febrianti et al., 2023; Van Rompay et al., 2009), furthermore packaging can in some cases influence food product experience (Schifferstein et al., 1999). Taste of the food product is most important characteristic, followed by the smell and packaging should present those characteristics by its shape, colour, typography and other design elements. Stating the previous it must be mentioned that not all consumers pay equal attention to the packaging design and are not equally affected by it (Bloch et al., 2003).

Artificial Intelligence (AI) is affecting all industries and packaging industry is no exception. There are many applications of AI in the packaging industry, but graphic design of the packaging is perhaps most impacted by introduction of AI. New tools and techniques in graphic design are being developed based on the ability of the image generating Ai to analyze and interpret huge data bases while learning and adapting. Generating designs based on learning data and user preferences is changing the way the packaging design is created and interpreted. Graphic designers have already few decades of experience of using AI, first applications were limited to automation of repetitive tasks, such as image manipulation, typography, and layout (Bahaa, 2023). This freed time for designers to focus on more creative aspects of their work. Advancements in the field of deep learning and neural networks led to the development of AI-based design tools that can generate designs based on data and user preferences. Ability to create designs that are tailored to specific demographics, browsing history, and purchase history improves consumer engagement and loyalty (Bahaa, 2023). The use of AI has its advantages and disadvantages. Advantages are increased efficiency and productivity, while the loss of human touch and creativity is one of the main concerns. There is debate focuse on the fundamental difference between humans and machines, whether AI solutions are “killing creativity” and “replacing designers” by creating products much faster and cheaper than humans. (Anantrasirichai et al., 2022; Tomić et al., 2023).

Having in mind popularity of AI technologies and function of packaging design to communicate clearly products characteristics there is a need to examine how successful AI image generators are at creating comprehensive visual representation of the products taste. In order to determine are the designs proposed by AI image generator perceived in the intended way by human observers experiment was conducted by generating packaging designs with gradation in the strength of taste by AI image generator. This was done for sweet, sour, bitter, salty taste and feeling of hotness for spicy food. Afterwards participants were asked to grade packaging designs on their perception of the presumed product taste.

ORCID numbers are provided at the end of the paper.

2. METHODS

The experiment was conducted in order to examine the ability of the AI image generator to create packaging with taste impression. First task was creation of the prompt instructions for the AI image generator. Prompts were refined additionally with adjectives for each taste in order to get desired results, and eliminate as much visual noise which could later influence participants judgment of the perceived product taste. Getimg.ai platform for generating images from text was used. For each taste (sweet, sour, bitter, salty taste and feeling of hotness for spicy food) three different designs were created for every level of taste intensity, four levels of intensity were used. Basically, after refinement of the prompts twelve images of the designs were created for each taste.
Images were randomized and numbered in order to be identified. This collage of twelve images was used as stimuli in the online survey conducted by Google forms. Figure 1 shows the example collage of twelve images used as stimuli for bitter taste, as an example.



Figure 1: Collage of twelve images used as stimuli for bitter taste

Survey was sent to 100 participants, 62 of them have taken part in the survey. There were 53 females and 27 males, in the wide range of ages 13 to 54 and wide range of professions and education. Participants were asked to grade perceived taste intensity of the product shown in each of the images in the collage. Each of the images could receive one unique grade, so the result would be clear gradation of the products perceived taste intensity. Besides judgment of the taste intensity participants were asked to give their comments on the design presented and write suggestions on which element could, in their opinion, help improve communication of a taste.

3. RESULTS

Results shown in the Tables 1 - 4 are an example for bitter taste, with prompt used, image of the design, graph and descriptive statistics. Graph in the table is showing received grade and number of the participants giving the grade. Descriptive statistics for all other tastes are shown in Table 5, without images of the design and graphs.

Table 1: Results for three different designs in the lowest taste intensity category for bitter taste

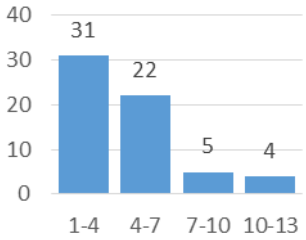
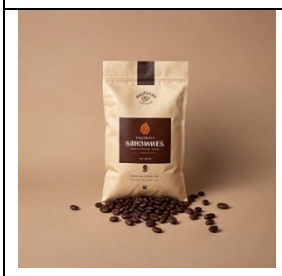
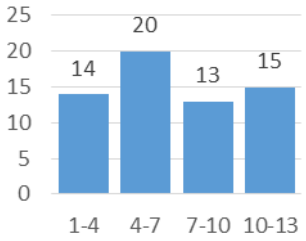
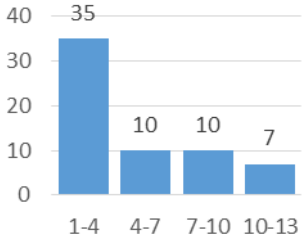
Prompt: Design a packaging that exudes a subtle and inviting aroma of coffee. Incorporate warm tones and soft imagery that evoke comfort and relaxation. Consider using a gentle gradient background with a single coffee bean illustration to represent the mild bitterness level.			
		**Mean**	4.03226
		St. dev.	2.57967
		Skewness	0.98156
		Kurtosis	0.3606
		**Mean**	6.59677
		St. dev.	3.39459
		Skewness	0.21106
		Kurtosis	-1.07631
		**Mean**	3.93548
		St. dev.	3.62537
		Skewness	0.94111
		Kurtosis	-0.47939

Table 2 (part 1): Results for three different designs in the second in strength taste intensity category for bitter taste

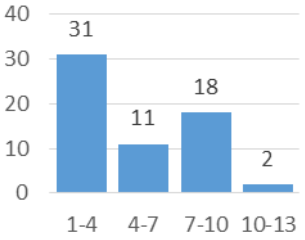
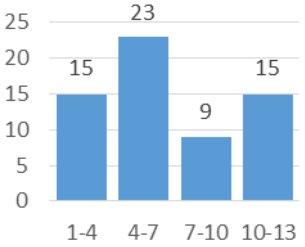
Prompt: Craft a packaging design that balances sophistication with a hint of robustness. Integrate deeper shades of brown and burgundy to convey richness and depth. On the label, utilize imagery such as a steaming cup of coffee or a swirling aroma to signify the medium level of bitterness. Add a touch of elegance with minimalistic typography.			
		**Mean**	4.74194
		St. dev.	2.88544
		Skewness	0.59673
		Kurtosis	-0.78443
		**Mean**	5.96774
		St. dev.	3.21863
		Skewness	0.35926
		Kurtosis	-1.18357

Table 2 (part 2): Results for three different designs in the second in strength taste intensity category for bitter taste

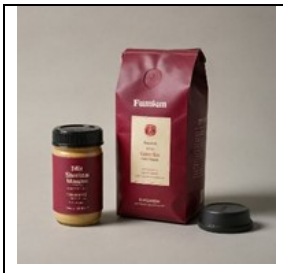
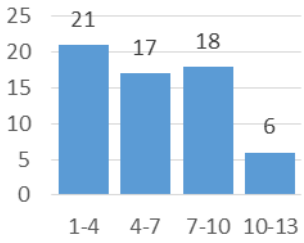
		**Mean**	5.32258
		St. dev.	2.82712
		Skewness	0.28046
		Kurtosis	-0.89885

Table 3: Results for three different designs in the third strength taste intensity category for bitter taste

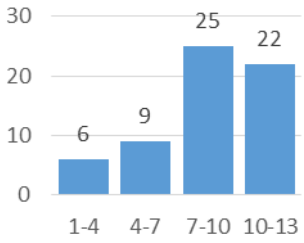
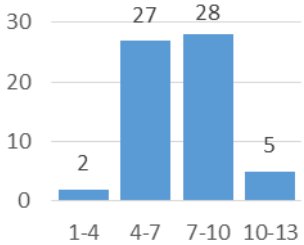
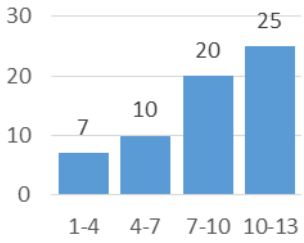
Prompt: Develop a packaging in the shape of a bag that commands attention and intensity. On the label, employ bold colours like dark espresso brown or charcoal grey to reflect the strength of the coffee. Incorporate imagery such as cracked coffee beans or a rugged landscape to symbolize the bold flavour profile. Utilize sharp and angular typography to convey the robustness of the product.			
		**Mean**	8.1129
		St. dev.	2.66799
		Skewness	-0.9064
		Kurtosis	0.24686
		**Mean**	6.79032
		St. dev.	2.12816
		Skewness	0.22031
		Kurtosis	0.95159
		**Mean**	8.29032
		St. dev.	3.41831
		Skewness	-0.60492
		Kurtosis	-0.66255

Table 4: Results for three different designs in the highest taste intensity category for bitter taste

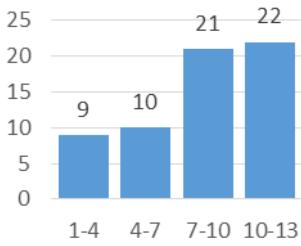
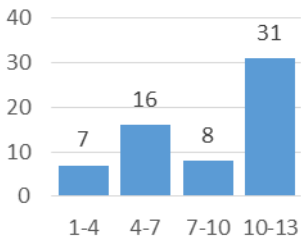
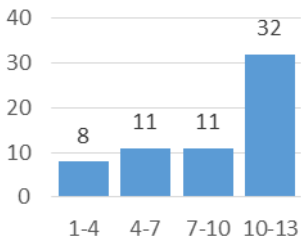
Prompt: Create a packaging design in the shape of a coffee bag that exudes power and boldness. On the label, opt for a striking contrast of colours, such as black and fiery red, to evoke a sense of intensity. Incorporate imagery like a thunderous storm or a roaring flame to represent the extreme bitterness level. Use dynamic typography with jagged edges to convey the electrifying taste experience.			
		**Mean**	7.59677
		St. dev.	3.14908
		Skewness	-0.62012
		Kurtosis	-0.79766
		**Mean**	8.25806
		St. dev.	3.42094
		Skewness	-0.56773
		Kurtosis	-0.97977
		**Mean**	8.35484
		St. dev.	3.28981
		Skewness	-0.70488
		Kurtosis	-0.83283

Table 5 (part 1): Results for three different designs in four categories of taste intensity for sweet, sour, salty taste and feeling of hotness for spicy food. 1-lowest taste intensity, 4 highest taste intensity

Taste/intensity		Sweet/1	Sweet/2	Sweet/3	Sweet/4	Sour/1	Sour/2	Sour/3	Sour/4
1	Mean	5.75806	6.6129	6.17742	7.66129	3.45161	5.1129	4.70968	8.06452
	St. dev.	3.0282	2.89349	2.621	3.78497	2.93468	1.9342	3.37001	2.70925
	Skewness	-0.0318	-0.17854	0.31952	-0.26261	1.41588	0.57967	0.605	-0.70932
	Kurtosis	-1.13913	-0.90519	-0.35505	-1.55923	0.93196	1.05423	-0.56642	-0.2715
2	Mean	7.91935	5.96774	6.96774	7.82258	3.96774	7.8871	8.06452	9.40323
	St. dev.	4.04604	2.52832	2.75781	3.75707	2.61125	2.78818	3.11459	3.03779
	Skewness	-0.51339	-0.02543	-0.01381	-0.68112	1.45209	-0.5645	-0.85589	-1.35238
	Kurtosis	-1.28237	-0.32724	-0.15046	-1.18131	1.78069	-0.15297	0.2441	1.0004
3	Mean	4.40323	4.54839	7.8871	6.27419	5.45161	5.0	8.12903	8.75806
	St. dev.	3.41386	2.3447	2.97589	4.40257	2.88397	2.73412	2.77272	3.05515
	Skewness	0.70293	0.83589	-0.81243	0.03398	0.41166	0.78572	-0.8866	-0.91771
	Kurtosis	-0.8917	-0.06281	-0.14749	-1.72121	-0.1863	-0.48877	0.29226	0.09664
Taste/intensity		Salty/1	Salty/2	Salty/3	Salty/4	Hot/1	Hot/2	Hot/3	Hot/4
1	Mean	3.54839	4.14516	8.56452	8.40323	5.75806	7.82258	6.27419	7.72581
	St. dev.	1.90493	2.97997	2.66502	2.67017	3.62453	2.28699	1.90056	4.20448
	Skewness	0.79794	0.76491	-0.53329	-0.94068	0.21684	-0.23344	-0.18636	-0.55217
	Kurtosis	0.43564	-0.15664	-0.06671	0.78215	-1.45077	-0.70972	0.37919	-1.41187

Table 5 (part 2): Results for three different designs in four categories of taste intensity for sweet, sour, salty taste and feeling of hotness for spicy food. 1-lowest taste intensity, 4 highest taste intensity

2	Mean	5.77419	6.29032	8.83871	4.16129	4.16129	9.01613	4.16129	9.69355
	St. dev.	4.3473	2.41842	3.03636	2.82955	2.29178	2.82548	2.74724	3.27729
	Skewness	0.16447	0.43083	-0.46935	1.17205	0.49638	-0.9677	0.64949	-1.68767
	Kurtosis	-1.63897	0.59847	-1.21518	0.49424	-0.37819	0.13126	-0.56306	1.79901
3	Mean	6.17742	7.54839	8.83871	5.70968	3.54839	6.54839	5.66129	7.62903
	St. dev.	2.6459	3.3175	2.77101	3.05355	2.64065	2.62196	2.986	2.94893
	Skewness	0.03233	-0.50697	-1.31772	0.42773	1.23829	0.1634	0.18711	-0.47526
	Kurtosis	-0.926	-0.90654	1.03653	-1.17754	0.56761	-0.93418	-0.88212	-0.48304

4. DISCUSSION

Results shown in previous section indicate limited ability of AI image generator to produce good results in visual representation of the packaging taking in to consideration the taste of the product. For some of the tastes and some of the designs, for example sour taste, there is noticeable gradation of the grades given by the participants in the relation to the intensity of the taste. It must be emphasized that gradation is not linear which suggest that fine differences in the neighbouring intestines were not recognized by all of the participants. On the other hand results for designs of salty taste were not consistent, which indicates that participants had trouble recognizing taste intensity gradation of the presented designs. Means of taste intensity levels two and three especially do not give clear results, presumably as the differences are small and participants personal subjective opinion prevailed.

Participants gave their free comments and suggestions how the taste could be better presented. Images of fire in the fourth level of bitterness were deemed as unsuitable for bitter taste and more suitable for spicy hot taste, while AI image generator used the illustration of the flames in all three suggested designs. Usage of the blue colour for salty taste was also frequent comment, while AI image generator used blue colour sporadically in three out of twelve designs.

Participants suggestions are welcomed, with the caveat that not all of them are experienced in the field of graphic design. Those more experienced, based on their occupation noticed influence of the background on their judgment. Minimization of the background variations was attempted in the prompts writing, but it was rather unsuccessful as AI image generator always created the image with background as a part of the design.

5. CONCLUSIONS

AI image generator tools such as Getimg.ai platform used in this study are becoming ever more popular as a tool for designer to get inspired and come up with greater number of ideas and approaches to the packaging design solution. Although very effective in producing great number of designs in a short time, study shows potential for the visual representation of the product taste, but that potential is limited to greater steps in taste perception gradation as subtle differences in the neighbouring intestines of the taste were not recognized by the human observers. Usage of colour and illustration elements in the AI generated designs were also deemed as unsuitable by the humans. This study could benefit from larger number of participants and clear division in groups based on the graphic design experience, which leaves room for further studies to be conducted in the future.

6. ACKNOWLEDGMENTS

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IDENTIFICATION OF GAZE PATTERNS IN THE OBSERVATION OF FONT-WEIGHT AND ILLUSTRATION SIZE ON THE PACKAGING USING EYE-TRACKING ANALYSIS

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Abstract: *Nowadays, manufacturers across various sectors, including food, cosmetics, pharmaceuticals, and other industries, are continually expanding the range of products available in the market. Given this expansion of products, branding, and packaging have become critical differentiating factors. To effectively influence consumer behaviour and encourage brand preference, packaging designers must thoroughly understand the challenges faced by existing products and the needs of consumers. By employing various graphic elements, such as colour palettes, illustrations, typography, and others, designers can effectively present products and communicate with consumers, thereby enhancing product recall. To achieve these objectives, it is essential to investigate whether specific patterns exist in consumer perception regarding packaging. This is precisely why this preliminary research was conducted. A total of 40 participants, divided into two groups, aged 20 to 25, from the same demographic group (students) participated in this eye-tracking analysis. Each group of participants had a different set of stimuli, depending on whether the subject of the test was logo font-weight variation or illustration size variation. The results of this preliminary research show that logo font weight has no statistically significant effect. Also, the results of this research show that the specific graphic element - illustration is observed the longest, regardless of the size change.*

Key words: font-weight, packaging, graphic design, eye tracking, illustration

1. INTRODUCTION

Packaging holds significant importance for consumers today, particularly in influencing their purchasing decisions. Regardless of the product type, packaging serves as a representation of the product itself and often constitutes the initial point of interaction between the consumer and the product. Packaging has several different roles such as protecting the product, enhancing usability, and increasing functionality (Robertson, 2012). Furthermore, the role of packaging in sales and promotion has become increasingly significant. Packaging serves as a distinctive and highly effective means of informing consumers and promoting products within the marketplace (Moskowitz et al., 2009; Riaz et al., 2015; Shehzadi et al., 2016). In the era of consumerism, where the market is saturated with similar competing products available in various retail environments, both physical and online, packaging serves as the sole means of product differentiation. Effectively designed packaging has the potential to capture consumer attention, generate interest, and ultimately foster a desire to purchase, thereby influencing consumer preferences for specific products (Shrestha, 2024; Zekiri & Visoka Hasani, 2015; Ahmed et al., 2014). Additionally, packaging can evoke a range of emotions, including pleasure and desire, as well as negative responses such as aversion toward a product. According to Yaqub (2024), nearly 81 percent of consumers report that they purchased a product specifically due to its attractive and engaging packaging. Furthermore, 72 percent of respondents assert that packaging design significantly influences their purchasing decisions. Niv and Harris (2018) indicate that the purchase decisions of younger adults, who tend to be more educated and possess higher earnings and purchasing power than other demographic groups, are particularly influenced by both the design of the packaging and the materials utilized in its construction.
Product packaging plays a vital role in the growth and marketing strategy of any company today. First impressions are crucial, and packaging often serves as a consumer's initial introduction to the product. It allows consumers to familiarize themselves with newly launched products and their features, marking the beginning of their interaction with them. The branding of packaging can significantly influence consumer responses; designs that contain excessive information may overwhelm consumers, leading them to overlook the packaging entirely. Conversely, packaging that lacks sufficient branding may fail to differentiate itself from competing brands, resulting in consumers overlooking the product altogether

ORCID numbers are provided at the end of the paper.

(Roggeveen et al., 2015; Spence, 2016). This interaction is critical in shaping consumer perceptions of the product's quality and functionality. Therefore, product packaging is an essential aspect that manufacturers should never underestimate. Numerous factors can influence consumer preferences regarding packaging, including its shape (Chitturi et al., 2019; Koo & Suk, 2016), material (Purwaningshi et al., 2019), ergonomics, the presence or absence of graphic representations (such as images or illustrations of the product) (Chitturi et al., 2021; Hasibuan & Nuraeni, 2023; Spence, 2021), typography choices, and more. Despite this complexity, it remains challenging to definitively ascertain what makes packaging attractive and how its various elements, particularly the graphic components, contribute to the formation of consumer preferences for specific products. An additional critical inquiry revolves around how respondents engage with the packaging, specifically which graphic elements capture their attention most frequently and for the longest duration, as well as which elements are deemed less significant during their initial encounter with the packaging.

This preliminary research seeks to identify potential patterns in packaging perception that are characteristic of consumers, as well as to determine whether variations in font-weight impact the visibility of the product and, consequently, consumer preferences. Furthermore, the research investigates whether the size of the illustration representing the product influences the duration of observation, which may subsequently lead to the development of consumer preferences.

2. METHODS

Within this study, two main independent factors were defined: the font-weight modification of the product title displayed on the front of the packaging (primary font-weight of the title, secondary and tertiary font-weight of the product title), and the illustration size alterations on the front of the packaging, representing product (primary illustration size, secondary and tertiary illustration size), therefore, it was necessary to prepare two different sets of stimuli for two different groups of participants. Dependent variables in this study included Time Viewed in seconds, Number of fixations, and Revisits number for each area of interest.

2.1 Participants

Eye tracking analysis was conducted within two distinct groups, each comprising 20 participants, resulting in a total sample size of 40 individuals. The participants, aged between 20 and 25 years, were exclusively drawn from student demographics. The first group, focusing on font-weight modification of the product title, comprised 80% female and 20% male participants. In contrast, the second group, emphasizing alterations in illustration size representing the product, included 50% male and 50% female participants. It is important to note that, due to the accuracy and objectivity of the research itself, the participants were intentionally kept unaware of the purpose of the study. Participants were informed, however, that the presented samples represented prototypes of the front-facing packaging design for five distinct dietary supplements.

2.2 Samples

It was necessary to prepare samples of the front of the packaging for five different dietary supplements (Figure 1) so that they would be adequate for eye-tracking research. Although many studies prove the importance of the shape of the packaging in creating consumer preferences and making purchase decisions (Westerman et al., 2013; Shen et al., 2015; Koo & Suk, 2016; Velasco et al., 2018; Chitturi et al., 2019), for the purposes of this research, we decided to show only the front side of the cardboard rectangular packaging for five different dietary supplements. This decision was made in order to exclude the influencing factor of the material and shape of the packaging, as well as the factor of displaying additional information on the side of the packaging, which would undoubtedly draw the attention of the participants and therefore negatively affect the results of the experiment. For the purposes of this preliminary research, a fundamental colour palette comprising five shades was established, with each colour representing a specific dietary supplement (supplements intended for women, men, women in menopause, and individuals with gastrointestinal disorders). Research conducted by Wan et al. (2015) highlights the significance of colour in influencing the perceived effectiveness of dietary supplements. Also, for the purpose of this preliminary research, a logo composed solely of typography, devoid of illustrations, lines, or other graphic elements, was selected to enhance visibility and readability. The

stimuli representing the front of the packaging included an illustration, logo, product title, and supplementary information, such as the product quantity and a description of the product.



Figure 1: The primary set of samples used in the research

The first group of samples involved modifications to the font-weight of the product title. All samples were created using the Audrey typeface, available in regular, regular italic, medium, medium italic, and bold weights. For the purposes of this research, the regular variant was employed for the primary samples, medium for the secondary samples, and bold for the tertiary samples (Figure 2). Other elements, such as the manufacturer's logo and information about the quantity and product description, remained unchanged in terms of font-weight, size, or position. These elements were not taken into consideration when defining areas of interest and during statistical data processing.



Figure 2: Font-weight variations used in the research

The second group of samples involved altering the size of the product illustration displayed on the front of the packaging. The original illustration dimensions of 80x75 mm were used for the primary samples. In the secondary samples, the illustration was reduced to a 1:1.5 scale relative to the original, while in the tertiary samples, it was scaled down to 1:2 (Figure 3). This scaling was chosen to ensure the illustration remained visible on the display device, allowing participants to view it without difficulty. The colour and position of the illustration on the packaging front were kept constant. Additionally, other elements of the packaging, including the product title, manufacturer's logo, and product information (such as quantity and description), were unchanged in terms of size, colour, and typography. It is important to note that all samples were created and prepared using Adobe Illustrator software.



Figure 3: Illustration size alterations used in the research

2.3 Procedure

The data presented in this study was gathered using the Gazepoint eye-tracking device. All participants have undergone a 9-point screen-based calibration to ensure accurate test performance, after which they were presented with samples from the subordinate group. Each group consisted of 15 samples, with each sample being displayed for 6 seconds. Preliminary testing indicated that this duration was sufficient to allow participants to observe the front of the packaging adequately. The samples were presented in a randomized order to further ensure the examination's objectivity. After viewing all the samples, it was necessary to define the areas of interest for each specific graphic element (logo, product title, and illustration) and collect data on the gaze movements of all participants.

3. RESULTS

One-way ANOVA tests were used to examine for statistically significant differences in the alteration of the position and colour variations across the experimental comparisons. Differences with p-values less than 0.05 were considered statistically significant.

3.1 The influence of graphic design element type on participants' perception

A one-way ANOVA was first performed in order to compare the effect of each area of interest, representing graphic design elements, such as logo, product title, and illustration, on gaze duration, number of fixations, and number of revisits (Table 1).

Table 1: One-way ANOVA results for defined areas of interest that represent each graphic element

		Sum of Squares	df	Mean Square	F	Sig.
Gaze Duration	Between Groups	169.983	2	84.992	141.708	.000
	Within Groups	334.069	557	.600		
	Total	504.052	559			
Number of fixations	Between Groups	2610.657	2	1305.328	183.982	.000
	Within Groups	3951.842	557	7.095		
	Total	6562.498	559			
Number of Revisits	Between Groups	136.671	2	68.336	26.662	.000
	Within Groups	1427.615	557	2.563		
	Total	1564.286	559			

A one-way ANOVA revealed that there was a statistically significant effect of defined areas of interest on time viewed at the p<0.05 level for the three conditions [F (2,557) = 141.708, p = 0.000]. One-way ANOVA also revealed that there was a statistically significant effect of defined areas of interest on fixation number at the p<0.05 level for the three conditions [F (2,557) = 183.982, p = 0.000]. Finally, one-way ANOVA revealed that there was a statistically significant effect of defined areas of interest on revisits number at the p<0.05 level for the three conditions [F (2,557) = 26.662, p = 0.000]. Post hoc comparisons using the Tukey HSD test indicated that the illustration (M = 1.6139, SD = 1.134) was significantly (p = 0.000) longer gazed upon than the logo (M = 0.483, SD = 0.588), and the title (M = 0.409, SD = 0.413). Post hoc comparisons using the Tukey HSD test also indicated that the illustration (M = 7.14, SD = 3.700) had a significantly (p = 0.000) higher number of fixations than the logo (M = 3.07, SD = 2.266) and the title (M = 2.17, SD = 1.580). Finally, Post hoc comparisons using the Tukey HSD test indicated that the illustration (M = 2.31, SD = 1.611) had a significantly (p = 0.000) higher number of revisits than the logo (M = 1.73, SD = 1.730) and the title (M = 1.10, SD = 1.450). The results of the post hoc test revealed no statistically significant difference in the gaze duration time for the logo compared to the product title.

3.2 Impact of title font-weight on participants' perception

A one-way ANOVA was conducted to compare the impact of font-weight variations on participants' gaze patterns. The analysis also explored the effect of font-weight variation on gaze duration, the number of fixations, and the number of gaze revisits. However, one-way ANOVA revealed that there wasn't any statistically significant effect of defined areas of interest (product title font-weight variations) on gaze duration [F (2,557) = 0.980, p = 0.376], number of fixations [F (2,557) = 1.067, p = 0.345], or number of revisits [F (2,557) = 1.655, p = 0.192]. On the other hand, a comparison of the average gaze duration values, as illustrated in Figure 4, indicates that the product title was observed for the longest duration in the samples where the product title was presented in bold font-weight.

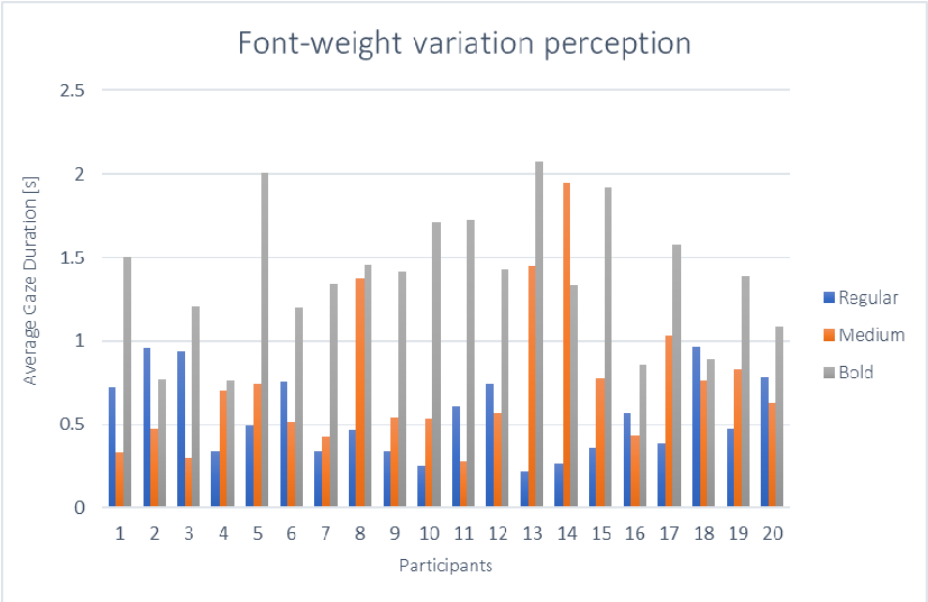


Figure 4: Average gaze duration for each font-weight

3.3 Impact of illustration size on participants' perception

A one-way ANOVA was performed in order to compare the effect of illustration size alteration on gaze duration, number of fixations, and number of revisits (Table 2). A one-way ANOVA revealed that there was a statistically significant effect of a defined area of interest (illustration size) on the number of revisits at the p<0.05 level for the three conditions [F (2,297) = 6.730, p = 0.001]. Post hoc comparisons using the Tukey HSD test indicated that the primary illustration size (M = 2.74, SD = 1.784) has a significantly (p = 0.001) higher number of revisits than the tertiary illustration size (M = 1.82, SD = 1.702). In other instances, the results of the one-way ANOVA did not reveal statistically significant differences resulting from alterations in illustration size (primary, secondary, and tertiary adjustments). Additionally, no significant effect of these alterations on gaze duration or the number of fixations was observed.

Table 2: One-way ANOVA results for illustration size alteration

		Sum of Squares	df	Mean Square	F	Sig.
Gaze Duration	Between Groups	5.094	2	2.547	2.358	0.096
	Within Groups	320.863	297	1.080		
	Total	325.957	299			
Number of fixations	Between Groups	40.609	2	20.304	1.307	.272
	Within Groups	4614.386	297	15.537		
	Total	4654.995	299			
Number of Revisits	Between Groups	42.560	2	21.280	6.730	.001
	Within Groups	939.160	297	3.162		
	Total	981.720	299			

4. DISCUSSION

The predominance of visual representation over textual representation in the context of packaging design is a widely recognized phenomenon. According to Bateman (2014), typography, or textual content displayed on packaging without the integration of images or illustrations, can be retained in short-term memory by observers or consumers. However, there is a high likelihood that such information will not be transferred to long-term memory. In contrast, visual representation is the dominant means of acquiring new information and recognizing objects and products in the environment. Visual content is more easily retained in long-term memory, enhancing the potential for easier product identification (Kahn, 2017; Gil-Pérez et al., 2020). Many studies show that the visual representation can be related to the taste of a product, the smell of the product, the properties of the product, the material from which it is made, the tactile experience of the product, the amount of product in the packaging, and the like (Dematte et al., 2006; Ares et al., 2011; Balzarotti et al., 2015; Krishna et al., 2017; Carvalho et al., 2020). A multimodal approach to product presentation, incorporating images, illustrations, or similar elements, has the potential to engage consumer interest and facilitate long-term memory retention related to the packaging, the product itself, and even the brand (Bateman, 2014). This multimodal strategy conveys additional product information, enabling the manufacturer to effectively communicate the narrative they wish to share with their target audience. Support for this theory can be observed in Figure 4, which presents the heat map results for the stimuli used in this preliminary research. While statistical data highlight the dominance of pictorial representation, participants also allocated attention to other textual elements on the packaging, such as the product title, logo, and additional information.



Figure 4: Heat map results of participants' gaze patterns

With regard to the font-weight used for the product title, the greater contrast in colour and surface area, along with the bolder stroke, indicates the dominance of the bold font-weight compared to the medium and regular font-weights. When it is necessary to emphasize specific information, such as the product name, warnings, usage instructions, or composition, bold font variants are generally a more effective option compared to other font-weights (Spence, 2016). Additionally, older consumers and those with visual impairments tend to prefer products where the specifications and essential information are clearly visible on the packaging (Braun et al., 1992). According to Grohmann et al. (2013), selecting appropriate typography can significantly influence the message a manufacturer aims to convey to its target audience, thereby playing a crucial role in shaping the brand's image.

The size of the image or illustration that represents the product is also extremely important. With larger displays, details are clearly displayed and emphasized, which facilitates the transfer of information from the packaging to the user. A greater number of clearly displayed details can attract and retain the attention of consumers, which can further result in cognitive processes and the creation of preferences regarding a certain packaging or product. Many studies and research point to the importance of this phenomenon (Childers & Houston, 1984; Nelson, 2004; Berning et al., 2008; Zinko et al., 2020). The findings of this preliminary research suggest that the higher frequency of repeated glances in samples with the primary illustration size (1:1 scale), compared to those with the tertiary illustration size (1:2 scale), can be attributed to the richness and quality of details in the illustrations presented to the respondents. These details likely stimulated curiosity and a general inclination to re-examine the illustration further.

5. CONCLUSIONS

Packaging plays a crucial role in shaping and influencing consumer purchasing behaviour and can significantly impact a product's market positioning. Consequently, manufacturers invest considerable resources in improving and rebranding their products, with particular emphasis on packaging design. This includes considerations of the materials used, the packaging shape, and, importantly, how information is displayed, to effectively communicate the manufacturer’s message. As a result, packaging has become one of the most important marketing tools for product promotion, regardless of the product type or industry.

As trends in packaging design evolve over time, it is essential to continuously conduct tests and research to better understand how consumers perceive products and develop preferences based on packaging design. This preliminary research aimed to investigate whether there are statistically significant differences in consumer responses to various graphic elements displayed on the front of the packaging, which often serves as the first point of contact in retail environments. Specifically, the study explored whether differences exist in the font-weight used to present information, as well as in the three predefined sizes of the product illustration. The findings revealed statistically significant differences between the illustrations and the text elements displayed on the packaging. While the illustrated graphic element clearly dominated the overall packaging content, the size of the illustration did not have a statistically significant impact on participants, except when it came to revisiting the graphic element in samples with the original illustration size. Additionally, no statistically significant differences were found between the three font-weights used for product titles, although the bold font-weight was observed for a longer duration than the others.

The results of this preliminary research, while confirming certain theories regarding the influence of graphic elements in packaging design on consumer preferences, also highlight the lack of established rules governing consumer behaviour and preferences toward specific graphic elements. This insight may prove valuable for designers and marketing professionals when approaching packaging redesign or the development of new product packaging for market introduction. Moreover, these findings provide designers with a degree of creative freedom in their approach to packaging design. In the future, this research could be expanded to include a larger and more diverse sample of participants, along with additional variables such as packaging shape, the mode of stimuli presentation, stimuli orientation, and the inclusion of information about the material and texture of the packaging.

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INFLUENCE OF ULTRASONIC TREATMENT ON THE MECHANICAL AND SURFACE PROPERTIES OF POTATO STARCH-BASED FILMS WITH VARIOUS GLYCEROL CONTENT

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Abstract: *Starch-based films are suitable for applications such as single-use food packaging for products with a short shelf life, offering a potential green alternative to certain plastic packaging materials. Although starch-based films offer suitable gas barriers and optical properties for packaging applications, their poor moisture resistance and mechanical strength limit broader use. Ultrasonication presents a promising and efficient solution to these challenges, offering high effectiveness, environmental sustainability, and safety. Selected properties of potato starch-based films with or without ultrasonication were investigated. To explore the impact of glycerol (GLY) content and ultrasonication on starch-based films, a series of films with varying concentrations of glycerol (ranging from 20% to 80%) were developed. The resulting films were characterized by tensile properties, water contact angle (WCA), Fourier Transform Infrared Spectroscopy (FTIR), surface roughness, and Scanning Electron Microscopy (SEM) techniques. It was observed that the application of sonication treatment had both positive and negative effects on the films' overall characteristics. Specifically, the tensile strength values increased by 20% following ultrasonication treatment, particularly in films containing 20% and 40% GLY. Furthermore, the values of WCA increased, indicating slight hydrophobization of the film surface. Finally, the SEM images confirmed the smoothness of the film surface. It was found that ultrasound treatment can improve the overall film performance.*

Key words: potato starch, starch films, mechanical properties, ultrasonic treatment

1. INTRODUCTION

Plastic is widely utilized across many industries, one of the largest being the packaging sector. Since the 1950s, plastic packaging has replaced other reusable materials used for packaging, such as paper, glass, metal, etc. Nowadays, plastic consumption in Western Europe is 150 kg per person, and worldwide, around 60 kg per person (European Environment Agency, 2024). Plastic production has increased from 2 Mt in 1950 to 460 Mt in 2019. It is expected that in 2060, plastic production will almost triple, reaching 1 231 Mt (OECD, 2022). Plastics are highly valued in packaging due to their excellent qualities, including strong mechanical properties and effective barriers against gases and moisture, making them ideal for food packaging. Typically, plastic films are used as single-use packaging, necessitating recycling after use. However, only 38% of plastic packaging waste is recycled in the EU (Eurostat, 2024). Hence, in 2021, each person in the EU generated more than 36 kg of plastic waste, and only about 14 kg per person were recycled.

The primary drawback of traditional plastic materials lies in the recycling process. Plastic films pose a challenge due to their inability to degrade in the natural environment. As a result, the European Union implemented regulations on single-use plastics within the European Green Deal (European Commission, 2019). One of the Green Deal policies is to ensure that all packaging in the EU market is reusable or recyclable by 2030.

Bio-based and biodegradable alternatives have been introduced to reduce the usage of conventional nondegradable plastics based on fossil resources. Some of them are already industrially produced, for example, polylactide (PLA), polycaprolactone (PCL), polyhydroxyalkanoates (PHA), etc. (Żołek-Tryznowska & Cichy, 2018). Polysaccharides like starch derived from potatoes, rice, corn, or wheat are among the most non-toxic and widely used polymers. Starch is seen as one of the most promising alternatives to non-degradable plastics due to its abundance, low cost, biodegradability, edibility, and excellent film-forming properties (Zarski, Bajer & Kapuśniak, 2021). Compared with conventional packaging plastics, starch-based

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films have certain shortcomings, including poor mechanical and moisture barrier properties, which limit their further development and application (Mi et al., 2023).
The starch films can be obtained by either extruding and followed by a blowing process or by casting, dipping, or spraying from usually water solution and by a drying process (Lagarrigue et al., 2008; W. Liu et al., 2020; Matzinos et al, 2002; Thunwall, Boldizar & Rigdahl, 2006; Żołek-Tryznowska & Cichy, 2018). Due to native starch's large molecular size and strong hydrogen bonding, it is difficult to dissolve the starch in water, so starch dispersion is prepared at low starch concentrations at elevated temperatures (higher than 90°C) (Chang et al., 2021). In conclusion, the basic recipe for obtaining starch film includes the formation of starch dispersion. Next, the solution is heated to gelatinize the starch dispersion, and finally, it is cast and dried by natural forced air convection to produce a film. Additionally, before the casting process, the starch solution can be treated with an ultrasound. Ultrasound treatment is an environmentally friendly process, and it can be used for dispersion solutions to improve the performance of biodegradable films. The ultrasonic starch treatment was performed as early as 1933 (Kardos & Luche, 2001). Some papers have reported the influence of ultrasonic treatment. Few works in the literature (Abral et al., 2018; Borah et al., 2017; Gaquere-Parker et al., 2018; Huang, Chen & Liu, 2024; P. Liu, 2018a) confirm the effect of ultrasonic treatment on the behaviours of gelatinized starch dispersions and the starch film properties. However, in these papers (Abral et al., 2018; Borah, Das & Badwaik, 2017; Gaquere-Parker et al., 2018; Lima & Andrade, 2010), commercially available ultrasonic baths were used, which work at a limited frequency of ultrasonic 20 or 40 kHz. The ultrasonic treatment can affect starch dispersions and damage the granules (Zuo et al., 2009). Moreover, ultrasonic at 20 kHz frequency can reduce the molecular weight of amylose and amylopectin due to the breakage of C—C bonds, which decreases viscosity (Peres, Leite & Silveira, 2015). The degree of amylose and amylopectin degradation depends on the power and amplitude of the ultrasonics. Ultrasound treatment provides a homogenous starch solution and increases the starch solubility in water. The increase in frequencies of ultrasonic transfers leads to more excellent dispersion and limits the disintegration of C—C bonds. However, the literature research on the influence of ultrasound is not a deeper analysis, despite the usage of commercially available ultrasonic baths at 20 kHz and 40 kHz frequencies and the influence on the limited properties of films.
We apply ultrasonic treatment to improve the properties of starch-based films with various plasticizer contents. Attempts were made in the present paper to investigate the mechanical and surface properties of starch-based composites containing up to 80% of glycerol contents as a plasticizer.

2. METHODS

2.1 Materials

Potato starch (30.3 wt% amylose, 18.1 wt% water content, CAS 9005-25-8) and glycerol (purity ≥ 99%, CAS 56-81-5), as a plasticizer, and diiodomethane (purity ≥ 99%, CAS 75-11-6) were purchased from Sigma Aldrich and used as received.
Amylose content in starch was determined according to ISO 6647 standard at 620 nm with a PerkinElmer Lambda 35 model spectrophotometer.

2.2 Film production

The film production description was shown in our previous works (for example, see (Żołek-Tryznowska & Holica, 2020) or (Żołek-Tryznowska et al., 2024). Briefly, 10 g of starch and 2, 4, 6, and 8 g of glycerol (GLY) were dissolved in water and heated to 95°C at 3°C per minute with continuous mixing. Before pouring, the gelatinized potato starch dispersion solution was placed in an ultrasonic cleaner InterSonic IS-1 ultrasound frequency 35kHz±5% for 15 minutes. Next, the mixture was poured onto Teflon® plates placed using a K Paint Applicator (TMI machines, UK) with an adjustable micrometre spreader gap set at 3 mm after cooling to around 50°C. Obtained starch film sheets had dimensions of approx. 100mm × 150mm. Before analyzing their properties, the films were stored under controlled conditions: at a room temperature of 23±0.5°C and a relative humidity of 50±1% RH, protected from light. All the measurements were conducted one week after film preparation to ensure repeatable measurements.
Table 1 shows the solution formulation. The film abbreviations were coded as S20, S40, S60, and S80, according to their glycerol content (20, 40, 60, or 80 %) in the film-forming solution and sonification process (U for sonicated samples).

Table 1: Starch film abbreviation and formulation

Sample abbreviation	Starch [g]	GLY [g]	Sonification [min]
S20	10	2	-
S40	10	4	-
S60	10	6	-
S80	10	8	-
S20U	10	2	15
S40U	10	4	15
S60U	10	6	15
S80U	10	8	15

2.3 Film properties

The mechanical properties were determined using a Z010 tensiometer (Zwick-Roell, Germany) according to the ISO 527-1 standard. the following measurement conditions were used: the samples were 15 mm in width and 100 mm in length; the initial distance of the clamps was 50 mm; the stretching speed was 100 $mm \cdot m^{-1}$. The thickness for the mechanical measurements was performed with a hand-held micrometre with 0.001 mm resolution and an error of ± 0.5 mm. The parameters (tensile strength (TS), elongation at break (EaB), and Young modulus (YM)) were obtained from the stress-strain curves. The measurements were repeated ten times, and the average values were taken.
The water contact angle (WCA) was determined using the Drop Shape Analysis System (DSA 30E, Krüss, Germany) in agreement with the ISO 15989 standard.
ATR FT-IR spectra of developed films were collected at room temperature over the 400–4000 cm^{-1} range, with a resolution of 4 cm^{-1}, using a Nicolet iS5 spectrometer fitted with a Platinum single-reflection diamond ATR module. The spectra were analyzed using OMNIC Specta™ software (version 9.12.968).
A digital microscope (Keyence VHX-7000, Japan) and SEM (JOEL JCM-7000) were used to observe the surface structure of developed films. The film's surface roughness (*Sa*) was evaluated with Keyence VHX-7000. The surface morphology was analyzed with SEM. Firstly, the film samples approx. 1 cm^2 was fixed on the sample table with double-sided conductive adhesive. Then, they were covered with a thin layer of gold for SEM image determination. SEM images were received at an acceleration voltage of 15 kV.

2.4 Data analysis

The statistical analysis was performed using the Statgraphics Centurion 19 (v.19.1.3 StatPoint®, Inc., Warrenton, VA, USA). The effect of non-sonicated and sonicated treatment on the mechanical properties of films at a 5% significance level was identified using analysis of variance (ANOVA). The data were expressed as means±SD.

3. RESULTS AND DISCUSSION

3.1 Film appearance

Figure 1 shows the dried film samples. The films were odourless and transparent. The films shrunk during drying, and the edges of the films were brittle. Despite that, they have an acceptable appearance, and they could be peeled from the Teflon plates without damage.

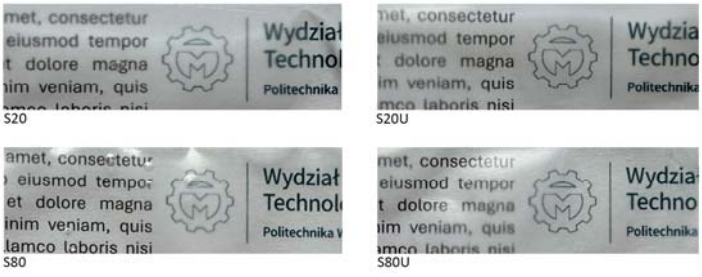


Figure 1: Film samples non-sonicated and sonicated treatment of starch film with 20% and 80% of GLY

3.2 Tensile properties

Average values of Young modulus (YM), tensile strength (TS), and elongation at break (EaB) are summarized in Table 2. The changes of YM, TS, and EaB are shown in Figure 2. The YM and TS decrease with the addition of GLY plasticizer. At the same time, the values of EaB increase, which is related to the higher flexibility of films with higher GLY content.

There is a slight increase in TS and EaB for low GLY values and a decrease in EaB for higher GLY values. For example, values of TS increased by approximately 20% after ultrasonication of starch-based films with 20% and 40% of GLY as a plasticizer. This observation contrasts with (Garcia-Hernandez, Vernon-Carter & Alvarez-Ramirez, 2017). Garcia-Hernadez et al. where the authors observed a decrease in TS and EaB with the sonification time.

Table 2: Mechanical properties of starch-based films: thickness (h), Young modulus (YM), tensile strength (TS), elongation at break (%)

Sample abbreviation	h [mm]	YM [MPa]	TS [MPa]	EaB [%]
S20	0.057±0.016	1313±53	36.4±2.0	4.8±1.1
S40	0.146±0.020	52.5±19.7	4.83±1.08	48±1
S60	0.114±0.007	15.8±2.3	2.66±0.37	70±2
S80	0.157±0.012	8.0±4.1	1.49±0.59	53±1
S20U	0.054±0.005	906±24	42.7±1.2	8.2±0.9
S40U	0.113±0.010	72.8±14.9	5.99±1.18	49±1
S60U	0.134±0.013	19.4±8.3	2.65±0.30	63±2
S80U	0.138±0.010	7.5±0.9	1.35±0.39	45±1

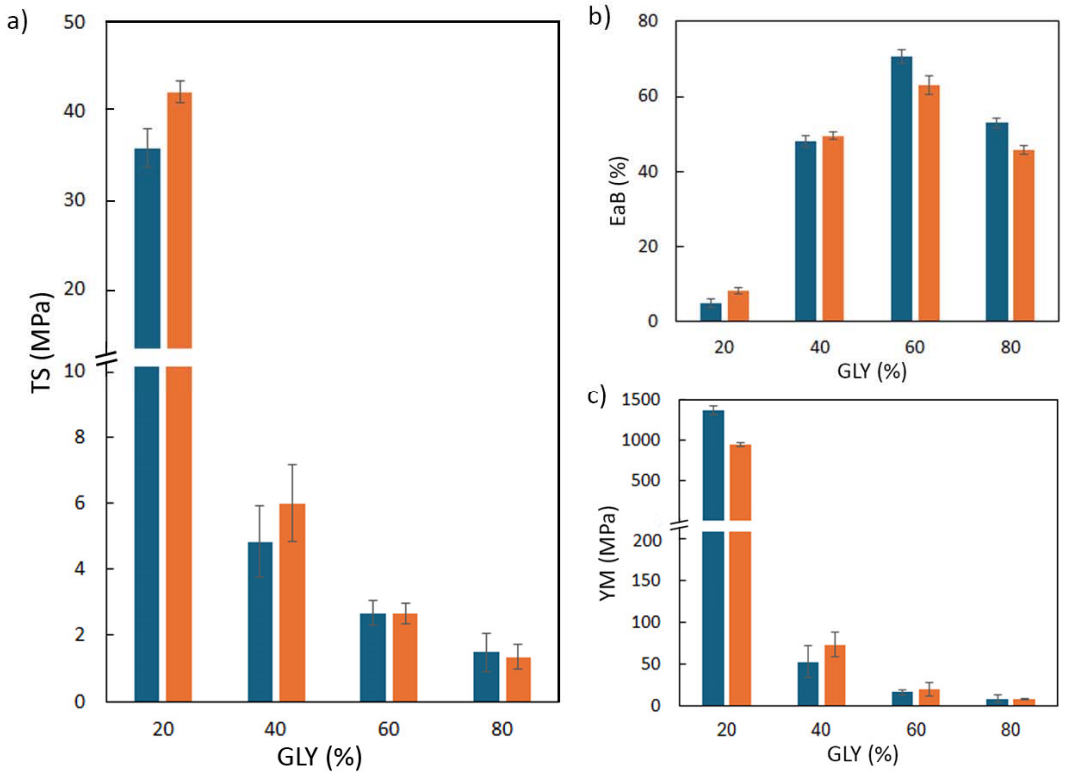


Figure 2: Changes of TS, EaB, and YM prior (blue column) and after sonification (orange column)

3.3 Surface properties

The results of the water contact angle, WCA, measurements are shown in Figure 3. The WCA values indicated the hydrophilicity (CA < 90) or hydrophobicity (CA > 90) of the surface (Sganzerla et al, 2020). Strach-based materials are mostly hydrophilic with great water affinity due to hydroxyl groups in the starch molecules. The values of WCA are in the range of 79.7±2.0 and 95.6±1.3° for S20 and S60U, respectively. The sonification treatment influences the hydrophobic character of the surface. After the sonification process, the WCA values of films with 20%, 40%, and 80% GLY content exceeded slightly 90° and amounted to 94.8+2.5, 95.6±1.3, and 91.4°, respectively. This observation agrees with (Abral et al., 2019). On the other hand, Gracia-Hernandes et al. reported decreased wettability and reduced WCA with the sonification treatment time (Garcia-Hernandez, Vernon-Carter & Alvarez-Ramirez, 2017).

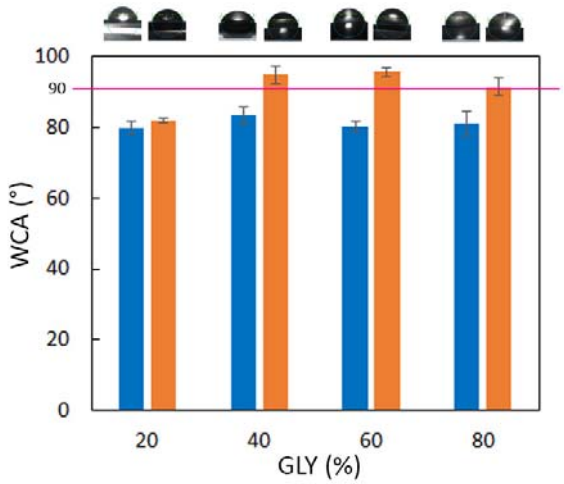


Figure 3: Changes of WCA prior (blue column) and after sonification (orange column)

The FTIR spectra in the range of 500 to 4000 cm^{-1} and the fingerprint region of the developed film are presented in Figure 4. Generally, the film spectra seem similar, and sonification does not affect the FTIR spectra of films. In terms of band shapes and intensity, slight changes may be observed. The typical characteristic peaks of native starch are also revealed in starch-based films. A broadband around 3300 cm^{-1} is attributed to O—H stretching vibrations. The peak near 2910 cm^{-1} is attributed to the C—H stretching vibration present in the starch molecules (Bergo, Sobral & Prison, 2010). The bands in the fingerprint region can be assigned to C–O bond stretching (Vicentini et al., 2005). Two peaks might be observed in this region: at 1015 and 994 cm^{-1}. The peak observed at 1015 cm^{-1} appears as a shoulder lower GLY concentration (S20 and S20U films) and becomes more prominent and presented for films with higher GLY content.

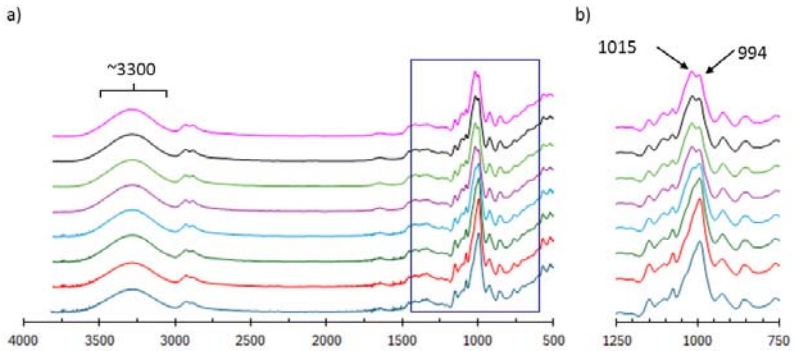


Figure 4: FTIR spectra for a) S20 (blue line), S20U (red line), S40 (dark green line), S40U (light blue line), S60 (violet line), S60U (light green line, S80 (black line) and S80U (pink line); b) fingerprint region

Table 3 summarizes the roughness profiles of the developed film surface, Sa. *S*a indicates the average roughness of a surface – the difference in height of each point compared to the arithmetical mean of the

surface. The *Sa* parameter decreases with the addition of GLY from 2.88 µm to 4.04 for S20 and S60, respectively. The *Sa* parameter is lower for S80 and equals 2.77 µm. The sonification treatment reduces the *Sa* values and the SEM analysis confirmed this observation.

Table 3: Surface roughness parameters of developed films

Sample abbreviation	***Sa*** **[µm]**
S20	2.88
S40	3.06
S60	4.04
S80	2.77
S20U	2.56
S40U	2.94
S60U	2.92
S80U	2.98

Figure 4 presents the samples' scanning electron microscopy (SEM) images. All the films showed smooth surfaces without cracks, breaks, or pores, indicating the excellent integrity of starch films. In the non-sonicated films, some impurities can be observed. This is related to the presence of partially gelatinized starch (Abral et al, 2019). This agrees with Liu et al, who reported continuous and uniform texture of the potato starch films after ultrasonic treatment (Liu et al., 2018b). Liu et al. suggested that the film-forming components become more compatible after ultrasonication treatment – ultrasonication results in a more regular, smothered surface without pores, cracks, and agglomerates.

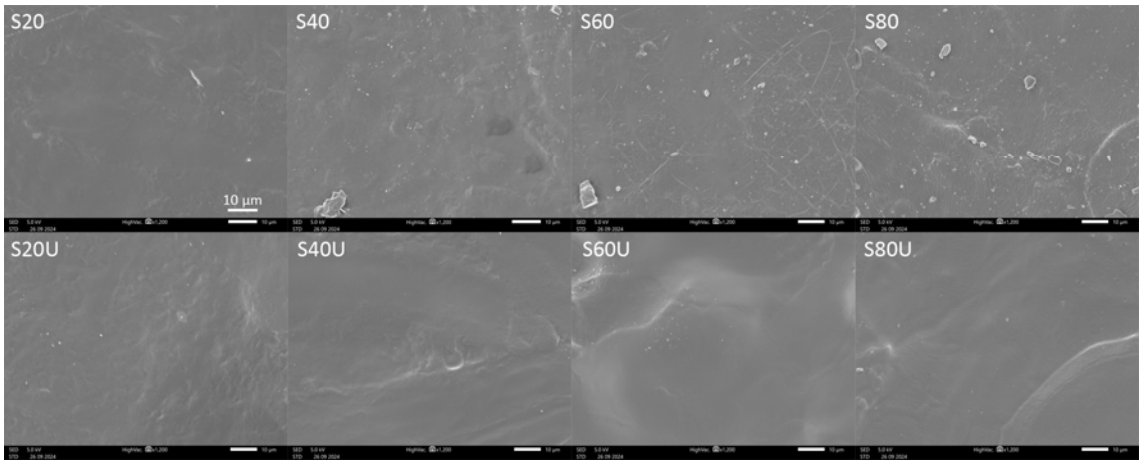


Figure 4: SEM structure photos of the films before (upper row) and after sonification (bottom row)

4. CONCLUSIONS

The study explores the effects of GLY content and sonification treatment on the properties of potato starch films. Adding GLY enhanced the films' flexibility, as evidenced by increased elongation at break, but decreased both tensile strength and Young's modulus. Sonification positively impacted mechanical properties for low GLY concentrations, increasing tensile strength and elongation at break.

The sonification treatment influences surface properties and increases hydrophobicity for treated films with higher GLY content. While the FTIR spectra remained largely unaffected by sonification, surface roughness (*Sa*) decreased, suggesting that sonification causes microstructural change. SEM images revealed smoother, more uniform film surfaces post-sonication.

In conclusion, the study demonstrates that ultrasonication can be a valuable tool for optimizing biodegradable starch-based films' mechanical, structural, and surface properties, particularly when combined with glycerol as a plasticizer, making these films potential candidates for packaging applications.

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DESIGN



https://doi.org/10.24867/GRID-2024-p59 Original scientific paper

IDENTIFICATION TENDENCIES IN THE ONOMASTICS OF NON-ALCOHOLIC BEVERAGE PACKAGING DESIGN IN AKURE, NIGERIA

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Abstract: *Non-alcoholic beverages (NAB) are widely consumed by diverse demography. Also, there are myriads of names for branding NAB for identification purposes. However, the proliferation of various naming styles on NAB packaging—such as cans, bottles, cartons, and plastics—can lead to misinterpretation, causing consumers to mistakenly associate these products with different categories. This misinterpretation can result in consumers spending more time searching for their preferred products or avoiding them altogether. Previous research highlights instances of negative brand names that evoke strong responses that may send contary signal. In Nigeria, despite the potential impact of such naming styles on consumer behavior, there has been little public outcry against them. This paper contributes to existing knowledge on product naming strategies by focusing on NAB packages commonly sold in Akure, Nigeria. Utilizing a quantitative research design associated with a survey method, the study involves visiting the Akure shopping mall to observe NAB package designs. The sample includes 184 NAB package designs across various categories: 37 milk brands, 46 soft drink brands, 31 wine brands, 38 fruit drink brands, 16 tea brands, 13 cocoa-based drink brands, and 9 coffee brands. Data collection methods include participatory observation, and the brands are classified based on onomastic styles. Participants aged 12 to 41 years observe a visual display (VD) of the sampled NAB, where only the names and shapes are available for viewing, with all other packaging variables eliminated to avoid noise. Participants then rate the ease of product identification on a scale from 5 (Very Easy) to 1 (Very Difficult). This study aims to examine how consumers perceive these brand identities in terms of onomastics, providing insights for stakeholders—brand managers, manufacturers, marketers, entrepreneurs, food regulation agencies, and designers—to achieve successful product branding.*

Key words: branding, consumers, NAB, onomastics, packaging design

1. INTRODUCTION

This study examines how non-alcoholic beverages (NABs) sold in Akure are identified by consumers, focusing on onomastic features and packaging form or shape. A product's identification is crucial because it directly connects the product to its characteristics. If a consumer has difficulty identifying a product, it becomes challenging to understand or describe its qualities. Successful identification occurs when the label or packaging clearly represents the product. In Akure, Nigeria, it may seem that NABs do not have identification issues, as there has not been significant public concern or media coverage on the matter. However, it is a truism that when a vulnerable consumer encounters unfamiliar onomastic features on product packages that fail to provide detailed information on the principal panel, misidentification or rejection of such product may occur at first encounter. It is expected that such brand should be involved in outdoor advertisements for the benefits of majority. Figure 1 shows a Nigeria nuclear family including children sitting together with their parent to enjoy their meal with a NAB called 'Veleta'. NAB brands are widely promoted through various outlets, with billboard advertisements (see Figure 1) in strategic locations suggesting that these brands are well-recognized (Oladumiye, 2013). However, these ads typically feature older, well-known brands, while newer brands often remain on store shelves or in the homes of those who buy them. Many of these new brands eventually become municipal solid waste (MSW), with their names and packaging often found discarded by the roadside or in waste bins. This suggests that some brands may be misidentified or mistaken for other products, likely due to their absence in public outdoor advertising in Akure. It is significant to carry out this study on NAB because they are widely consumed by diverse demography and there are non-edible products that resemble NAB in this present day ultramodern product design in terms of color, shape, and onomastic features to mention a few.

ORCID numbers are provided at the end of the paper.



Figure 1: Example of outdoor advertisement of NAB called 'VELETA' in Akure

There are myriads of names for branding NAB for identification purposes. However, the proliferation of various naming styles on NAB packaging—such as cans, bottles, cartons, and plastics—can lead to misinterpretation, causing consumers to mistakenly associate these products with different categories. This misinterpretation can result in consumers spending more time searching for their preferred products or avoiding them altogether. The challenge arises when vulnerable consumers encounter new products, especially when the names, packaging, or shapes are confusing or resemble other products. With the presence of international stores in Akure, consumers are increasingly exposed to both locally produced and imported NABs, making it likely they will encounter unfamiliar brands. Similarly, within households, vulnerable individuals may come across new or strange brands for the first time. For instance, products like Fabuloso, a brightly colored multipurpose cleaner with fruit on the label, which led to 94 cases of accidental ingestion in Texas (Miller et al., 2006), are now available in Akure. The packaging could easily be mistaken for a beverage, highlighting the risk. This issue is further complicated by the practice of reusing packaging waste for selling homemade beverages in Akure. Lax regulations on safe storage and packaging of household products in Nigeria lead to dangerous accidental ingestions of substance such as alcohol, diesel, insecticides, medicine, cosmetics, soap, shampoo and other household agents (WHO & UNICEF, 2008; Edelu et al., 2016; Ijezie et al., 2016) as result of reusing packaging similar to NAB within the household vicinity.

Beyond confusing packaging designs and shapes, another factor is the creation of distinctive product names that can lead to misconceptions. Consumers may spend more time searching for their preferred product, make incorrect choices, or avoid certain brands altogether. For example, brand names like Frog Piss, Fat Bastard, and Monster Energy Drink, which are known for their negative connotations, might be avoided by consumers if not properly advertised or explained (Guest et al., 2016) Moreover, based on pilot study, the growing number of NAB brands in stores does not correspond to the number of outdoor advertisements in Akure. Thus, this study assumes the possible propensity for identification error among vulnerable consumers.

In Figure 2, 'UK' is prominent on the principal panel of the white bottle of a yogurt drink while on the other side of the same bottle is the letter 'I'. This is a problem of typography as regard the management of length of words and visibility of important variables of the package design. This also affect the product identifier/descriptor as it is also overstretched and the contrast is also not good enough. The actual name of the yogurt is 'AUKI yoghurt' but poor design influenced the product identity. If compared with the 'Hollandia yoghurt' it will be seen that this problem is not present. Poor packaging design, often due to unskilled designers in Nigeria, also worsens the identification issue (Oladumiye, 2018). Thus, present study concerns the identification tendencies in the onomastics of non-alcoholic beverage packaging design in Akure, Nigeria by focusing on packaging form or shape and features that relates to the naming of the NAB.



Figure 2: Package label of 'AUKI yoghurt' in comparison to the package design of 'Hollandia Yoghurt'

1.1 Conceptual background of the study

The packaging of Non-Alcoholic Beverages (NABs) needs careful attention to ensure it promotes healthy consumption and supports sustainable development goals (SDGs 2, 3, and 11). Although these drinks are widely consumed, especially by vulnerable groups like children, pregnant women, the elderly, and the illiterate, there is often little concern about the potential risks posed by unusual packaging designs. These designs can be especially problematic for people who are inexperienced, tired, or distracted, leading to frustration, confusion, or misidentification of products.

In Akure, Nigeria, such packaging issues could prevent the achievement of SDG 3, which aims to ensure good health and well-being. If safety in packaging design is not prioritized, it could lead to several risks, such as confusion, accidental ingestion, longer time spent searching for the right product, and loss of consumer trust. For example, some packaging might mistakenly make a product appear non-alcoholic when it contains alcohol, or vice versa, which could have serious health consequences. Additionally, efforts by companies to create unique product names and designs might cause further confusion. When consumers spend extra time looking for their preferred product, it could be due to the packaging's shape, design, or naming features. It is crucial to address these issues to make sure that NAB packaging supports both healthy consumption and sustainable development.

1.2 Onomastic features and visual elements of non-alcoholic beverage packaging

Visual elements like shape, color, and label graphics significantly impact consumer impressions at first contact (Noble & Kumar, 2010; Marcell & Isaacson, 2015). These features form the aesthetic aspect of product packaging, enabling the product to reach its target audience quickly (Oluyemi, 2018). According to Poslon, Kovačević & Brozović (2021), shape and materials contribute to the packaging appearance in the aspect of revealing the quality of a product like coffee. The package shape/form (Poslon, Kovačević & Brozović, 2021), colors (Wei et al., 2015), illustration, and text elements (Pensasitorn & Disatapandhu, 2014) are for both attracting and providing information about the product (see Figure 3).



Figure 3: Graphical Elements in NAB Packaging Design (Pensasitorn & Disatapandhu, 2014)

Figure 3 shows the graphical elements in a particular NAB. The text elements are not only verbal languages on package design as seen in Figure 3 but they are also visual. Among the features of text elements are the onomastic features, typography, and other information. Onomastic features are the characteristics that relate to naming conventions and there are significant to the branding of non-alcoholic beverages (NABs). Williamson (2013) propounds that creators use a number of strategies in the naming process in order to achieve the desired end result. Examples include the use of compound words, sound symbolism, clipping of pre-existing words and blending, and combination of prefixes and suffixes. Naming conventions for beverage according to Haryati (2014) include blending, compounding, wishy-washy, onomatopoeia, and coinage. Others that are also very common include borrowing, clipping, acronym, and alphabetic abbreviations (Kabir, 2018); those that are not very common but also used are blending, compounding, and coinage (Kabir, 2018). An advantage of a coined name is that it has no prior meaning and is more likely to be usable in multiple languages and countries (Arthur & Bejaei, 2022).
Most of the products' names are created by applying borrowing and reducing words (clipping, acronym and alphabetic abbreviation) while fewer products' names are formed by applying blending, compounding, and coinage (Kabir, 2018). Basically, Schmidt (2011) in the psycholinguistic investigations of brands via word recognition and memory experiments classified them into image-oriented and self-descriptive. Guha (2010) shows that naming can be grouped as descriptive, person-based, associative, geographic, and alphanumeric. In a study by Forbes and Deans (2013), they are considered as regional, geographic, indigenous, animals, humorous, personal, and international. Cann (2014) classified them as color, informative, catchy, animals, and real words. Moreover, they are also classified as descriptive, suggestive, and empty vessel names (Catchword, 2014). In line with Williamson (2013), the focus of creator of these names should be to reveal how the product functions; as well as aid consumers' understanding and desired consumption of the product. However, it seems some of them tends towards causing misinterpretation which may not aid identification. The justification is that some of them prioritize trade mark ability of the names above easy product identification by avoiding genericide and also aiming at been more novel by deviating from the conventional norms. Thus, present study concerns the identification tendencies in the onomastics of non-alcoholic beverage packaging design in Akure, Nigeria by focusing on packaging form or shape and features that relate to the naming of the NAB.

2. METHODOLOGY

This study is a quantitative research design associated with a survey method to observe NAB package designs. The survey starts from January 2020 to February 2023 in the Akure shopping mall. It involves purposive sampling technique for collection of NAB package design. Participatory and observation methods are adopted as means of data collection. Pen and paper are used in recording the information during the survey. By observing NABs as displayed on the shelf (Figure 4), the names and package forms/shapes are recorded with the aid of pen and paper. Also, some of these products are also purchased during each visitation to the mall.



Figure 4: NABs displayed on the shelf within the Akure Shopping Mall

The sample includes 184 NAB package designs across various categories: 37 milk brands, 46 soft drink brands, 31 wine brands, 38 fruit drink brands, 16 tea brands, 13 cocoa-based drink brands, and 9 coffee brands. The next phase of the study involves the use of visual display (VD) of the sampled NAB, where only the names and forms/shapes are available for viewing, with all other packaging variables eliminated to avoid noise (Figure 5). This is line with previous studies on predictive packaging (Ares & Deliza, 2010; Velasco et al., 2014; Oluyemi, 2018; Poslon, Kovačević & Brozović, 2021;) that investigates certain design variables for NABs' product quality that aligns with consumers' expectation.



Figure 5: Development of Research Stimuli for NAB packaging as regards forms/shapes (Oluyemi, 2018)

These stimuli are shown to one hundred participants whose age range from 12 to 41 years. The participants include 80 consumers of only non-alcoholic beverages (NABs) while the remaining 20 participants are consumers of both alcoholic beverages (AB) and NAB. 12 to 15 years only consumers NABs; 16-41 and above consists of those who consumers both NAB and AB. Majority of the participants are also male while 44 are female participants.

Microsoft Excel and IBM statistics 23 are the tools used for analysis of the collected data. Some of the data are also presented by using set notation, pie chart, perceptual mapping and bar chart. Participants rate the ease of product identification on a scale from 5 (Very Easy) to 1 (Very Difficult) when the stimuli are displayed.

3. RESULT AND DISCUSSION

3.1 Identification of NAB in terms of Package Form/Shape Categories

Figure 6 shows the identified package shapes/forms in which selected NAB product brand are sold in Akure. One of the distinctive observations in figure 6 is the variation in sizes of the package shapes. The NAB packaging are classified into twenty three forms/shapes (see Figure 6); namely, can with opener (A), can without opener (B), big can with replaceable lid (C), small can with replaceable lid (D), cup (E), box (F), folding carton (G), standing pouch without sprout (H), standing sprout pouch (I), metallic tub (J), plastic tub (K), big pillow-shaped pouch (L), small pillow-shaped pouch (M), thin polyethylene pouch (N), glass bottle (O), plastic bottle (P), flat faceted plastic bottle (Q), long faceted plastic bottle (R), faceted plastic bottle with handle (S), Tetra classic aseptic (T), Tetra brik aseptic (U), Tetra prisma aseptic (V), and Tetra rex (W).

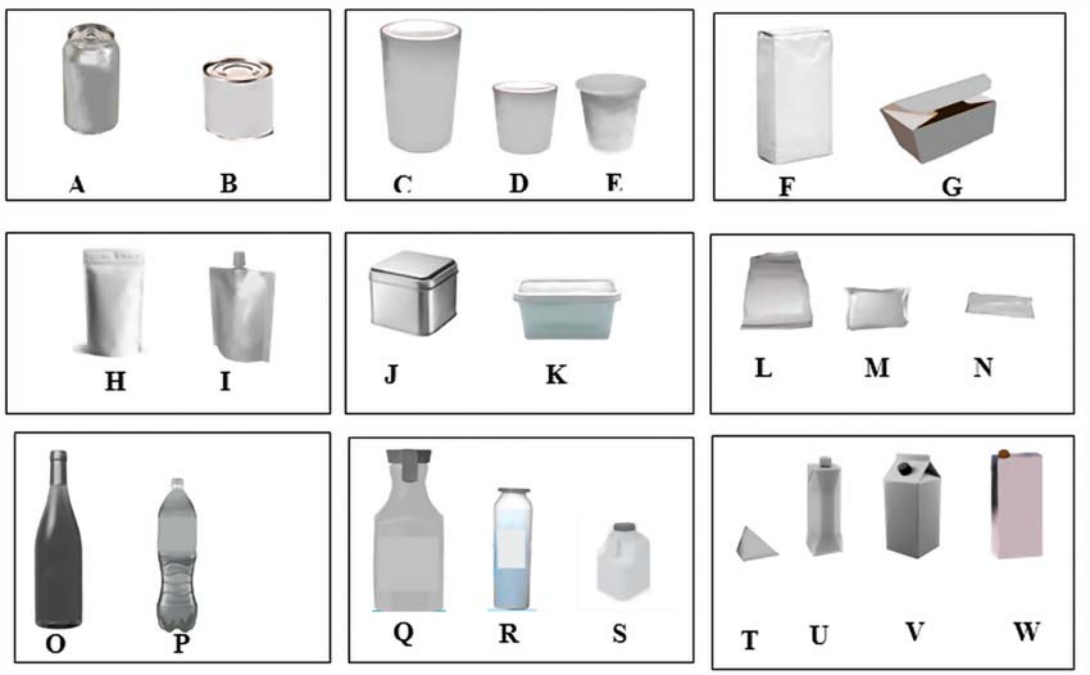


Figure 6: Identified shapes in which NAB Product Packaging Forms exist in Akure

Set notation in terms of set's elements is used to enumerate the package form/shape in which the selected NABs are enclosed, for example: milk-based drink=(A, B, C, D, E, F, I, K, L, M, N, O, P, Q, R, S, T, U, V, W); fruit drink=(A, C, D, I, L, M, N, P, Q, S, T, U, V, W); soft drink=(A, G, I, J, L, P, T); coffee=(A, C, D, F, G, H, L, M); tea=(G, L, H, M); cocoa-based drink=(A, C, D, F, G, L, P, T); and wine=(A, O). The results in Figure 7 is a bar chart showing the amount of the package forms/shapes predominate in the branding of the selected NABs in Akure, Nigeria.

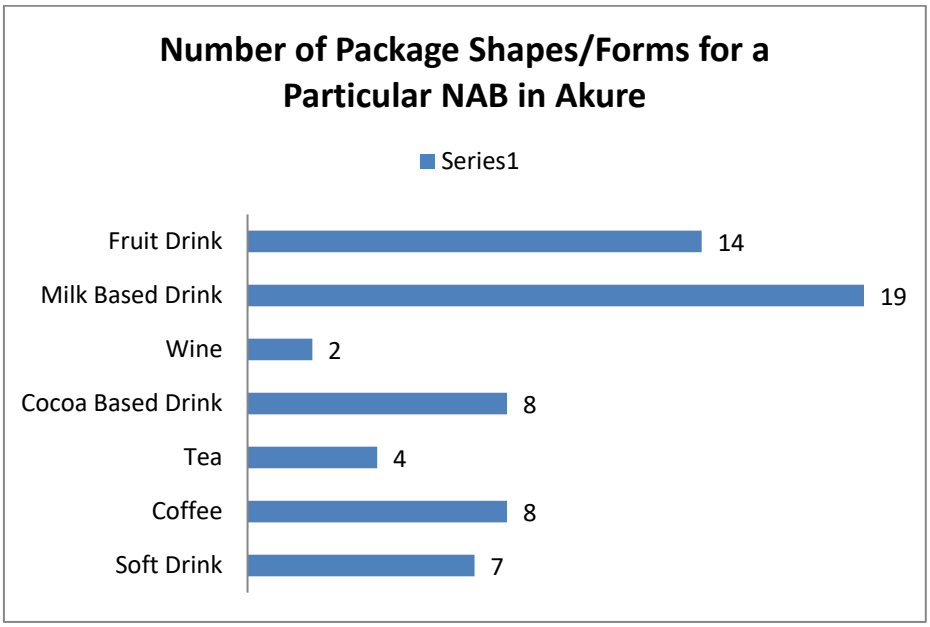


Figure 7: package forms/shapes predominate in the branding of the selected NABs

The numbers in the bar chart are obtained by counting the numbers of set's elements of package forms used for packaging each selected non-alcoholic beverage (NAB). Among the selected NABs, a particular milk-based product exists in 19 different package forms/shapes; fruit drink exists in 13 different package forms/shapes; wine and tea exist in just 2 and 4 forms/shapes respectively; cocoa based drink and coffee exist in 8 different package forms/shapes and soft drink exists in 7 different package forms/shapes (see

Figure 7). In Figure 7, wine exists in the lowest number of package form/shape while milk-based product exists in the highest numbers of package form/shape. By using set notation, wine and tea are not existing in similar package shape/form as seen in equation (i). Can with opener (A) is common to wine, soft drink, coffee, cocoa, milk-based NAB, and fruit drink excluding tea (see equation ii). In equation (iii), soft drink, coffee, tea, milk-based products, and fruit drinks have big pillow-shaped pouch as their common package form/shape.

- (Wine ∩ Tea) = {∅}.....(i)
- (Wine ∩ Soft Drink ∩ Coffee ∩ Cocoa ∩ Milk∩ Fruit Drink) = (A).....(ii)
- (Soft Drink ∩ Coffee ∩ Tea ∩ Cocoa ∩ Milk ∩ Fruit Drink) = (L).....(iii)

In Figure 8, dimension 1 represents packaging multiplicity on the x-coordinate while dimension 2 represents packaging individuality in y-coordinate. There is certain level of closeness among NAB packaging as regards how selected NAB sticks to a few specific packaging form/shape. Cluster of NAB in particular quadrants are obvious; for example coffee and soft drink; fruit drink and wine; cocoa and milk are together. Each cluster is perceived to use similar types of packaging. This suggests that, at a glance, consumers may not see a huge difference between the packaging form/shapes of these product categories. Examples are the NABs of high packaging multiplicity and low individuality (.e.g. milk based drink and cocoa based drink) because they exist in more diverse range of packaging forms/shapes and overlap with packaging forms/shapes of other NABs.

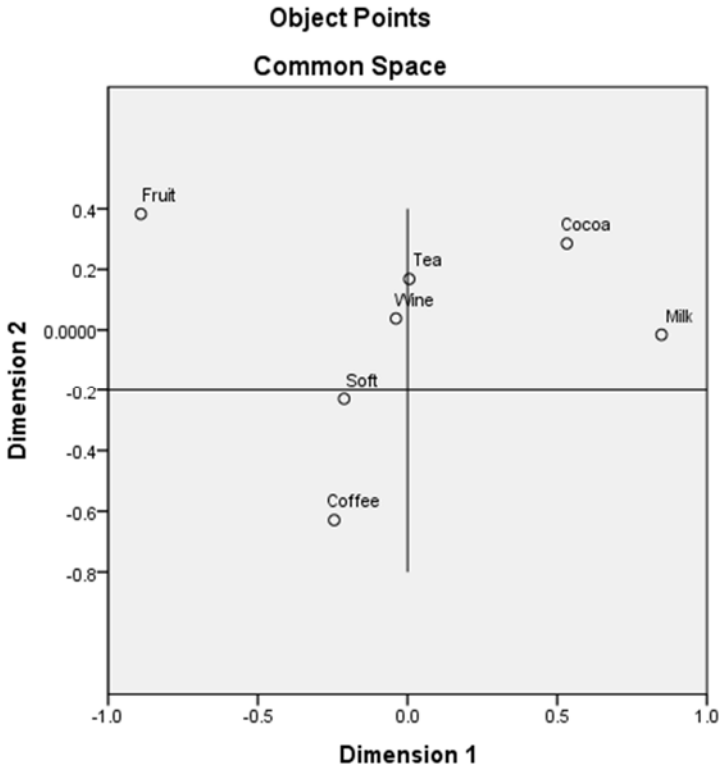


Figure 8: Perceptual map for closeness among NAB packaging as regards forms/shapes

As it can be seen they are in the positive area - signifying some similarities. Fruit drink also exist in similar package form/shape to wine but in very few occasions. This may lead to challenges in brand recognition, product differentiation or identification among similarly looking package form/shape except if the onomastic features can aid identification properly and visible across packaging forms. NAB with low packaging multiplicity are available in few package form/shape as well as have less of overlapping with many other NABs (e.g. tea and wine). As it can be seen, tea and wine are separated closely by the x-axis. This signifies that they are very different. This is expected to minimize identification problem.

In overall, there is no common product packaging form/shape for all NABs; accordingly, this is expected to aid brand recognition, product identification, and differentiation devoid of confusion. In overall, NAB

product packaging form/shape in Akure are not stereotyped to a particular group of selected Non-Alcoholic Beverages. This is also ascertained by the data presented in Table 1. The stress and fit measurement shows that stress value (0.22252) is higher than 0.10; Tucker's coefficient of congruence also shows a perfect fit of 0.93264 (see Table 1). There is a null set for the intersection of NAB packaging as shown with the aid of set notation: (Wine ∩ Soft Drink ∩ Coffee ∩ Tea ∩ Cocoa ∩ Milk ∩ Fruit Drink) = {Ø}.....(iv)

Table 1: Stress and Fit Measures

Normalized Raw Stress	.13019
Stress-I	.36082[a]
Stress-II	.86519[a]
S-Stress	.22252[b]
Dispersion Accounted For (D.A.F.)	.86981
Tucker's Coefficient of Congruence	.93264

3.2 Identification of NAB in terms of its Association to Alcoholic Beverage (AB)

Majority of the participants find it difficult to identify non-alcoholic beverages (NAB) that are branded under family branding despite the availability of their advertisements among outdoor advertisements in Akure. According to Johnson 1988, some attributes shared by products from different categories can be used to evaluate all of them despite been of different categories. This may be happening to participants because of the onomastic features or package form. Participants doubts the identity of the non-alcoholic beverages thinking it is also in the same category with the alcoholic category. More than 20 consumers of alcoholic beverages (AB) doubt the identity of the NAB. This means it includes both consumers of NAB and AB. Probably, the advertisements are not effective in terms of frequency of exposure in Akure. This is because the pilot study carried out along Akure roads and junctions shows that out of five locations close to FUTA, only two display poster designs in public spaces where they can be seen and there are no billboard advertisements of the brands. In Figure 9, 63 percent agreed that the NAB are easily identified when they do not belong to a family brand that also produces alcoholic beverages.

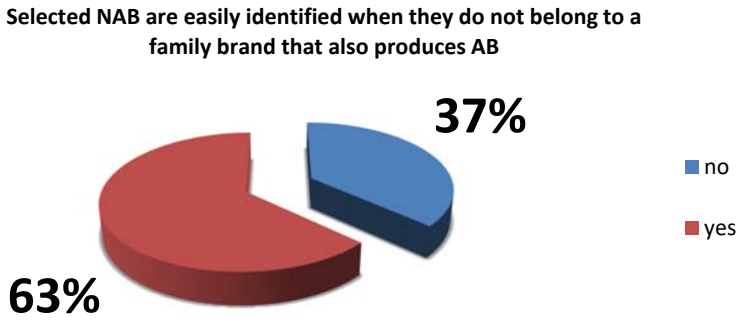


Figure 9: Pie chart showing consumers' perception about family branding in NAB packaging

The reverse is the case for other NABs that belong to family brands but are strictly focused on NAB production without extending to alcoholic beverages (ABs). In family branding, all products use the same means of identification and have no additional brand names or symbols attached (Healthy Eating Research, 2015). All products are branded with the same name (Musa, 2015).

3.3 Identification of NAB in terms of Onomastics Features

In Figure 10, NAB with alphanumeric names are very easy to identify with 23%, probably because of the product descriptor included in the package labeling as well as the consumers' familiarity with the brand names. 32% of the respondents find it somehow difficult to identify NAB labeled with alphanumeric names. Present study reports another aspect of how consumers process alphanumeric brand names different form that of prior study (e.g. Yan and Duclos, 2013). In present study, an average percentage of

32% finds it somehow difficult to identify alphanumeric onomastic features. This shows that majority finds it somehow difficult to identify. According to prior study, anchoring theory of alphanumeric names helps them to correctly associate the product name. They propose that the anchoring effect comes from the numbers in denoting certain attributes of the products positively. However, present research detects that the anchoring effect for identifying NAB with alphanumeric names might be as result of the product descriptor or suggestive names which some of the alphanumeric names have. In Figure 11, NAB with eponym are easy to identify with 24% while 38% finds it difficult to identify, probably because of the product descriptor included in the package labeling as well as the consumers' familiarity with the brand names. Present research detects that the commonness of eponym in the naming of brands have assisted the consumers to believe positively in their encounter with NAB branded with eponym. In the research carried out by Forbes and Dean (2013), NAB (e.g wines) having eponym relate to dignity, honour prestige and respect. An average of 18% finds NAB branded with eponym somehow difficult while a large percentage of 38% find it difficult. This is shows that any product that will be branded with eponym must make the product descriptor/identifier very prominent.

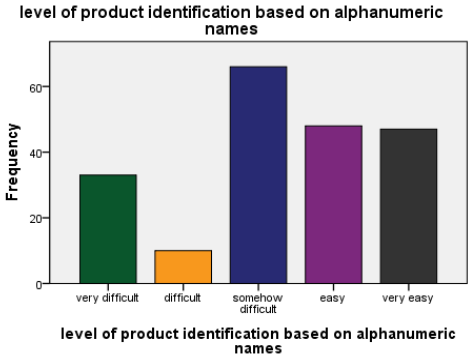


Figure 10: identification in terms of alphanumeric onomastic features

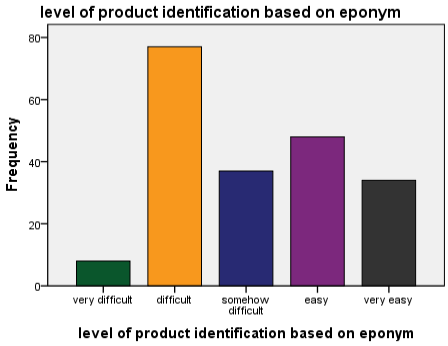


Figure 11: Identification in terms of Eponym

Also in Figure 12, NAB with homonyms are easy to identify with 38% while 24% find it very easy to identify, probably because of the product descriptor included in the package labeling as well as the consumers' familiarity with the brand names. Present research detects that the homonyms are product suggestive and positive-related probably because of the sound. A sound that seems related to the language of consumers in Akure shows a positive perception of NAB, hence, they are rightly identified.
In Figure 13, descriptive names on NAB are somehow difficult to identify with 48%. This could be as a result of the effect of the use of bizarre brand names which might have actually made intending consumers find it hard to believe any names either descriptive or strange without any actual description of the product. The package form used as container for the NAB might also be the reason for this perception. One would presume that descriptive names would be very easy to be identified; surprisingly, they are found to be somehow difficult. However, 19% of the respondents perceived that NAB with descriptive names are easy to be identified. This is not a surprise because they are expected to be identified.

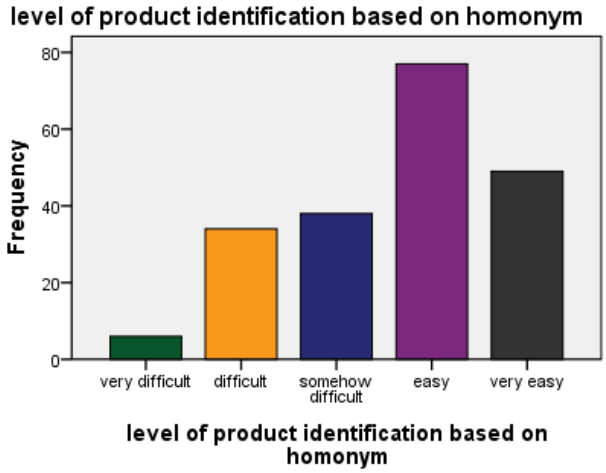


Figure 12: Identification in terms of homonym

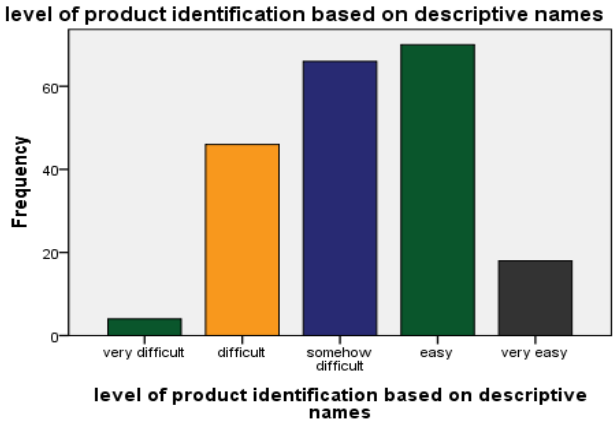


Figure 13: Identification in terms of descriptive onomastic features

Likewise in Figure 14, fanciful names on NAB are somehow difficult to identify with 38% while 20% find it very easy to identify. This could be a result of the effect of the use of bizarre brand names which might have made intending consumers find it hard to believe any names either descriptive or strange without any actual description of the product. The package form used as container for the NAB might also be the reason for this perception.

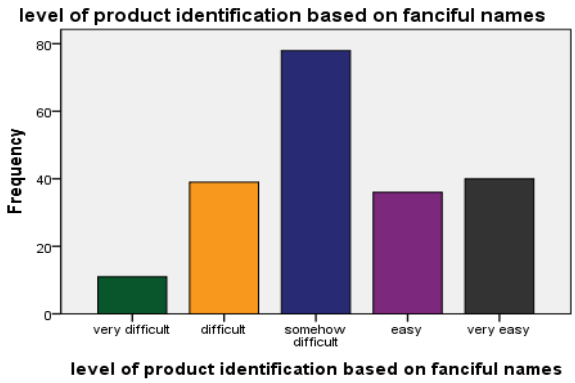


Figure 14: Identification in terms of fanciful names

In Figure 15, NAB with generic names are very easy to identify with 34% while 31% finds it easy to identify, because of the generic names used are the common names for the NAB. However, trademark

law encourages the avoidance of generic names, the Food, Drugs and Related Products (Registration, etc.) Act. (1993), demands for the use of generic on NAB packaging for easy identification (UK Statutory Instruments, 2013) even while using bizarre names.

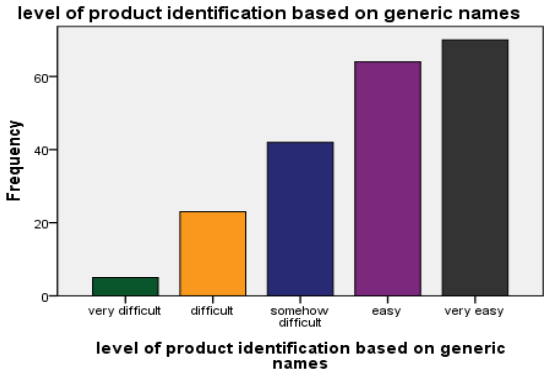


Figure 15: Identification in terms of generic names

In Figure 16, NAB with abbreviations are somehow difficult to identify with 34% while 19% find it very easy to identify, probably because of the descriptor included in the abbreviation and the packaging form used for NAB design. An average percentage of the respondents perceive NAB with abbreviation to be somehow difficult to identify.

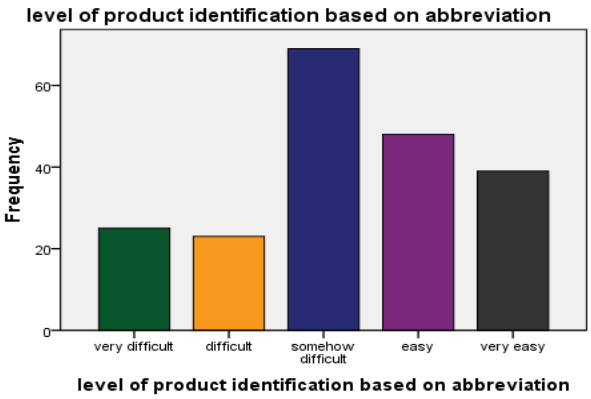


Figure 16: Identification in terms of abbreviation

Arbitrary names on NAB are somehow difficult to identify with 35.3% while 14.1% perceived that NAB with arbitrary names are difficult to be identified. The majority perceived that NABs with arbitrary names are difficult to identify. This could be as a result of the bizarre nature of the names which might be hard to believe as an actual description of the product. The package form used as a container for the NAB might also be the reason for this perception. It is not surprising that arbitrary names are difficult to be identified by the majority. Trademark law encourages the use of arbitrary names, given this the Food, Drugs and Related Products (Registration, etc.) Act. (1993), demands the use of generic on NAB packaging for easy identification (UK Statutory Instruments, 2013) even while using arbitrary names.

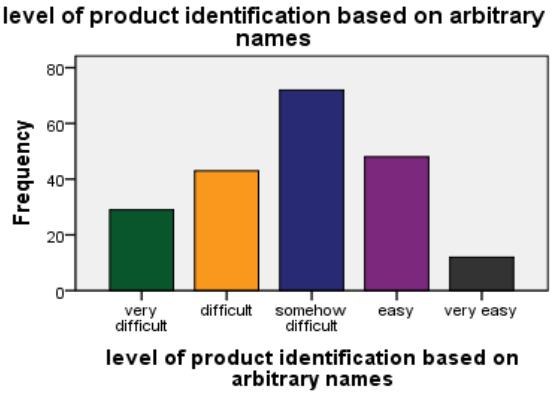


Figure 17: Identification in terms of arbitrary names

In Figure 18, the use of toponyms on NAB is somehow difficult to identify with 48%. According to Forbes & Dean (2013), they only perform respectably and are easy to pronounce so they can also be helpful for a new wine brand. In such situation, the package form e.g. glass bottle would assist intending consumers to easily identify them. The research of Oladumiye et al., (2018) on the visual typicality of Non-Alcoholic Beverages in Akure also reports that glass bottle is the predominant form most identified as the NAB packaging for wine. This shows that both appropriate easy to identify typical package shape/form and onomastic features should be adopted for the NAB package brand.

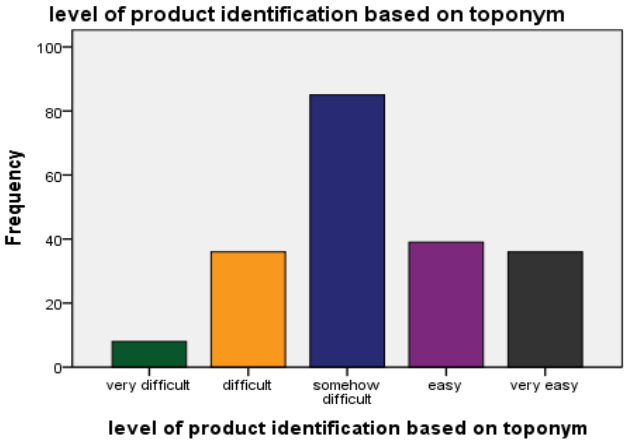


Figure 18: Identification in terms of toponym

In Figure 19, suggestive names on NAB are very easy to identify with 28%. The majority perceived that NABs with suggestive names are very easy to identify. This is not surprising because Catchword (2014) explains that they are the most popular kind of brand name which are also communicative in showing features and benefits of the goods being offered.

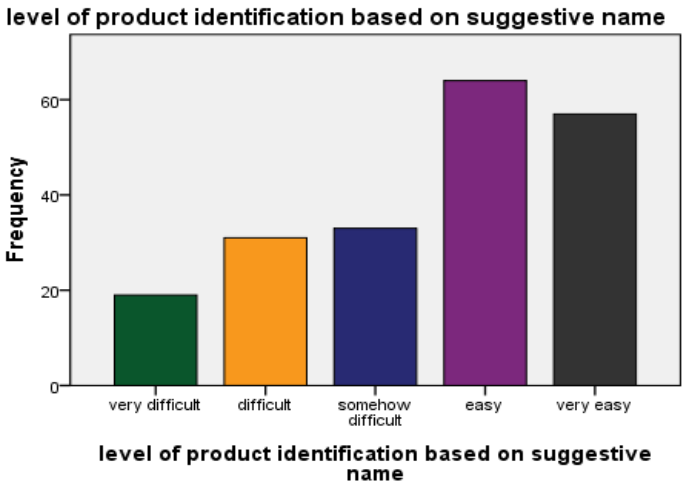


Figure 19: Identification in terms of suggestive onomastic features

In Figure 20, onomastic features are considered by participants to be more influential than package shape/form in terms of easy NAB product identification. 40% of the participants strongly agree that onomastic features are more influential than the package form/shape while only 1% strongly disagreed. This may be because product packaging form/shape for all NABs in Akure are not stereotyped to a particular group of selected Non-Alcoholic Beverages (NAB). Although, brand naming styles are not also stereotyped to a particular group of selected NABs, but there are onomastic features such as the identifier or descriptor that serve as anchorages to assist in easy NAB classification and identification. Also, there are some prefixes and suffixes in the names that could suggest NAB products.

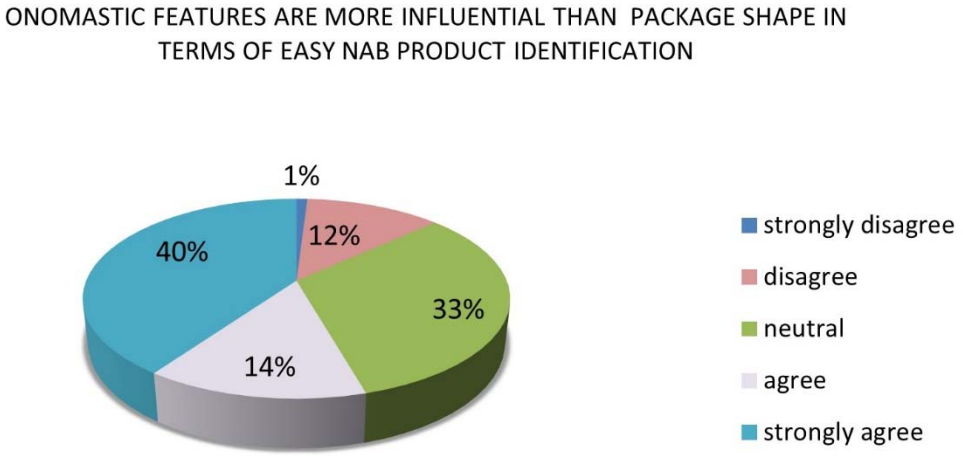


Figure 20: Comparing onomastic features and package form/shape in terms of NAB identification

In Figure 21, search time for preferred NAB is quicker when product names are used as means of distinguishing or identifying them than when package shape/forms are used. This is one of the reasons why suggestive names and other anchorages to other naming styles can be tailored towards brand recognition, product identification and differentiation devoid of confusion. Figure 21, shows that 52% of the participants strongly agreed that product name will reduce prolong search time for preferred NAB than the package shape.

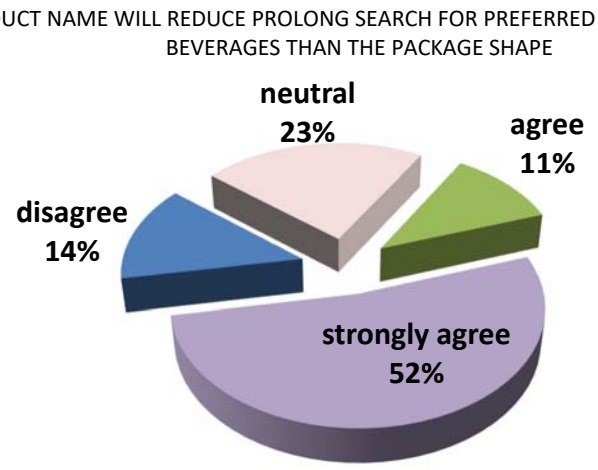


Figure 21: comparing package form/shape with onomastic features in terms of search time

4. CONCLUSION

Easy identification of preferred non-alcoholic beverages (NABs) in terms of correct selection or choice, categorization, comprehensible and proper use/re-use of packaging can contribute positively towards achieving SDGs 2, 3, and 11; namely: zero hunger, good health, and well-being, sustainable cities and communities. A product package design that aids appropriate choice, product categorization, understanding, and proper re-use of packaging will aid the well-being and safety of vulnerable consumers. Efficient product identification and categorization can lead to reduced food waste by ensuring consumers choose the right products, enhance consumers' trust and satisfaction, improve supply chain as well as foster sustainable communities. Eventually, this will facilitate access to correct information devoid of confusion, errors and waste. This will also enhance the overall well-being of the vulnerable consumers. By making product identification easier, we can create a more sustainable and equitable future, aligning with the sustainable development goals (SDGs). Thus, the present study examines how consumers perceive the NAB brand in terms of onomastics, providing insights for stakeholders—brand managers, manufacturers, marketers, entrepreneurs, food regulation agencies, and designers—to achieve successful product branding. Apart from product identifiers or indicators and other captions that are descriptive of th products' function and benefits, the following are diverse brand naming styles appended on NAB packaging; namely: alphanumeric names, eponym, homonym, generic names, abbreviation, arbitrary names, toponym, and suggestive onomastics.

Present research detects that homonym used for NAB are onomatopoeic. Thus, they are product suggestive because some brand names' sound seems related to the language of consumers in Akure. This reflects positive perception of NAB, hence, they are rightly identified. The use of bizarre names as eponym, abbreviation, descriptive, toponym, fanciful, and alphanumeric onomastic features on NAB can actually make intending consumers find it hard to believe in the actual description of the NAB product. This shows that any product that will be branded with any naming style must make the product descriptor/identifier very prominent. This is in line with NAFDAC (2021) that the generic or common name shall be printed in letters that are as large and visible as those of the brand (proprietary) on both the principal panel and other labeling components. NAB brand that elaborates on generic names as common names are more identifiable than any other onomastic features. The avoidance of generic names due to trademark ability or strength should be moderated. This is in line with the Food, Drugs and Related Products (Registration, etc.) Act. (1993), which demands the use of generic on NAB packaging for easy identification (UK Statutory Instruments, 2013). The fact that consumers can confuse a trademark as a fruit varietal name should not cancel trademark rights if such a product brand is considered as a strong trademark at the genesis of such product brand. There should be room for moderation. It is a general observation that even old brands like 'Coke' for Coca-Cola are now used as generic names for any carbonated drink in Akure due to their extensive popularity in the public space.

The package form used as container for the NAB can also be the reason for misidentification. In this study, package shape/form associated to selected NAB shows that some of the NABs (e.g. milk-based

drinks and fruit drinks) overlap with other NAB categories due to high packaging multiplicity (.i.e. the use of many diverse package forms/shapes but similar to the package form of other NAB categories). The shape and size of a can with an opener are also found to be common to the majority of NAB; also big pillow-shaped pouch is also common. Accordingly, consumers depend more on the use of onomastic features for NAB product identification than package shape. For instance, the study outcome shows that search time for preferred NAB is quicker when product names are used as means of distinguishing or identifying NAB than when package shape/forms are used. This is one of the reasons why suggestive names and other anchorages to other naming styles are more tailored towards brand recognition, product identification and differentiation. This helps to identify the gap that more package forms or shapes needs to be designed in categorical manner that will typify product categories. For instance, fruit drink should have package form/shape that will be different from wine. This also necessitates the importance of package size. In situations when the package form or shape of a particular NAB is similar to one another, the package size can help in distinguishing them. In this study, majority perceived that NAB with suggestive names are very easy to be identified. This is in accordance to prior study that they are communicative in showing features and benefits of the goods being offered.

This study shows that family branding is good for easy identification of NAB but it is favorable for producers that stick to only NAB. Accordingly, majority of the participants find it difficult to identify non-alcoholic beverages (NAB) that are branded under family branding despite the availability of their advertisements among outdoor advertisements in Akure. The reverse is the case for other NABs that belong to family brands that are strictly focused on NAB production without extending to alcoholic beverages (AB). The recommendation is that whatever strategy that are used in creating names for NAB, the onomastic features should reveal product functions as well as aid consumers' understanding. The recommendation for trademark that are highly fit as trademark is that they should deviate from implicit description that lack meaning that relates to NAB. They used also engage in frequent advertisements by using all media, especially sustainable outdoor advertisement. Producers of alcoholic beverages should use brand architectures that will not cause confusion or identification error when extending their product line to include NAB. Individual branding, endorsed branding and any other brand architecture will be better than family branding in such situation of extending from alcoholic to non-alcoholic and vice-versa.

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MODERATION OF CONSUMERS' CONFUSION IN THE ATYPICALITY OF PACKAGING DESIGN THROUGH THE USE OF E-LABELING TOWARDS SUSTAINABLE CONSUMPTION

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Abstract: *This study aims to explore how e-labelling can moderate consumer confusion caused by atypical packaging designs, thereby promoting sustainable consumption. The pursuit of sustainability in product packaging has prompted the quest for exploration of various innovative approach to reduce environmental impact while maintaining user friendly interface for consumers. Utilizing a literature review to establish the theoretical framework, the research employs focus groups and Delphi techniques for data collection. The focus groups, comprising diverse consumer segments from Akure, Nigeria. The Delphi technique engages a panel of experts, including brand managers, marketers, and packaging designers, to achieve a consensus on the efficacy of e-labelling in mitigating confusion. Findings from the literature review suggest that clear and informative e-labels can significantly enhance product identification and reduce confusion. Focus group discussions reveal that consumers are receptive to e-labels, appreciating the additional information that aids in quick and accurate product recognition. The findings of the study shows that e-labelling will enable circular economy and environmental sustainability by preventing material waste. it may help reuse of product package as well as encourage recycling through education that can be provided. Also, e-labelling is considered preferable because it will enable comprehensive product packaging design due to its adaptation for multilingual content and real time update. In conclusion, the integration of e-labelling into sustainable packaging design represents a promising avenue for reducing environmental impact, enhance consumer engagement and drive innovation in the packaging industry. The Delphi panel supports these findings, emphasizing the role of e-labels in fostering sustainable consumption by reducing waste and promoting informed purchasing decisions. This study contributes to the body of knowledge on sustainable packaging practices and offers practical implications for stakeholders. By demonstrating the potential of e-labelling to alleviate consumer confusion, the research provides a pathway towards more sustainable consumption patterns in Akure, Nigeria.*

Key words: Atypicality, consumers' confusion, design, e-labelling, physical label, sustainable product packaging

1. INTRODUCTION

Casually, “sustainable consumption” can be seen as ‘the ability to maintain the use of available resources. The term is viewed by some researchers as a consumption pattern focused on not jeopardizing the needs of future generations (Bennett & Collins, 2009; Lee, 2014; Mont & Bleischwitz, 2007). It can be considered as a consumption that is based on informed choice. Informed choice is based on having good knowledge and rationale for making the right decision (Thorpe, 2010). According to Thorpe (2010), a change of lifestyle in terms of consideration for efficient resource consumption and waste minimization is germane to sustainable consumption. According to Thorpe (2010), this involves two sides; namely supply and demand. In terms of supply, this involves producing less environmentally damaging goods, and in terms of demand: it will be necessary to educate consumers about these improved goods. Thus, present study considers the moderation of consumers' confusion in the atypicality of packaging design through the use of e-labelling towards sustainable consumption due to the increasing non-food designs resembling food items (Buchmüller et al., 2022). There are category-based visual codes that could be followed to avoid such confusion in the aspect of graphic design innovation (Celhay et al., 2017) but atypicality of packaging design deviate from these norm, standard, conventional, or usual design. Fishel (2003) in Celhay, Folcher, & Cohen (2013) report that product designers and marketing managers agree that there are category-based visual codes, in terms of package design, that typify certain product categories. Examples include specific form, shapes, colours, materials, typefaces, layouts, and illustrations most frequently seen in a given product category. It is the notion of present study that this may help in contributing to consumers' safety. Atypical

ORCID numbers are provided at the end of the paper.

designs may pose greater risks to vulnerable consumers, including children and those with limited literacy, who may struggle to comprehend warning labels, leading to misidentification and misuse. Adults, as shown in a study by Basso et al. (2014), unintentionally mistake dangerous products for edible ones. If safety in packaging design is not prioritized, it could lead to several risks, such as confusion, accidental ingestion, longer time spent searching for the right product, and loss of consumer trust. In this study, it is assumed that these issues of atypicality could prevent the achievement of SDG 3, which aims to ensure the well-being and health of the consumers except if improved by providing enough information.

2. METHODS

This study utilizes a literature review to establish the theoretical framework and employs focus groups together with Delphi techniques for data collection. The Delphi technique engages a panel of experts, including brand managers, marketers, and packaging designers, to achieve a consensus on the efficacy of e-labelling in mitigating confusion. Delphi techniques does not require large samples(Hsu & Lin, 2013). The Delphi method engages anonymous experts on a particular topic. Anonymous experts offer professional experience, knowledge skills and opinions, and exchange views with other experts until a consensus is reached. For the Delphi participants, only 7 people are involved. The focus groups, comprising diverse consumer segments from Akure, Nigeria. A partially structured focus group discussion is employed. The interviews are conducted in four phases: planning, participant recruitment, conducting interviews, data collection, and interpretation of obtained data.

2.1 Planning Phase and participants' recruitment

The purpose of the focus group discussion is to ascertain that consumers are interested in the use of e-labels. For this purpose, consumers of household products especially those that are aware of the presence of some non-edible products imitating edible product design in Akure, Nigeria are involved. An announcement soliciting voluntary participation is made to 30 potential consumers of household products. To ensure anonymity, the specific identity or location of the consumers remains undisclosed, as per the agreement with the participants. Next, the investigation's questions and the focus group's principles (agenda, timing, location, audio recording) are presented to the participants.

2.2 Conducting interviews and data collection

Two research assistants facilitate the interviews: one conducts the interview, while the other listens. The interviews are recorded using mobile phones and conducted in a distraction-free environment. On average, each interview lasts for 10 minutes

2.3. Sample Description

Twenty-four (24) out of the 30 potential consumers volunteer to participate in the study. Accordingly, participants are assigned numbers from 1 to 24 for identification. Four (4) focus group sessions are conducted with the participants' ages ranging from 15 to 58 years old. Table 1 provides further details regarding the sample composition.

Table 1: Demography of Participating Consumers

Focus Group (FG)	Participants' Age	Numbers of participants	Participants by Gender	
			Male	Female
FG1	15-25	6	3	3
FG2	26-36	6	3	3
FG3	37-47	6	3	3
FG4	48-58	6	4	2
Total		**24**	**13**	**11**

The execution and topics of the focus group interviews are carefully designed to facilitate open and descriptive discussions among participants. The questions are straightforward, avoiding simple yes or no answers, and encouraging participants to provide detailed responses. Participants are given the

opportunity to express their opinions, experiences, and disagreements without interruption. The questions allow multiple responses, fostering a rich exchange of ideas. The interviews focus on various aspects related to the extraction from literature review concerning e-labelling in relation to atypical package with the view of moderating confusion and its advantages for sustainable consumption. The challenges of adopting e-labelling and their interest in or acceptance of e-labelling are also discussed.

3. RESULT AND DISCUSSION

3.1 Findings through literature review to establish the theoretical framework

The Packaging Institute International defines packaging as the enclosure of products, items, or packages in a wrapped pouch, bag, box, cup, tray, can, tube, bottle, or other container form to perform one or more of the following functions: containment, protection, preservation, communication, utility and performance (Saka, 2011). Physical protection, barrier protection, information transmission, reducing theft, convenience, and marketing to mention a few are the vital significance of product package design (Grundey, 2010). Packaging preserves and protects its products from the hazards of the distribution cycle. Young (2003) considers some threats to packaging design and expresses his attitude in the following statement: "The most attractive or popular design is not necessarily the most effective one at the point of sale, because it may fail to communicate a key message quickly and clearly. This necessitates the need for sustainable packaging design not only in material consideration but also in graphical communication. Sustainable Packaging Coalition. SPC considers sustainable packaging as packaging that throughout the entire life cycle is beneficial, safe, and healthy for individuals and society as a whole (Kozik, 2020). According to Kozik (2020), such package design should meet the expectations and needs of consumers. Through these means, it helps to reduce product waste and conserve resources. The key measurement tool to assess a product's environmental impact is the life cycle assessment (Chengcheng, 2023). However, the spaces available on the product package to reveal information pertaining to life cycle assessment (LCA) may not be enough and the use of the logo may not be explicit enough. An example of the aforementioned is the fact that some packaging designs have started encouraging consumers to engage in recycling of packaging materials through the use of graphics (Choi et al., 2015). They include various graphic design symbols such as package pictograms for recycling, proper handling to minimize waste, and proper disposal to mention a few (Figure 1) Although, sustainable package design is more material dependent; visual communication such as the use of labels and logos may also suggest sustainable product packaging (Magnier et al., 2016). When codes or other nomenclatures are used to reveal LCA on product packaging, it is assumed that not all consumers will understand them. However, this aspect of LCA is not the focus of this study but the use of e-labelling towards sustainable consumption due to consumers' confusion about the atypicality of packaging design. It is believed that e-labelling can be useful for the unfolding of all these kinds of useful additional information.



Figure 1: Examples of package pictogram suggesting sustainable consumption

Although according to (Choi et al., 2015), some of the packaging designs encourage consumers to reuse or suggest how to recycle the package by providing information on the package but this study is of the notion that this practice needs to be improved to cater to achieving SDG 3, which aims to ensure the well-being and health of the consumers. In the aspect of illiteracy and language barrier, foreign product brands found in the supermarket without English language may not be understood by consumers in Nigeria. To provide multilingual information on product package design may not be convenient due to limited space; thus, it is believed that e-labelling can help in providing more space for information display but in a digitized form; thus, reducing usage of materials for labels.

E-labelling is still new and has not yet been adopted across several products. For example, the United States only started allowing it for telecommunication products in 2017. This means that product information and regulatory details which transcends conventional physical labelling can be accessed and displayed on the digital screen of such products. When it is without a screen,comprehensive and current product data can still be assessed by using digital devices for interacting with the embedded digital marker on the product package. This study is of the notation that e-labeling should be extended to other product categories like Non-Alcoholic beverages to contribute to sustainable consumption as well as moderate atypical package design. Thus, it minimizes over dependence on physical labels (i.e. tactile material) which may require raw material processing and a lot of production cost. This line of thought is in accordance with circular economy as it aims to reduce the use of raw materials and reduce the amount of waste. Circular economy involves several stages, from the initial design of products to their end-of-life management by keeping them in use for as long as possible. Circular economy is characterized as the regenerative system that will minimize waste and promote long-term environmental sustainability. This will responsibly manage the end of a product's life and minimize the amount of waste sent to landfills so as to contribute to a more sustainable and environmentally friendly system. Thus, it is believed that linking sustainability data with digital technology through e-labelling can inform consumers about the actual identity of the product brand despite the atypicality. Also, it will inform the consumers on proper packaging disposal (recycling, composting, etc.) in the area in which the product is used and this would provide a much-needed connection for the consumers (Boz et al., 2020). Some countries (such as Canada, Japan, and the United States) have started discussions about how to extend e-labels to other product categories (Cory, 2017) beyond ICT products. Although some countries may be contemplating whether to adopt e-labelling or not because of possible challenges that can be involved. Due to the advantage that consumers can access comprehensive and current product data by using digital devices for interacting with the embedded digital marker on the product package necessitate the need for e-labelling so as to moderate consumers' confusion in the atypicality of packaging design towards sustainable consumption. The following attributes are gathered from the literatures so as to be used as rationale for exploring e-labelling as way of moderating consumers' confusion in the atypicality of packaging design towards sustainable consumption:

1) material waste reduction due to appropriate choice and use,
2) instructional videos to learn more about the product brand,
3) multilingual content to be able to translate to understandable languages,
4) interactive content which will enable consumers to communicate with other stakeholders ,
5) real time updates which will enable quick response and delivery of useful information. This will also be useful for reuse of the packaging since the old information can easily be updated without printing of new ones,
6) visual appeal and branding of the products can be improved due to the opportunity of managing the available space on the product packaging and
7) clear and informative e-labels can significantly enhance product identification and reduce confusion.

3.2 Findings through focus groups comprising diverse consumer segments

Twenty (24) out of thirty (30) actually volunteered to participant in this study. Four (4) out of twenty four (24) participants decided to participate because they find the topic very interesting and they have been looking for opportunity to discuss about designs of non-food products imitating food. Majority does not understand the meaning of atypical design but they easily understand the topic when it is presented as 'designs of non-food products imitating food'. The remaining 20 participants are silent and give no response about the reasons for participating in the discussion. *"As a consumer who have design background, this topic should be discussed with the advertising agencies and practitioners. They are in the position to know if e-labelling will assist in brand promotion and consumers' engagement. Although, I do see designs of insecticides resembling food because of the pictures of fruits and the names or captions used but I believed the designs are creative means of making the product more attractive to consumers. The topic will be discussed better in advertising perspective than under 'sustainable consumption.*" (50 years old male, no.22). *"I think I will accept e-labelling because on several occasions within the supermarket, foreign brands without English language captions are encountered. In fact, I saw a biscuit but I thought it was a soap because there are no pictures of biscuits or somebody eating biscuit on it. It was a foreign language throughout without any English language. I have to peruse every part of the packaging until I saw an e-label. I had to scan this*

code with my mobile phone and I was able to see many things about the brand. The surprise is that everything is still in foreign language but when I saw the videos showing the process of manufacturing the products, I can finally conclude that the product is a biscuit. The video shows the production and packaging process, continues with distribution of the product." (36 years old female, no.13). *"E-labelling is good and I want to accept it but it should be used for providing additional information. It should not replace the physical label. I still want to see the tangible label and I like it more when e-labels are included to provide more information such as videos and opportunity to chat with the producers*."(58 years old female, no 24). *"I accept and like e-labelling and want it to be legalized. This will not cancel physical package label but allows reuse of physical package label. Instead of the package labels to result to refuse or waste; they can be reused as much as possible until they can no longer be used again. The package container will then be washed, cleaned and sterilized for further usage instead of resulting to package waste. After several uses, they can then be recycled. This is will aid sustainable consumption and circular economy. When someone find it difficult to understand the identity of product because of resemblance to something else like non-food resembling food, e-labelling will be useful to seek for more information and make complaint to the producers through chatting.*" (20 years old male, no 5).*''I will support the adoption of e-labelling if the policy makers and regulatory bodies can legalize the use of e-labelling for the provision of more information for consumers so as to minimize any form of confusion. I observe that e-labels are more used for only transactions and not for providing information for consumers in Nigeria. When the codes are scanned, they only show the prices. Also, some of them will show the Facebook page or other social media belonging to the brands. Sometimes, there are new information to be learnt at the social media pages of these brands. I accept e-labelling for all products in Nigeria on the basis that they will be used to provide enough pieces of information for consumers.*" (25 years old female, no.6). *''The ideal of e-labelling should be presented to the government, policy makers and regulatory bodies; no matter how good it may seem to be; we consumers cannot make its adoption to be possible. But I accept the idea of e-labelling. By considering the challenges for those who cannot use new technology, I advise that both physical labels and e-labels should be used. Then, gradually, physical label may be fading away gradually until only when everything will be absolutely e-labels in the nearest future. At that stage, the entire citizens of Nigerian might have been used to it. Nigeria is a country with citizens that easily adjust and adapt to new conditions.*" (58 years old male, no. 23).

The observation is that majority welcome the idea of e-labelling as means of providing adequate information to consumers and the challenges of the technology in terms of internet and other technicalities are infinitesimal to majority of the consumers. Analysis of the interview shows that none of the participants consider the challenges of understanding how to use e-labels. All of them have smart mobile phones and planning to buy more advanced phones. "*I think this is a very good idea because it will provide more job opportunities. The creation for contents either text, videos and images for the consumers will allow more job opportunities. This will also solve the problem of identification problem since someone can easily scan the e-labels to know more about the product brands. The people living in the villages can even enjoy the fact that they can watch videos showing how the products they are using are produced. In places, where there is no internet connectivity the physical labels will be made available for them. This is the evidence that both e-labelling and physical labels should co-exist*" (26 years old male, no.7).

Majority of them think that the use of e-labelling will not be challenging to consumers since they are always fond of using their smart phones for purchase of goods. *"Getting physical cash is now a problem in Nigeria, even, when you visit the bank you will not be given enough money despite having money in bank account. Thus, consumers are getting used to e-transaction. I think e-labelling cannot pose any challenges to consumers if they are used on product package design to provide more information for comprehension and understanding a particular product brand. When a soap looks like a bread or bread looks like soap, one can verify by scanning the e-labels to understand better. Although, this kind of designs should be discouraged. Design should follow standards and they must be easily comprehended even when they are minimalist* (19 years old female, no.4). "*To be considering that not all consumers have smart phone is negligible because majority of the people in Akure has a smart phone and they are even thinking of buying another one. The electronic gadget is not a problem but if such policy about the adoption of e-labelling will be made then, government must try all means to allow the prices of such gadget to be reduced, so that people can easily afford one. Then, if possible, codes that will work without the use of internet should be used. If this can be done, then the adoption e-labelling as means of providing more information will be very welcome and acceptable''.* (18 years old male, no.3). *"I think this will aid sustainable consumption in the aspect of fake*

products and retailers that may be selling expired products since e-labelling can be used to assess the genuineness of the product brand. This will support good health and well being. Also, it will minimize confusion due to misunderstood designs. I like and accept the use of e-labelling as means of providing additional information on product package design. They can also educate consumers on how to recycle or return already used product package to the nearest collection centre through the use of e-labelling. I am not even aware if there is any collection centre in Akure where already-used product packages can be submitted. " (40 years old male, no.15).

The majority of participants (20 out of 24) welcome the idea of e-labelling as a means of providing additional information to consumers. Participants see e-labelling as a solution to challenges such as confusion due to product designs that imitate food, lack of information on product packaging, Identification of genuine products, and provision of additional information such as videos and manufacturer details. Some participants suggest that e-labelling should not replace physical labels but rather complement them. The majority of participants do not see challenges in using e-labels, as they are already familiar with using smartphones for transactions.

A few participants suggested that the government and regulatory bodies should legalize the use of e-labelling and ensure that it is accessible to all, including those without smartphones. From these findings, it can be recommended that regulatory bodies should consider legalizing the use of e-labelling. E-labelling should be designed to complement physical labels, not replace them. Measures should be taken to ensure accessibility and inclusivity in the adoption of e-labelling. Also, it is very important that education and awareness campaigns should be implemented to inform consumers about the benefits and use of e-labelling.

3.3 Findings through focus groups comprising diverse consumer segments

The Delphi technique engages a panel of experts, including brand managers, marketers, and packaging designers, to achieve a consensus on the efficacy of e-labelling in mitigating confusion. The consensus reached is shown in Table 2. The Delphi panel supports the role of e-labels in fostering sustainable consumption by reducing waste and promoting informed purchasing decisions in the sense that atypical design can be understood when the e-labels are scanned. The findings of the study show that e-labelling will enable a circular economy and environmental sustainability by preventing material waste. It may help reuse of product package as well as encourage recycling through education that can be provided. Also, e-labelling is considered preferable because it will enable comprehensive product packaging design due to its adaptation to multilingual content and real-time updates.

Table 2: Consensus reached during three rounds by the Delphi participants

Consensus Reached by Delphi Participants on the use of e-labelling as means of moderating confusion that can be caused by atypical package design	1ST Round		2ND Round		3RD Round	
	Yes	No	Yes	No	Yes	No
Reduce material waste as well as aid sustainable consumption	7	0	7	0	7	0
E-labelling should provide instructional videos for consumers	6	1	4	3	5	2
Multilingual content through e-labelling will minimize confusion	7	0	7	0	7	0
Interactive content through e-labelling will increase consumers' trust	4	3	7	0	5	2
Real time update will aid sustainable consumption	7	0	7	0	5	2
Divers Target Audience will be reached and satisfied	1	6	5	2	4	3
Regulatory requirements will be monitored and well sustained	7	0	7	0	7	0
Mobile Applications (App) that will not require internet can be used	1	6	2	5	2	5
Compliance to regulatory requirement may be easy for manufacturers	7	0	7	0	7	0
Accessibility and technological barriers will be well managed	7	0	7	0	4	3
Enhance consumers; experience and atypical design will be fun to them	6	1	4	3	4	3
Improved in-store experience and User Interaction	6	1	4	3	4	3
Enhanced visual appeal of the products and package re-use	7	0	7	0	7	0

4. CONCLUSION

Findings from the literature review suggest that clear and informative e-labels can significantly enhance product identification and reduce confusion. Focus group discussions reveal that consumers are receptive to e-labels, appreciating the additional information that aids in quick and accurate product recognition. In conclusion, the integration of e-labelling into sustainable packaging design represents a promising avenue for reducing environmental impact, enhance consumer engagement and drive innovation in the packaging industry. The Delphi panel supports these findings, emphasizing the role of e-labels in fostering sustainable consumption by reducing waste and promoting informed purchasing decisions. This study contributes to the body of knowledge on sustainable packaging practices and offers practical implications for stakeholders. By demonstrating the potential of e-labelling to alleviate consumer confusion, the research provides a pathway towards more sustainable consumption patterns in Akure, Nigeria. It can be recommended that regulatory bodies should allow e-labelling to be used for providing adequate information and they should be designed to complement physical labels, not replace. Also, it is very important that education and awareness campaigns should be implemented to inform consumers about the benefits and use of e-labelling.

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THE INFLUENCE OF AUTHORSHIP INFORMATION ON THE PERCEPTION OF GRAPHIC MEDIA MESSAGES

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Abstract: *At a time of increasing use of artificial intelligence (AI) in the design and shaping of media messages, it is important to understand how people perceive messages shaped by artificial intelligence compared to those created without the help of artificial intelligence. This article investigates whether authorship information (AI vs. designer) affects the perception and evaluation of graphic messages. The goal of the research is to determine whether information about authorship can become part of a communication strategy that achieves a better connection with the content and can have a marketing value that contributes to shaping the desired image. An experimental study was conducted with randomly selected participants, divided into two groups. The first group rated graphic messages that were told they were designed by an AI, while the second group rated the same messages with the information that they were designed by designers without the help of AI. Questionnaires with a Likert scale were used to assess aesthetic value, creativity and overall impression. The results of the research are presented through descriptive and inferential statistics to understand the perception of the participants. The research results provide a basis for further research and practical applications in design practice and marketing communication, with the aim of optimizing the use of AI technology in design.*

Key words: authorship, design, artificial intelligence

1. INTRODUCTION

Artificial intelligence (AI) is an interdisciplinary field of study based on mathematics, computer science, linguistics, psychology, and other fields. Benefits of AI are being seen across a wide range of industries and sectors, from automation in design to innovation in media (Russell and Norvig, 2021). In graphic design its use goes from self-made websites to various design software's (Rezk, 2023). Individuals and organizations often decide to cooperate with AI, especially when it comes to developing ideas and making decisions (Jain et al., 2023). Zhou et al. showed that the AI significantly improves the designer's performance, the efficiency of the iteration process and the quality of the generated solutions (Zhou, Zhang & Yu, 2023). AI significantly helps designers in making decisions, increasing their cognitive activity and design solutions. Due to high implementation of AI in graphic design designers have more time to focus on other aspects of work like brainstorming, new design possibilities, conceptualizing new projects, etc. However, AI designs can become too similar and generic, leading to a decrease in uniqueness and individuality, and homogenization of design. Also, the reliance on AI s may lead to a loss of human touch and creativity in designs, reducing the overall quality and relevance of graphic design work (Mustafa, 2023). Floridi and Chiriatti (2020) discuss whether AI can truly be considered a "creator" or if it merely replicates patterns based on existing data (Floridi & Chiriatti, 2020). AI works in a specific order and cannot "think" independently because they are unable to evaluate the context in which a task should be performed (Rezk, 2023). Therefore, there are some concerns related to implantation of AI in design and the role of humans in design. Scientific reflection on the role of the author in the creation and interpretation of a message is not a new topic. Barthes in his essay argues for a departure from the traditional view of authorship, where the author holds a central role in creating and interpreting meaning (Barthes, 1977). Instead, he proposes that the focus should shift to the reader, or in this case, the viewer, who actively participates in constructing the meaning of the work. When applied to AI-generated design, Barthes' concept of freeing the work from the authority of the author becomes particularly relevant. AI does not function as an individual creator with personal intent and emotional context, it is a tool programmed with rules and algorithms. This "disappearance" of the traditional author in AI design further blurs the boundaries between human and machine creativity. Barthes' thesis on the "death of the author" encourages a re-examination of the role of authorship in modern communication strategies, especially in the context of design and artificial intelligence.
Authorship information could be important in graphic design for several reasons as it can enhance professional reputation, protect the designer's work from unauthorized use and distinguish it from AI made

ORCID numbers are provided at the end of the paper.

work (Sun, 2021). The latter is especially important as recent studies indicate general public puts more value on work made by human rather than AI (Dio et al., 2023).
Historically, the concept of the author has evolved significantly. Early definitions of authorship were related to any idea or creation. Over time, literary and critical theories, particularly post-structuralism, challenged the traditional view of the author as the central figure in the creation of meaning. In graphic design, the application of authorship is problematic, particularly when considering the collaborative nature of the profession and the commercial context in which most design is produced. The rise of post-modernism and the deconstruction of texts has led some designers to explore authorship by embracing fragmented, reader-based designs. However, this approach has often been criticized for being more about self-expression than about the critical engagement with content (Rock, 1996). Early graphic design emphasized anonymity over authorship. Many rejected the elitism of traditional art, favouring functional, minimal, and rational forms inspired by machines. As the profession evolved, objectivity became central, and some designers still prioritize clarity in conveying a client's message, aware of the challenges of true neutrality. However, many modern designers now create their own content, asserting artistic presence and sparking debates on graphic authorship. This shift has revived a sense of agency in design, challenging traditional views and practices (Armstrong, 2009). Manovich (2002) among types of authorships defines collaboration between the author and the software as Authoring using Al. The author sets up general rules but has no control over the concrete details of the work. Authorship that uses electronic and computer tools is a collaboration between the author and these tools that make possible certain creative operations and certain ways of thinking while discouraging others. Of course humans have designed these tools, so it would be more precise to say that the author who uses tools engages in a dialog with the software designers.

1.1 Literature review

Public opinion on AI has an important role in product adoption, commercial development, research funding, and regulation of AI (Kelley et al., 2021). Therefore, a body of research has focused on people's perception on the AI made works in various fields, like music (Hong et al., 2022), and visual arts (Caporusso et al., 2019; Kobis & Mossink, 2021). Some research points to a positive role of AI. For example, in one study Kelley et al. (2021) showed that the public has a widespread perception that AI will have significant impact on society. Some of the key themes they attribute to AI with are; exciting, useful, worrying, and futuristic. McCosker and Wilken (2020) investigated how people react to AI-generated art and how AI affects their evaluation of creativity (McCosker & Wilken, 2020). They concluded that while AI-generated content can be aesthetically pleasing, there is a persistent bias in favour of human-created work due to emotional depth and uniqueness. Mostly the research focused on copyright or value of AI created works. For example, Park et al. examined whether people can distinguish between paintings drawn by a real artists and art created using AI (Park, Kang & Kim, 2023). They found that people have difficulty distinguishing authentic from AI artwork and that additional information about artists and artworks can affect people's criteria for judging paintings. Similarly, Ragot et al. (2020) asked participants to evaluate paintings in four dimensions: liking, perceived beauty, novelty, and meaning, and found that the paintings perceived as painted by humans were rated higher than those made by AI. In another study Jain et al. (2023) determined that with the increase in human age, the aversion to AI decreases. Furthermore, the results show that people have less trust in AI when they use it occasionally, that is, for sporadic parts of tasks and when AI and human do not have different roles in performing tasks. However, in situations where humans and AI work parallel and have different roles, human trust in AI is greater.
Dio et al. (2023) explored the impact of authorship beliefs on aesthetic judgments of abstract art, examining how perceptions of human versus robot creators influence evaluations of beauty and liking. The research found that participants rated artworks differently based on whether they thought a human or a robot created them, even when the artworks themselves were identical. When participants believed a human created the artwork, they gave higher liking ratings in the primed condition compared to the blind condition (where authorship was unknown). This suggests a bias favouring human artists when it comes to emotional connection with the art. Conversely, robot-created artworks received lower beauty ratings in the primed condition than in the blind condition. This indicates a reluctance to attribute artistic competence to robots. The study highlights that people tend to resist attributing artistic value and emotional depth to robot-generated art. The human element in art-making is strongly linked to emotional resonance and perceived creativity, which are seen as distinctively human traits.
Gangadharbatla conducted a study to explore how people perceive and evaluate AI-generated art compared to human-created art (Gangadharbatla, 2022). The study aimed to understand whether

individuals could distinguish between artworks produced by humans and those generated by AI, and how knowledge of the artwork's authorship (human vs. AI) influenced their attitudes and evaluations. The study revealed that participants generally struggled to accurately distinguish between artworks created by humans and those generated by AI. This finding suggests that AI technologies can produce art that is visually similar to human-made art, blurring the lines between human and machine creativity. Despite the difficulty in distinguishing between human and AI art, participants tended to associate figurative (representational) art with human authorship and abstract art with AI authorship. This bias suggests that people may have preconceived notions about the types of art that humans and AI are capable of creating. When participants were informed about the authorship of the artworks before evaluating them, this information significantly influenced their attitudes, purchase intentions, and evaluations of the art. Specifically: Artworks identified as human-made received higher evaluations in terms of originality, creativity, expressiveness, aesthetic value, composition, uniqueness, and emotional connection. When abstract artworks were attributed to AI, they were evaluated more positively compared to when the same artworks were attributed to humans.

1.2 Theoretical Background

Aesthetic value theory has broad applications, particularly in the evaluation and critique of art, design, and media. It provides a framework for understanding why certain works of art are revered while others are dismissed and how these judgments can vary across cultures and historical periods. In the context of AI-generated art, aesthetic value theory can help explore how traditional notions of beauty and artistic value are challenged or upheld by new technologies (Liang, 2022). Aesthetic value theory is concerned with the nature and evaluation of art, beauty, and taste. It explores how and why certain objects, artworks, or experiences are deemed beautiful, moving, or artistically valuable. This area of study encompasses various perspectives, ranging from classical theories rooted in ancient philosophy to contemporary approaches that incorporate cultural and psychological insights. One of the central debates in aesthetic theory is whether aesthetic value is objective or subjective (Goldman, 2005).
Aesthetic value is often linked to the experience of beauty or art. The philosopher Monroe Beardsley argued that aesthetic experience is characterized by an intense focus on the sensory qualities of an artwork, leading to a kind of aesthetic pleasure (Beardsley, 1982). This concept becomes relevant when examining how individuals perceive graphic designs, whether created by humans or AI.

2. METHODS

In designing the research methodology for this study, the primary goal is to investigate how authorship information (AI vs. human designer) influences the perception of graphic media messages. The research builds on previous studies that have examined subjective responses to design and art (Chamberlain, 2022; Thüring & Mahlke, 2007; De Angeli, Sutcliffe & Hartmann, 2006). Our study's approach, carefully designed for measuring user perception will contribute to understanding how people interact with new forms of creative outputs, especially in relation to aesthetic value, creativity, and overall impression. This study utilizes a controlled experimental design, where participants are divided into two groups and exposed to the same graphic designs, with only the information about authorship varying (AI vs. human). This approach is inspired by Magni, Park and Chao who found that AI's involvement in creative processes can alter perceptions of creativity and originality, particularly when participants are made aware of the design's authorship (Magni, Park & Chao, 2023). The findings suggest that while people sometimes ascribe lower creativity to AI-generated artifacts compared to human-made ones, this effect is not consistent across all cases. A key factor in this bias is the perception that AI exerts less effort in the creative process than humans, which drives lower creativity ratings for AI-produced works. Additionally, studies by McCosker and Wilken (2020) suggest that the use of AI in creative work often blurs the lines between human creativity and machine efficiency (McCosker & Wilken, 2020). Their work provides insights into how participants may struggle to differentiate between human- and AI-created designs, which is highly relevant to the aims of this study. Floridi and Chiriatti (2020) further contribute to this by discussing the philosophical implications of AI as an "author" and the challenges this poses to traditional notions of creativity and originality. These theoretical considerations are central to this study, as they provide context for how authorship bias might influence participant evaluations of the same graphic media messages. The combination of these insights will help frame the experimental design and guide data analysis, ensuring that the methodology not only addresses the key research questions but also aligns with current research in the field of AI and creative perception (Floridi & Chiriatti, 2020).

2.1 Research Design

This study employed a controlled experimental design to assess how authorship information (AI vs. human designer) affects the perception of graphic media messages. Participants were randomly assigned to one of two groups and exposed to the same set of graphic designs, with the key difference being the authorship information provided. Group 1 evaluated designs labeled as "created by AI," while Group 2 evaluated the same designs but with the label "created by a human designer."

2.2 Participants

A total of 166 participants were involved in the study. The sample included 92 females (55.42%) and 74 males (44.58%), with participants evenly distributed across the two experimental groups. The gender distribution of the participants was analyzed for the overall dataset as well as separately for Group 1 and Group 2. In the overall sample, 92 participants were female, accounting for 55.42% of the total, while 74 participants were male, representing 44.58%. In Group 1, there were 48 female participants, comprising 57.83% of the group, and 35 male participants, accounting for 42.17%. In Group 2, 44 participants were female, what is 52.38% of the group, and 39 participants were male, representing 47.62%. No significant difference in gender distribution was observed between the groups, as confirmed by a Chi-Square test ($p = 0.639$). The age distribution was also analyzed, covering participants aged 18 to 56+, with no significant difference in the age distribution between Group 1 and Group 2 ($p = 0.911$). The age groups assessed were 18-25, 26-35, 36-45, and 56+. The overall distribution showed that 31.79% of participants were aged 18-25, 25.17% were aged 56+, 21.85% were in the 26-35 age group, and 21.19% were in the 36-45 age group. In Group 1, 29.73% of participants were aged 18-25, 24.32% were aged 56+, 22.97% were aged 26-35, and 22.97% were aged 36-45. In Group 2, the distribution was as follows: 33.77% were aged 18-25, 25.97% were aged 56+, 20.78% were in the 26-35 age group, and 19.48% were in the 36-45 age group.

2.3 Materials

The stimulus material consisted of six different graphic media messages sourced from Behance. These visuals were selected to vary in theme and expression, ranging from generic designs to highly authorial works, and from emotionally neutral to emotionally charged messages. Each image was presented twice across the two experimental conditions, but with differing authorship information.

First used image depicts three different stages or versions of a product rendering process for a drink labeled "FruttaVit Sour Cherry." Left panel shows finished, rendered product with full color and details. The bottle is placed in a natural setting, surrounded by cherries, highlighting the drink's sour cherry flavor. In the middle panel is a grayscale, untextured 3D model of the same bottle. This is likely an intermediate stage in the product design, showing the structure of the bottle without textures or lighting effects. On the right panel is a wireframe view of the 3D model, showing the underlying mesh and geometry used to create the bottle. This stage reveals the technical details of the 3D modeling process. This setup is often used in design presentations to show the progression from a 3D model to a fully rendered product.

The second image is an advertisement for a well-known beer brand, set against the backdrop of a sunset. The image prominently features a bottle with a slice of lime at the top, a typical serving style for certain type of beer. The bottle is well-lit, with a glowing effect that emphasizes the golden hue of the beer. A vibrant, warm sunset fills the background, creating a relaxing and inviting mood. The sun's position is cleverly aligned with the bottle, adding to the visual impact, as the light appears to shine directly through the beer. The text "Sunset o'clock" is written across the image, suggesting that the ideal time to enjoy a beer is during sunset, possibly evoking emotions like relaxation, leisure, and enjoyment of the moment. The use of a minimalist font keeps the focus on the bottle and the scenic background, enhancing the simplicity and effectiveness of the message. The imagery likely targets consumers who associate the brand with outdoor experiences, leisure, and a carefree lifestyle.

The third image is a campaign for Alzheimer's awareness, specifically focusing on cherishing moments before memories fade. The design is powerful and symbolic, using artistic renditions of elderly faces that seem to be constructed from carved words. The central figures in the image are three elderly individuals whose faces are composed of three-dimensional wooden letters and words. This visually represents the connection between memories, language, and identity, all of which are deeply affected by Alzheimer's disease. The expressions on the faces convey emotion, particularly a sense of reflection, loss, or contemplation, which aligns with the theme of memory and fading moments. The words may represent the memories and knowledge slowly slipping away, a core feature of Alzheimer's. The artistic portrayal of

faces made from words effectively evokes a sense of empathy and urgency. It connects viewers with the emotional impact of Alzheimer's disease. The combination of familiar human expressions and the abstract use of typography creates a powerful metaphor for the cognitive decay associated with Alzheimer's.
In the next example we used an an advertisement for well-known energetic drink, showcasing the brand's connection to extreme sports and energy-driven activities.The design is consistent with branding—silver, blue, and red colors—with the logo clearly visible. The central focus is on a high-octane action moment. A motocross rider is launching off what appears to be an aircraft or platform into the sky. The rider is wearing a helmet and is mid-action, leaning forward as if performing a stunt, symbolizing speed, power, and adventure. A second figure, possibly a crew member or technician, appears to be refueling or "powering up" the rider's motorcycle with a hose connected to the drink can. This is a creative metaphor for how the drink is marketed as an energy-boosting drink, literally fueling action and excitement. The image reinforces drinks's association with extreme sports, adrenaline, and energy. The combination of the can and the action-packed scene of the motocross rider launching into the sky suggests that the drink provides the fuel and energy needed for high-performance activities.
The fifth image is a branding design for a nail care product or service. It emphasizes aesthetics and luxury through strong visual elements. The focus is on hands with striking, metallic, copper-colored nails. The high level of detail and reflective surface of the nails suggest a premium, polished product or service. The skin and nails are highly stylized with a smooth, metallic sheen, giving the image a futuristic and luxurious feel. The warm, orange hue adds to the rich, bold visual impact, making the nails the focal point. The large, clear font ensures that the brand name stands out against the vibrant background. The logo, placed above the brand name, consists of abstract shapes, possibly symbolizing movement, creativity, or fluidity, aligning with the aesthetics and craftsmanship of nail design. The color scheme predominantly features warm, metallic tones of copper, gold, and orange, evoking feelings of luxury and sophistication. The imagery and design choices convey a message of high-end, fashionable, and bold beauty services. The close-up, metallic textures, and sharp contrast of the nails against the skin make the advertisement visually striking and designed to catch attention.
The last used image showcases a vibrant and nature-inspired branding or advertisement for a soft drink. The central focus is a glass filled with a brightly colored orange soft drink, garnished with an orange slice and ice. The drink has a refreshing, fizzy appearance, highlighted by the bubbles rising in the glass, evoking a sense of refreshment and lightness. Surrounding the drink is a lush, green landscape filled with various flowers in shades of orange, pink, and yellow. The backdrop of a clear blue sky with soft, fluffy clouds enhances the idyllic and peaceful atmosphere, suggesting the drink is to be enjoyed in a natural environment. The use of vibrant oranges and greens connects the product to natural elements like citrus fruits and plants. The bright blue sky adds contrast, making the image pop and reinforcing a sense of clarity and freshness. This visual composition is crafted to promote the soft drink as a fresh, natural, and vibrant product. By placing the drink in a nature-filled setting, the image connects the product to ideas of purity and health, appealing to consumers seeking a refreshing and natural beverage. The use of vibrant, nature-inspired colors and a relaxing atmosphere supports the brand's identity as a refreshing and healthy choice.

2.4 Procedure

Participants were informed that they would be evaluating various graphic media messages. Each participant was presented with six images, and for each image, they were asked to rate it on the following dimensions:

- aesthetic value,
- creativity,
- overall impression.

These ratings were collected using Likert scales, ranging from 1 (very low) to 5 (strongly high). The only manipulation in the study was the information about the creator of the designs—whether they were labeled as created by AI or by a human designer. Group 1 participants were told that the designs were AI-generated, while Group 2 participants were told the designs were created by human designers.

2.5 Data Analysis

The collected data was analyzed using both descriptive statistics and inferential statistics. Mean scores for aesthetic value, creativity, and overall impression were calculated and compared across the two groups.

An independent samples t-test was performed to determine whether there were statistically significant differences in perception between the two conditions (AI vs. human authorship).

2.6 Ethical Considerations

All participants provided informed consent before the start of the experiment. The study was conducted following ethical guidelines to ensure participant privacy and anonymity. No personal or sensitive data was collected during the study, and all responses were anonymized for analysis.

3. RESULTS

An independent samples t-test was conducted to compare the ratings of aesthetic value, creativity, and overall impression between Group 1 (informed that the images were AI-generated) and Group 2 (informed that the images were created by a human designer).

3.1 Aesthetic Value

For Image 1, there was no statistically significant difference between Group 1 (M = 2.59, SD = 0.98) and Group 2 (M = 2.71, SD = 0.74), t(164) = 1.96, p = 0.372. For Image 2, the result was similar, with no significant difference between Group 1 (M = 3.62, SD = 0.99) and Group 2 (M = 3.73, SD = 0.81), t(164) = -0.80, p = 0.424. However, for Image 3, there was a statistically significant difference in aesthetic value ratings between Group 1 (M = 3.94, SD = 0.86) and Group 2 (M = 4.24, SD = 0.73), t(164) = -2.44, p = 0.016, with Group 2 rating the image more favorably. Similarly, for Image 4, Group 2 (M = 3.18, SD = 0.68) rated the image higher than Group 1 (M = 2.90, SD = 0.64), t(164) = -2.70, p = 0.008.
For Image 5 and Image 6, no statistically significant differences were found between the groups (p > 0.05) (Table 1).

Table 1: Aesthetic Value

Aesthetic Value						
		M	Sd	Md	t-statistics	p-value
Image 1	Group 1	2.59	0.98	2	1.96	0.372
	Group 2	2.71	0.74	3		
Image 2	Group 1	3.62	0.99	3	-0.80	0.424
	Group 2	3.73	0.81	4		
Image 3	Group 1	3.94	0.86	4	-2.44	0.016
	Group 2	4.24	0.73	4		
Image 4	Group 1	2.90	0.64	3	-2.70	0.008
	Group 2	3.18	0.68	3		
Image 5	Group 1	3.88	0.82	4	-0.35	0.728
	Group 2	3.93	0.96	4		
Image 6	Group 1	2.28	0.61	2	0.57	0.566
	Group 2	2.22	0.73	2		

3.2 Creativity

Creativity assessments followed a similar pattern. For Image 1 and Image 2, there were no significant differences between Group 1 and Group 2 (p > 0.05). However, Image 3 (Group 1: M = 3.94, SD = 0.86; Group 2: M = 4.24, SD = 0.73, t(164) = -2.44, p = 0.016) and Image 4 (Group 1: M = 2.90, SD = 0.64; Group 2: M = 3.18, SD = 0.68, t(164) = -2.70, p = 0.008) showed significant differences, with Group 2 providing higher creativity ratings. For Image 5 and Image 6, no significant differences were observed (p > 0.05) (Table 2).

Table 2: Creativity

Creativity						
		M	Sd	Md	t-statistics	p-value
Image 1	Group 1	2.59	0.98	2	-0.90	0.37
	Group 2	2.71	0.74	2		
Image 2	Group 1	3.61	0.99	3	-0.86	0.39
	Group 2	3.73	0.81	3		
Image 3	Group 1	3.94	0.86	4	-2.44	0.016
	Group 2	4.24	0.73	4		
Image 4	Group 1	2.90	0.64	3	-2.70	0.008
	Group 2	3.18	0.68	3		
Image 5	Group 1	3.88	0.82	3	-0.35	0.728
	Group 2	3.93	0.96	3		
Image 6	Group 1	1.92	0.72	2	-0.65	0.52
	Group 2	1.99	0.72	2		

3.3 Overall Impression

The analysis of overall impression revealed a significant difference for Image 1 (Group 1: M = 1.92, SD = 0.83; Group 2: M = 2.19, SD = 0.82, t(164) = -2.17, p = 0.03), with Group 2 providing a more favorable overall impression. Image 3 also showed a significant difference (Group 1: M = 4.19, SD = 0.67; Group 2: M = 4.60, SD = 0.66, t(164) = -3.96, p = 0.0001). For Image 4, there was a significant difference as well, but in favor of Group 1, who thought the image was created by AI (M = 3.43, SD = 0.67 vs. Group 2: M = 3.18, SD = 0.80, t(164) = 2.22, p = 0.028). There were no significant differences for Image 5 or Image 6 in terms of overall impression ($p > 0.05$) (Table 3).

Table 3: Overall impression

Overall impression						
		M	Sd	Md	t-statistics	p-value
Image 1	Group 1	1.92	0.83	1	-2.17	0.03
	Group 2	2.19	0.82	2		
Image 2	Group 1	3.72	0.79	3	-1.26	0.21
	Group 2	3.87	0.69	4		
Image 3	Group 1	4.19	0.67	4	-3.96	0.0001
	Group 2	4.60	0.66	5		
Image 4	Group 1	3.43	0.67	4	2.22	0.028
	Group 2	3.18	0.80	4		
Image 5	Group 1	2.42	0.70	3	-.094	0.35
	Group 2	2.52	0.61	3		
Image 6	Group 1	1.81	0.65	2	0.00	1.0
	Group 2	1.81	0.71	2		

4. DISCUSSION

The results of this study provide important insights into how authorship information influences the perception of graphic media messages. Partly consistent with previous research (Di Dio et al., 2023; Gangadharbatla, 2022), participants rated some images attributed to human designers more favourably in terms of aesthetic value, creativity, and overall impression compared to images they believed were AI-generated. This aligns with the notion that people tend to ascribe greater emotional depth and creativity to human-made works. This was particularly evident in the example related to Alzheimer's disease, where the emotional component of the message was strongly emphasized. The significant differences observed in the ratings of Image 3 and Image 4 suggest that participants had a bias towards human authorship, particularly when it came to creativity and aesthetic appreciation. These results support the idea that people may view AI-created designs as less authentic or emotionally resonant, despite the images

themselves being identical. Interestingly, for Image 4, participants who thought the image was created by AI gave it a higher overall impression score than those who believed it was human-created. This may indicate that in some contexts, participants view AI-generated works as innovative or novel, which could enhance their overall impression. The lack of significant differences for several images suggests that the bias toward human creators may not be universal and could depend on the specific characteristics of the design. This is consistent with findings from Ragot et al. (2020), which showed that the perceived beauty of an artwork could be influenced by whether participants believed it was created by a human or AI.

4.1 Limitations

A potential limitation of the research is that participants were only informed about the authorship of the images (Ai or human created). However, this information was quite general, with no specific information about the exact extent of AI's involvement in the production process. The primary objective of our research was to assess the overall effect of AI as a producer on creativity evaluations, rather than focusing on a specific aspect of the process. Secondly, we did not use specific definition of AI and rather left this open for participants, which might be a limitation as participants might have different ideas about what an AI is and what it can do.

5. CONCLUSIONS

The implications of these findings are relevant for both designers and marketers. For designers, understanding the bias toward human authorship can help in crafting strategies that either capitalize on this bias or address it by highlighting the unique contributions of AI in the design process. Marketers can also use these insights to tailor communication strategies, emphasizing human involvement in creative processes when targeting audiences that value emotional resonance, while promoting the innovation and efficiency of AI-generated work in other contexts. Further research is necessary to explore how varying levels of AI involvement in the creative process influence perceptions of design. Additionally, future studies could investigate whether providing more specific information about the role of AI (e.g., partial vs. full creation) could mitigate the bias toward human creators. Expanding the sample size and diversity would also allow for greater generalization of these findings across different demographics and cultural contexts. In conclusion, this study contributes to the growing body of knowledge on AI in creative industries, offering a deeper understanding of how authorship information shapes public perception. As AI becomes increasingly integrated into creative processes, balancing human creativity with machine efficiency will be crucial for optimizing both design outcomes and audience engagement.

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DIGITAL ILLUSTRATION AND ITS IMPACT ON CONSUMER PERCEPTION OF HEALTHIER FOOD PRODUCTS

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Abstract: *The role of packaging in influencing consumer perceptions is widely recognized within the domain of graphic communications. It is particularly effective in encouraging consumers to opt for healthier snack alternatives by incorporating visually appealing design elements, such as digital illustrations. This study employed an online survey with 116 Croatian participants with a diverse age range (18-71 years) to investigate the impact of digital illustrations on the attractiveness of packaging and product perception. Participants evaluated four different packaging samples for new healthy snack bars in two flavors using a 5-point Likert scale. The presence of digital illustrations served as the independent variable, while the packaging shape, size, composition, and typefaces were held constant. A choice task between packages with and without illustrations was also conducted. The results indicated the surprisingly infrequent consumption of this type of food product among participants. Additionally, the results on attitudes towards the importance of design suggested that the majority of respondents consider the packaging graphic design as a relevant product attribute, emphasizing its substantial impact on product perception. The implications regarding the role of digital illustrations in promoting healthier product choices were discussed, highlighting the potential benefits of deliberate packaging design in encouraging consumer preferences for healthier food options.*

Key words: illustration, packaging, snack, graphic design

1. INTRODUCTION

The role of packaging in influencing consumer perceptions is widely recognized within the domain of marketing and visual communications, and food product category is not an exception. For instance, many studies have demonstrated how packaging design (Hamlin, 2016; Lidón, Rebollar, Gil-Pérez, Martín, & Vicente-Villardón et al., 2018), color schemes (Marques da Rosa, Spence, & Miletto Tonetto, 2019), and imagery (Kovačević, Mešić, Užarević, & Brozović et al., 2022b; Rebollar et al., 2017; Timmerman & Piqueras-Fiszman, 2019) significantly affect consumers' evaluation of food products. This is particularly evident in the case of snack foods, where unhealthy options are often preferred. The previous research indicates that consumers frequently choose unhealthy snacks, driven by taste and convenience, rather than health considerations (Hartmann, Siegrist, & Van Der Horst, 2013). Thus, it not surprising that they often prioritize taste over health when selecting food, particularly under certain conditions such as a lack of time (Köster, Buabang, Ivančir, & Moors et al., 2023). This tendency to make poor food choices under time pressure can, however, be influenced by design. A study on fruit snacks packaging showed that front-of-package visuals may be a relevant aspect of the packaging when making quick buying decisions (Abrams, Evans, & Duff, 2015) and that packaging design may play a significant role in encouraging better product choices (Sabo, Bečica, Keleš, Kovačević, & Brozović et al., 2017) and has a potential to effectively communicate taste of the product (Gil-Pérez, Rebollar, Lidón, Martín, & Trijp et al., 2019; Veflen, Velasco, & Kraggerud, 2023).
Research on communication aspect of packaging suggests that people generally need more visual elements to understand the packaging messages, with a combination of text and illustration being the most effective approach (R. W. Y. Wang & Chou, 2010). As demonstrated in a study (Underwood, Klein, & Burke, 2001), illustrations may be particularly beneficial for lesser-known brands. However, illustrations do not always have a positive effect on information comprehension, especially among older consumers (Liu, Kemper, & McDowd, 2009). Therefore, the purpose of this study was to test the influence of digital illustration on the packaging for an unknown healthy snack brand in order to explore the potential of packaging visual design in encouraging consumer preferences for healthier snack options.

ORCID numbers are provided at the end of the paper.

2. METHODOLOGY

2.1 Participants

A total of 116 Croatian participants were selected for this study, who voluntarily participated in a questionnaire. The inclusion criteria for participation were age above 18 and internet access. Of the total, 66% were female, 33% were male, and 1% chose not to specify their gender. The age range of participants was 18 to 71 (M = 30.70, SD = 14.56).

2.2 Design of the packaging variants

The study employed a 2x2 experimental design, in which participants were exposed to packaging designs varying across two factors: flavor and visual design. A total of four distinct packaging designs were created by manipulating these two variables. The first factor, flavor, consisted of two distinct tastes (namely, banana and peanut). We included two product flavors in the analysis since consumer preferences for healthy snacks sometimes differ across products, even when products offer comparable health advantages (Okpiaifo, Dormoy-Smith, Kassas, & Gao et al., 2023). The second factor, visual design, also had two categories: a design without illustration and a design with illustration. The illustrated versions used a digital depiction of the main ingredient which represented a particular taste. The presence of digital illustrations served as a main independent variable, while the packaging shape, size, composition, and typefaces were held constant. Therefore, the versions without illustration contained identical elements to the design with illustrations. In the area designated for illustrations, a geometric, abstract pattern was applied to prevent the non-illustrated space from appearing incomplete and to ensure that the packaging reflected a typical commercial product aesthetic, as typical label designs are generally perceived as more aesthetically attractive (Celhay & Trinquecoste, 2015). Finally, four unique packaging designs were created (Figure 1); P1 (taste: banana, visual design: without illustration), P2 (taste: banana, visual design: with illustration), P3 (taste: peanut, visual design: without illustration), and P4 (taste: peanut, visual design: with illustration).

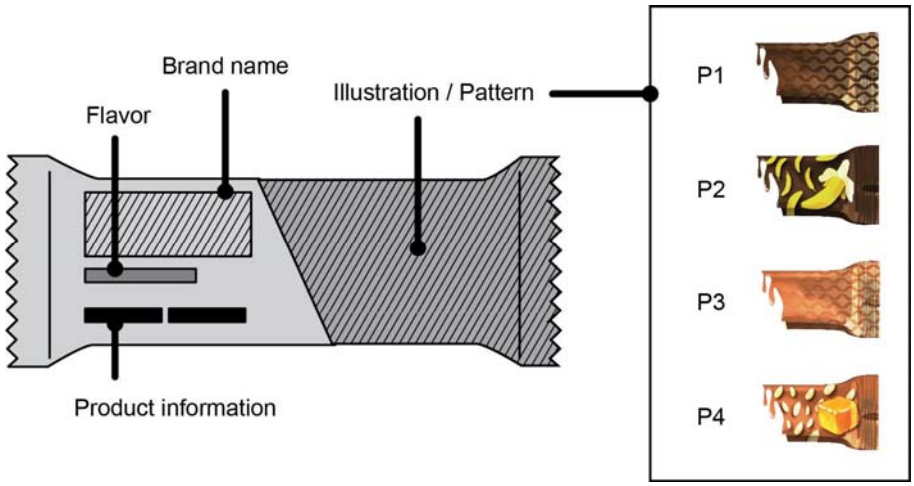


Figure 1: Design of the packaging variants used in the experiment

2.3 Procedure

The study employed an online questionnaire to collect data on snack bars consumption habits and the participants' perception of packaging visual design. The survey was developed using Google Forms. Data from the questionnaire were collected and stored securely on a cloud-based server. It consisted of demographic information, an evaluation of packaging designs, and a choice task. The questionnaire included ten questions in total, and the respondents were required to answer all the questions in order to complete the survey. All of them were informed about the purpose of the study and provided their informed consent.

Participants were first asked demographic questions regarding their age, gender, and how often they consume healthy snack bars. Response options were: never, rarely, once a month, and once a week.

Following this, they were presented with four different packaging designs. They were asked to evaluate the level of the snack attractiveness using a 5-point scale. After the evaluation, the participants completed a choice task in which they were shown the packaging designs without illustration and designs with illustration, and were asked to indicate which one they would purchase. Next, the participants were asked how important they consider packaging design to be. The final question was: "Do you think that packaging visual design can improve the perceived quality of a healthy snack bar?" with two response options (yes or no). There was no time limit for completing the questionnaire.
Statistical analyses were performed by using SPSS Statistics. For the purposes of statistical testing, a significance level of 0.05 was set as the threshold for determining the statistical significance.

3. RESULTS

The analysis began by examining the distribution of participants based on how frequently they consume snacks and the importance they attribute to packaging visual design. Participants were categorized based on their reported frequency of healthy snack bar consumption. A total of 56.03% of the participants reported eating healthy snacks bar rarely, while 26.72% reported they never eat them. 13.79% reported eating healthy snack bars once a month and only 3.45% reported eating the bars once a week. To assess participants' attitude toward the importance of packaging design, responses were collected as a binary variable (important or not important). 50.86% participants identified design as an important factor, whereas 49.14% participants did not consider it to be of significant relevance. When asked “Do you think that illustrations on packaging can improve the perception of product quality?, a remarkable 83.62% of respondents indicated “Yes”. Among the remaining participants, 8.62% responded “No”, while 7.76% indicated “I don't know”.

3.1 Choice task

In the choice task, the participants selected between the packaging without illustration and the packaging with illustration as their preferred option. A Chi-square test was conducted to examine the effect of illustration on participants' choice between two packaging designs. The results revealed a significant effect of the packaging visual design, $\chi^2(1) = 52.45$, $p < 0.001$, indicating that the illustration significantly influenced participants' choices (Figure 2). Specifically, the packaging with illustration was preferred over the packaging without illustration, suggesting that the presence of digital illustration positively affected participants' selection. To examine whether the participants’ age and their attitude toward the importance of packaging design moderated the relationship between the illustration and participants' choices, we included these variables in the analysis. The analysis showed no significant effect of age, $\chi^2(1) = 0.619$, $p = 0.43$, indicating that the age of participants did not significantly influence their choice between two packaging designs. Similarly, the participants’ attitude toward the importance of design also did not significantly affect participants' choices, $\chi^2(1) = 3.38$, $p = 0.07$.

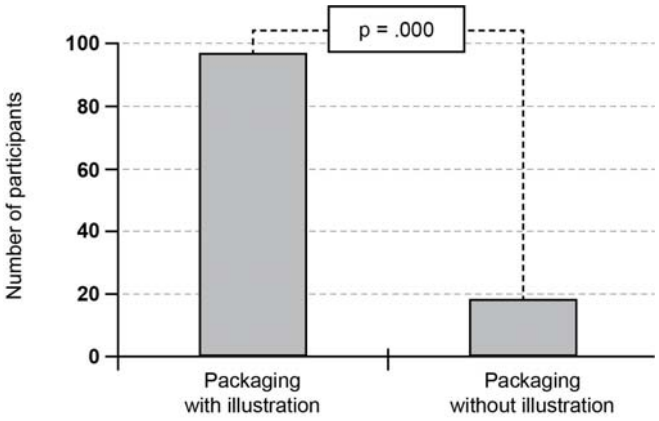


Figure 2: Results of the choice task

3.2 Attractiveness evaluation

Participants' responses were measured across two independent variables: flavor (banana versus peanut) and visual design (without illustration versus with illustration). A repeated measures analysis of variance (ANOVA) was conducted to investigate the effects of flavor and visual design on the attractiveness ratings. The analysis revealed a significant main effect of visual design, $F(1, 115) = 62.99$, $p < 0.001$, indicating that the packaging with illustration was perceived as more attractive ($M = 3.61$, $SE = 0.09$) than the packaging without illustration ($M = 2.86$, $SE = 0.08$). Figure 3 shows this effect. In contrast, there was no significant difference in the attractiveness between two flavors, $p = 0.50$. The interaction between flavor and visual design was also non-significant, $p = 0.15$, suggesting that the effect of illustration was consistent across both product types.

The participants' age and their attitude toward the importance of packaging design were included as between-subject factors in the analysis to examine their influence on the results of the packaging attractiveness evaluation. The results showed no significant main effect of age or attitude on the participants' responses, ps > 0.05. Furthermore, there were no significant interactions between these factors and the within-subject variables, indicating that neither age nor attitude toward the importance of packaging design moderated the effects of packaging visual design.

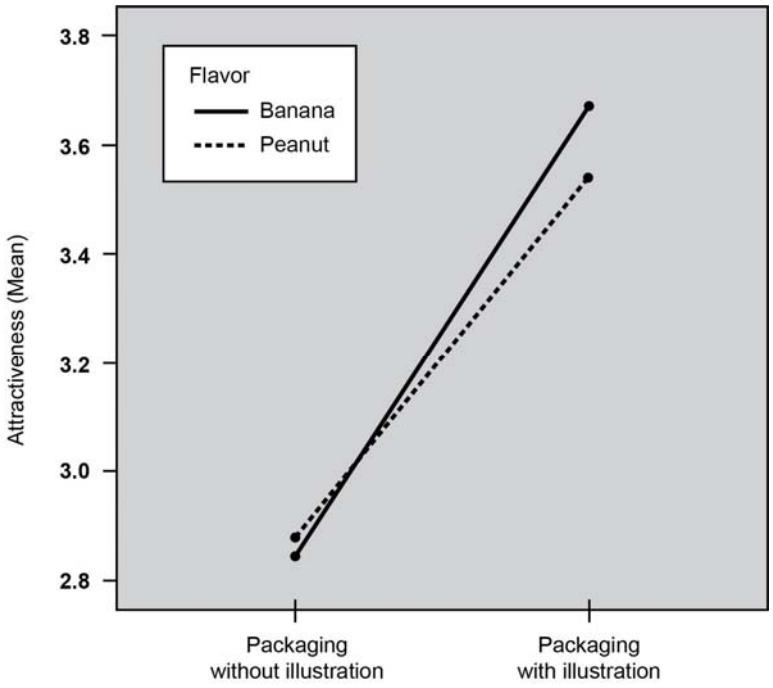


Figure 3: The effect of illustration on perceived attractiveness

4. DISCUSSION

The first part of our study, which explored the frequency of healthy snacks consumption among consumers from different age groups, indicated the surprisingly infrequent consumption of this type of food product among participants. This validated the need for more specific inquiries in our study, where the focus was on exploring the influence of digital illustration on their perception of the snack packaging designs. The main finding is that the packaging with illustration was perceived as more attractive than the non-illustrated packaging, which aligns with other studies conducted in the area of the food packaging design. For example, a study of wine packaging design (Boudreaux & Palmer, 2007) found that, among illustration, layout, and color, the illustration had the strongest effect on consumer responses. The positive effect of illustrated versions of packaging in our study can be attributed to their vivid and colorful design, which can be more appealing to consumers (Pires & Agante, 2011). The significance of color saturation was also validated in a study involving participants who were exposed to pictures of snack and drink products (Kunz, Haasova, & Florack, 2020). Their results demonstrated that displaying product images in grayscale reduced the

perceived correlation between healthiness and tastiness. Still, it should be acknowledged that these findings may not be entirely applicable to all cases. As reported in (Schifferstein, Lemke, & de Boer, 2022) the complexity of images may trigger additional, unintended interpretations, which, in some cases, can negatively affect the overall assessment of the packaging.

A surprising result in our study is that that neither age nor the participants' attitude toward the importance of packaging design moderated the effects of illustration on the packaging design. This is in contrast with previous research which demonstrated that age may influence packaging evaluation under certain conditions. For example, the findings from a study which compared the responses from different age groups (Vila-López, Küster-Boluda, & Sarabia-Sánchez, 2017) suggest that the form and visual presentation of healthy products are more influential for young adults than for adolescents. In a study on packaging-based odor associations (Kovačević, Kupres, Šepat, & Brozović et al., 2022a), it was found that younger participants were more sensitive to design variations compared to mature participants.

Additional results from the choice-task in our study confirmed the superiority of the illustrated packaging designs over non-illustrated ones. Our results are consistent with those of a study (H. Wang, Ab Gani, & Liu, 2023) which showed that among the several design elements, image stood out as the most influential factor in driving consumer purchase decisions. This effect is especially pronounced when concrete (F. Wang, Wang, & Cho, 2022) or realistic images are used (Kovač, Kovačević, Bota, & Brozovć et al., 2019). The findings align with earlier study, which highlight the importance of appropriate illustration, especially for instant coffee packaging, in shaping consumer preferences (Kobayashi & Benassi, 2015).

Finally, the results from both evaluation questions and choice-task are in accordance with the participants' positive responses to the question of whether they believe that design can enhance the perception of the product within the packaging. Considering all the study results, it can be concluded that the participants demonstrated consistency in their responses across various question types, strongly supporting the positive impact of the illustrated packaging design on the perceived attractiveness of the food product.

5. CONCLUSIONS

Our results on attitudes towards the importance of design suggested that the majority of our respondents consider the packaging visual design as a relevant product attribute, emphasizing its significant impact on product perception. This may indicate that digital illustrations on the packaging for snack bars can play a significant role in promoting healthier product choices, highlighting the potential benefits of deliberate packaging design in encouraging consumer preferences for healthier food options, regardless of their age. However, this study has certain limitations. First limitation is a relatively small sample group, which may have impacted generalizability of the results. Second limitation could be an online format of the questionnaire, which could have influenced answers dependent on respondents' subjective interpretation of the questions. These methodological constraints suggest that caution should be taken when applying these findings to a wider array of products or different populations.

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STOP MOTION AS A TOOL TO PRESENT, PROMOTE AND COMMUNICATE PRODUCT DESIGN

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Abstract: *Stop motion is an animation technique, where objects are physically manipulated in small increments between individually photographed frames, creating the illusion of movement, when the series of frames is played in sequence. Both stop motion animation and digital animation can attract and engage a user. Stop motion is known for its handcraft character and offers the feeling that what you watch really exists. It brings prototypes to life and highlights their characteristics, while at the same time, allows the storytelling transfer and offers dynamic visualization. Digital animation provides a versatile and dynamic platform capable of intricate detail and seamless integration with other digital media, making it suitable for a wide range of applications i.e. technical presentations, marketing campaigns. In the present paper, four rooms inspired by the four seasons of the year were created. All rooms include a set of furniture and several products, which are presented both physically and digitally. The main idea is to use the stop motion visual technique as an innovative tool for presenting, promoting and communicating the use of the products within the designed 3D space. In this way, an alternative advertising method is offered and can attract the user's attention. The implementation consists of using both physical and digital prototyping for presenting the use of the designed products.*

Key words: stop motion, digital animation, prototyping, product

1. INTRODUCTION

The product design process is getting a great deal of attention because all the decisions approved during this phase, lead to customer satisfaction and cost related outcomes. A number of methodologies (i.e. conceptual development) and technological tools (i.e. Computer Aided Design - CAD, render technologies, graphics, computer generated animation) affect both the performance and successful presentation of the products to the end user (Kyratsis et al., 2020). Examples of this approach are based on the computational product design that is a way to create extensive families of products with different geometries under a commonly defined brand principle, and unruly design that increases the creativity via including art within the conceptual design process (Kyratsis et al., 2022; Manavis et al., 2017).
Over the years, a number of physical techniques have been substituted by digital tools thus making the result more appealing to the customer for branding purposes mainly via the social media channels. Nevertheless, taking photographs with digital cameras and paying attention to the correct adjustments for fast moving items, or light performance, becomes more fashionable to a great deal of youngsters (Manavis & Kyratsis, 2021).

2. STATE OF THE ART

Prototyping is a design method that involves the use of physical or digital prototypes to explore and examine how a new product will be used before its final production. This approach allows for experimentation and research in the early stages of development, helping designers identify solutions to problems. Prototypes serve specific purposes and applications, as it is often not feasible to test all possible design ideas. Originally, prototyping emerged from the field of architecture and has since been adopted in product design.
Today, with the aid of digital tools, physical models have gained even more significance. Technologies such as 3D printing play a critical role, while C.A.D. (Computer-Aided Design) software is crucial for creating physical models. Examples of such methods include laser cutting and engraving, 3D printing, and CNC machine production. Furthermore, advancements in software have significantly contributed to the design process, enabling the creation of complex forms and shapes that enhance the prototyping methodology. The role of computers has also become increasingly important in this process (Efkolidis et al., 2020; Manavis et al., 2020;).

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Stop motion animation has emerged as a versatile and powerful tool for presenting, promoting, and communicating product design. Its unique characteristics, such as engaging storytelling, visual appeal, and the ability to demonstrate product functionality, make it an effective medium for capturing the attention of potential customers and fostering emotional connections with brands (Bonanni & Ishii, 2007; Davis, 2019). By creating compelling narratives around their products through playful and imaginative animations, designers can effectively communicate product features and benefit, leaving a lasting impression to the audience.

The handcrafted quality of stop motion, with its distinct aesthetic, stands out in a crowded digital landscape, making it an attractive choice for brands seeking to differentiate themselves. This tactile aspect resonates with consumers, who value authenticity in an increasingly digital world, allowing brands to showcase their values and craftsmanship (Heller, 2021). The imperfections inherent in stop motion can make brands appear more relatable and genuine, fostering trust and loyalty among consumers (Bennett, 2020).

While the production of stop motion can be time-consuming and requires significant expertise, advancements in technology and software have made it more accessible. Modern tools enable creators to streamline the process, making stop motion a viable option for businesses looking to differentiate their product presentations (Wang & Lee, 2022; Thompson, 2023). The integration of digital techniques with traditional stop motion practices allows for innovative storytelling that can significantly enhance the viewer engagement (Johnson & Smith, 2021).

Stop motion animation not only serves marketing and communication purposes but also proves valuable in the design process itself. By allowing designers to visualize concepts and prototypes in a tangible way, stop motion facilitates exploration and iteration of ideas before the final production, streamlining the design process and leading to more innovative and effective product solutions (Bonanni & Ishii, 2007; Davis, 2019). This iterative approach can lead to more refined designs that resonate better with the target audiences (Peters & Green, 2022).

Additionally, research has shown that stop motion can evoke emotional responses that enhance brand recall and consumer loyalty (Martinez, 2023). By leveraging the unique qualities of stop motion, brands can create memorable experiences that not only highlight product features but also foster deeper connections with their audiences.

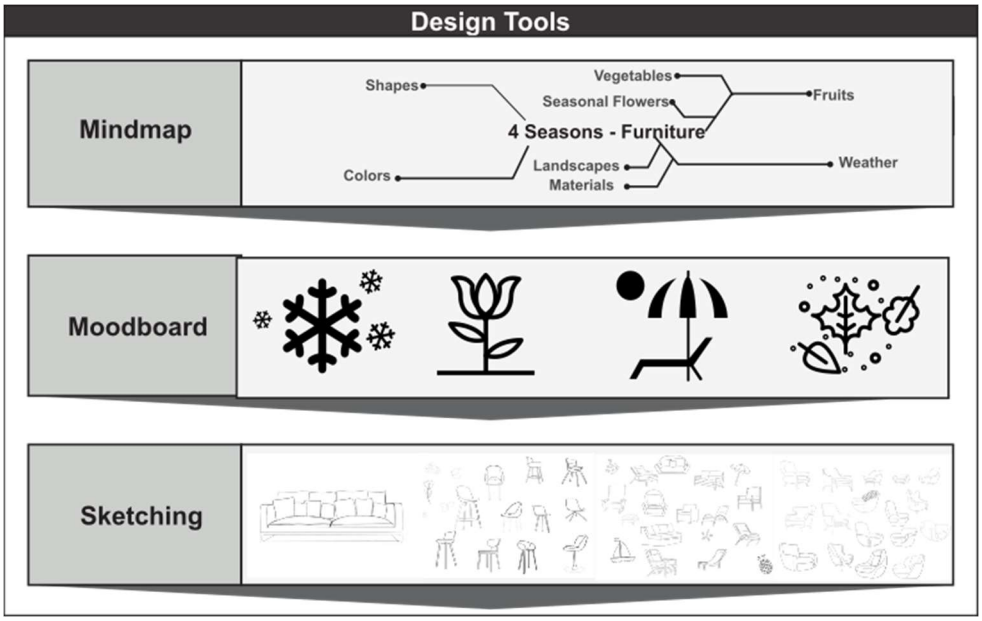
This present study aims to explore an alternative way of communicating and advertising a series of designed products. The project utilized design tools, digital techniques, and prototyping methods with an aim to create both digital and physical stop motion animations. The philosophy and techniques of stop motion, as well as of digital animation, were examined.

3. METHODOLOGY

In the initial experimental phase, various design tools were used, such as concept mapping, sketches, 3D visualization, photorealism, and prototyping. This phase concluded with the production of four digital animations and four stop motion animations, with the goal of investigating techniques and practices for the main project. The thematic focus required selecting one or more products, whose use needed to be highlighted for advertising purposes.

Furniture was chosen as the design focus, with the four seasons serving as inspiration due to their rich colors, forms, and shapes. Four rooms were designed, one for each season, containing various pieces of furniture. The design process involved using tools like mind maps, mood boards, sketches, 3D visualization, and prototyping. Based on the digitally created rooms, four digital animations were produced. Additionally, the rooms and furniture were physically constructed, and with the use of a manikin, four stop motion videos were filmed.

During the project, both physical prototyping techniques and digital animation techniques were utilized. Everything that was created digitally was later replicated physically as well. The implementation of the project began with the use of methodology-based design tools, such as mind maps, mood boards, and sketches. Figure 1 depicts the framework and the tools used for increasing the creativity aspect of the project.



igure 1: Framework used during the project

For the digital animations, the Blender™ design software was exclusively used. Further to its high performance, Blender™ is an open-source suite and free to use. Initially, the spaces were designed based on the four seasons of the year concept, and then the furniture that decorated the spaces were designed with an aim to support creativity and high appearance. In addition, the main character of the simulation was defined. The character was placed in each 3D space, and by using inverse kinematics, the movements performed within the space were created. Each movement was recorded using the inserted keyframes, and eventually, all these frames formed the animation (Figure 2).



Figure 2 (part 1): Character animations based on the four seasons (spring, summer, fall, winder)



Figure 2 (part 2): Character animations based on the four seasons (spring, summer, fall, winder)

Upon completion of the digital animations, the physical prototyping process was implemented. For prototyping the 3D spaces (rooms), foam board was used as the base, while the walls and floors were printed on vinyl with textures (i.e. colored plaster, wooden, marble floors, acoustic panels), which were then attached to the foam board. The furniture and various decorations in the available 3D space were crafted from materials like balsa wood, extruded polystyrene, fabrics, plexiglass, straw etc. Once completed, a pre-made stop-motion character was used for filming the animations. For the filming process, a smartphone (with high resolution camera), a tripod and the Stop Motion Studio™ mobile app were used. The models were stabilized in a fixed position, along with the smartphone and tripod. The character was attached to a soft wire that extended beyond the height of the "walls" and was secured to another piece of foam board, where pathways were carved for the wire and character to follow. The character was moved from place to place, with its limbs posed in each frame. Each pose was captured, and by maintaining consistency between the movements, the remaining poses were created. In the end, the piece of software compiled all the photos and generated the final videos (Figure 3).



Figure 3: Stop Motion character posed based on the four seasons concept

4. DISCUSSION

The project was presented, for an early evaluation, to a diverse audience comprising industry professionals, designers, and potential consumers. The feedback received was highly encouraging, with the audience expressing significant interest in the use of stop motion and digital animation as effective tools for product promotion and presentation. Attendees agreed that both stop motion and digital animation offer compelling methods for advertising, each bringing unique strengths to the table. The interactive and visual appeal of these techniques successfully conveyed the designer's intended message, demonstrating that the project's objectives were effectively communicated. The audience's positive response and acknowledgment of the project's ability to highlight product features and enhance brand messaging validated the approach and confirmed its relevance and effectiveness in the field of product design.

During this project, a total of four 3D digital animations and four stop-motion videos were created. In the videos produced, the manikin moves through each room and interacts with both the designed furniture and the 3D proposals of the interior. These efforts take place before sending the designed products for manufacturing and aims in presenting the work prior to production.

The digital animations highlight the design appearance and capacity of the designed products, while the stop-motion videos emphasize the physical prototype in real time. Although on a smaller scale, they provide an initial realistic sense of what geometry and appearance, of the designed products and scenes will achieve. Additionally, they help reveal design flaws that were not identified during the design stage.

The final videos serve as effective advertisements and a means of communication with potential customers, offering a preview of what will be produced. However, the creation of digital and stop-motion animations can be challenging. These processes are time-consuming and require meticulous attention to detail.

The elements that make up the scene, both digitally and physically, also demand careful consideration. For instance, lighting plays a crucial role, as it can either enhance the scene and convey the intended message, or, if used incorrectly, ruin both the animation and the message. Camera placement is equally important; the wrong angle can completely distort the product's image, undermining its strengths rather than promoting its potential. Beyond requiring significant time and attention to detail, prototyping also demands careful selection and management of materials. The right choice and use of materials contribute to effective communication with the audience, building excitement and anticipation for the product. Additionally, it allows the designer to understand how the design will look in production and to identify potential flaws.

The completion of four digital animations and four stop-motion videos provided valuable insights into using animation for product design, promotion, and communication. Each animation presented a unique interaction between the manikin and the furniture, highlighting both form and function. The combination of digital and stop-motion methods offered distinct perspectives on the products, allowing designers and consumers to engage more interactively.

Digital animations excelled in showcasing polished, versatile designs with control over light, camera angles, and textures, delivering an idealized version of the product for early-stage marketing. In contrast, stop-motion animations offered a more tactile, authentic representation, with physical models revealing textures and behaviors that digital renderings could not capture. The handmade quality of stop-motion enhanced the sense of craftsmanship, resonating with consumers seeking authenticity.

A key discovery was that stop-motion exposed design flaws overlooked in digital prototypes, offering a more holistic approach to product testing. However, both methods presented challenges, particularly in terms of time and precision. Lighting and camera placement were critical, as errors could distort the product's appearance or diminish its visual impact.

Material selection also played a crucial role. For stop-motion, materials needed to closely resemble the final product in order to provide an accurate portrayal. This helped improve communication between designers and end-users, offering a clearer understanding of the product's final form. Overall, combining digital and stop-motion animation provided a comprehensive framework for testing, promoting, and communicating product designs, ensuring both aesthetic appeal and functionality.

5. CONCLUSIONS

This project demonstrated the effectiveness of using both digital animation and stop-motion as innovative tools for product presentation and communication. By showcasing furniture designs within seasonally themed rooms, the combination of these techniques allowed for a compelling and engaging presentation, providing potential customers with an early glimpse of the product in use. The digital animations offered a high level of detail and flexibility, while stop-motion provided a tangible, handcrafted feel, reinforcing the authenticity of the designs. Both methods enable designers to visualize and experiment with product functionality before their final production, helping to identify potential design flaws that might not have been apparent during the initial stages of development.
However, the process of creating both digital and stop-motion animations was time-intensive and required careful attention to detail in terms of lighting, camera placement, and material selection. These factors played a critical role in enhancing the visual impact and ensuring that the final presentation conveyed the intended message. Ultimately, combining these animation techniques provided a powerful and versatile approach for product promotion, allowing for a richer storytelling experience and fostering stronger connections between the product, the designer, and the audience.

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IMPLEMENTATION OF SHAPE AND STYLE INTO CONTENT RECOGNITION

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Abstract: *Humans perceive a considerable amount of information through vision, with an estimated 80-85% of environmental information being processed through our eyes. This emphasises the importance of vision for human perception and interaction. The visual system detects and interprets stimuli such as colour, brightness, contrast, shapes, movement, speed, depth and texture. This enables us to navigate our environment, interact with it and respond to it effectively. Vision is crucial for activities such as reading, driving, recognising people and objects and maintaining balance and coordination. As part of the bilateral cooperation between the Republic of Slovenia (University of Ljubljana, Faculty of Natural Sciences and Engineering) and the US state of Kansas (Wichita State University), a joint project entitled Typography World Map was initiated. One of the goals of the project was to educate students from both countries about the importance of data visualisation and information design. This collaboration emphasised the professional integration of technology and graphic arts design and showed how their synergy can enhance the presentation and understanding of complex data. Properly presented, this approach can simplify the perception of complex information, such as statistical data, by making it visually appealing and easier to understand. As part of the project, students were given pre-designed names of different US states. This paper presents the results of their assignment, which was to compile and visualise selected statistical data and key information about the assigned states in the form of an infographic. As the visualisation of key information can greatly enhance the presentation and understanding of data, we wanted to assess how well the students could apply their newly acquired skills in typography, design and graphic prepress techniques to create these infographics. The results were interesting and provided valuable insights into the importance of data visualisation and individual data presentation.*

Key words: education, graphic prepress, graphic design, visualisation of information

1. INTRODUCTION

The dominance of visual perception is a key feature of human cognition and behaviour. By efficiently processing a variety of visual information, the human visual system enables us to interact meaningfully with our environment, demonstrating its critical importance in various contexts and activities (Harrison, Reinecke & Chang, 2015; Lin & Atkinson, 2011). The human visual system is not just a passive receiver of information, but an active and complex mechanism that recognises and interprets a variety of stimuli. Important visual attributes such as colour, brightness, contrast, shape, depth and texture are processed simultaneously, so that we can form a cohesive understanding of our surroundings.

The ability to perceive colours enables people to distinguish objects and assess their significance whether it's recognising ripe fruit or interpreting traffic signals. Brightness and contrast help to distinguish objects in different lighting conditions and improve our ability to cope in different environments. Shape recognition is crucial for identifying objects and facilitates tasks such as reading, where the brain quickly interprets letters and words based on their shape (Yarbrough, 2019).

These visual skills are the basis for many everyday activities, such as reading, driving and social interactions. Reading relies heavily on the rapid and accurate processing of visual symbols, while driving requires constant interpretation of a rapidly changing visual landscape, including road signs and the behaviour of other vehicles. Recognising people and objects also depends on visual cues, which are essential for effective communication and social cohesion.

In addition, the integration of visual information with proprioceptive and vestibular information is crucial for maintaining balance and coordination. This interweaving of different sensory modalities illustrates the complexity of human perception, as it involves the synthesis of information from different sources to produce a coherent experience of the world (Sober & Sabes, 2005; Evans & Treisman, 2011). The ability to combine visual cues with feedback from our body enables us to navigate and interact with our

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environment. This emphasises the paramount importance of vision for human cognition and daily life. (Glaser & Schwan, 2020)
Recognising the importance of visual perception, a collaborative initiative entitled "*Typography World Map*" was launched as part of a bilateral partnership between the Republic of Slovenia (University of Ljubljana, Faculty of Natural Sciences and Engineering) and the US state of Kansas (Wichita State University) (Pušnik et al., 2022a, Pušnik et al., 2022b). The main goal of this project was to educate students from both countries in the principles of data visualisation and information design. This collaboration emphasises the integration of technology and graphics and shows how their interaction can improve the presentation and understanding of complex data.
The aim of this study was to find out how well students can design an infographic that incorporates the existing typography of a particular US state in a recognisable and representative way, while including important information about the state. We also wanted to find out how well first-year students could do this task without any prior knowledge, as one of our goals was to identify gaps in their graphic design skills. Specific research objectives included assessing students' ability to:

- Apply basic typography and design principles in the creation of infographics.
- Apply graphic prepress techniques to improve the clarity and aesthetics of data presentations.
- Analyse the effectiveness of their visualisations to facilitate understanding of the information.

2. METHODS

The first step of the project was performed in the winter semester of the academic year 2021/2022, when the Slovenian master's students of the Creative Typography course (led by Assist. Prof. Dr. Nace Pušnik) individually developed various typographic solutions, which were combined into sets, presented in the course's seminar and linked to the content of the "*Typography World Map*" semester project. The results of this project were presented in the works Pušnik et al. (2022a) and Pušnik et al. (2022b).
In the second step, data visualisations and information designs were created for 16 selected US states, using the same typography as in 2022. A total of 32 students (from the Graphic prepress course led by Prof. Dr. Raša Urbas) worked together to create 16 infographics, each showing the chosen typography along with relevant information highlighting the typical characteristics and statistics of each state. Students conducted in-depth research on their chosen state or country, exploring various aspects such as cultural, social, linguistic and natural characteristics, as well as important events representative of the U.S. states. Students conducted online research on specific U.S. states and then shared their findings with other students in the U.S. This was because it was important to present commonly known facts in either a short text or a graphic design/element. The students used various graphic programmes (e.g. Adobe Illustrator and Photoshop) to design the infographics, set the graphic prepress settings correctly and visualise them. A great deal of attention was also paid to the graphic prepress stage, as the students had to prepare the designs for publication on the internet and for printing.
To ensure that the project produced adequate results, the students had weekly consultation hours to help them complete the semester assignment. As part of the learning process, the aim of the project was also to determine how much practical knowledge the students took away from attending the lectures and how they applied the theoretical knowledge they had acquired to the practical application of graphic prepress in the form of infographics. At the end of the project, the infographics created were assessed in terms of the choice of appropriate typography, its size, alignment and placement of the text, the selection of the image material and its quality, the placement of the content in the final format and, of course, the preparation of the file for publication on the Internet and as printed media. All 16 infographics were also printed and an exhibition on the project was presented at the Faculty of Natural Sciences and Engineering, University of Ljubljana. As part of the peer assessment, the students also evaluated their work using the so-called "post-it method", in which they selected the infographics they thought were the best and worst. Green Post-it notes labelled the best and red ones the worst infographics.

3. RESULTS AND DISCUSSION

The students were provided with pre-designed motifs for the names of various US states, each of which was reproduced in a different typographic style (Figure 1). Some of these selected typographic motifs contained recognisable features typical of the respective states, which added to the complexity of the task for the students. To streamline the process of fulfilling the project requirements, students were first instructed to research meaningful facts and data about each state. These findings were then to be supported by the integration of carefully selected graphic elements and illustrations.



Figure 1: Motifs of US state names

In infographics design, students had the task of summarising the data they had collected for each state into visually compelling representations. The research covered a wide range of topics, including demographic data such as total population, religion and racial composition, important landmarks and natural monuments, notable wildlife, and data on climate and weather patterns. In addition, the students analysed the geographical characteristics of each state, considering information about its size, shape and historical significance. The infographics also highlighted aspects of the economy, major cities and other culturally or economically significant elements to ensure a comprehensive representation of each state's identity.

The students showed a creativity with the choice of content for their presentations, often opting for unconventional and unexpected facts to represent the states. There were no restrictions on the selection of data; instead, they were encouraged to highlight what they felt was most representative of each state. The result was infographics with a variety of information ranging from the state's prestigious universities to unique details of state seals to the popularity of certain sports — such as the importance of golf in South Carolina. Some students emphasised the architectural significance of famous buildings, such as in New York, while others chose to highlight notable personalities or significant historical events, such as groundbreaking open-heart surgery in Minnesota. In addition, data on crime rates, cultural landmarks and other features were included in the final presentations, creating a rich and diverse picture of each state.

The project involved first-year students on the Graphic and Media Technology programme, many of whom had little experience with graphic design. Therefore, our expectations were tempered as we expected some errors in the design and layout of their work. Although consultations were offered to the students throughout the process, we realised that some of them would still struggle to meet the technical

specifications required to create files suitable for both web publishing and print, as they were not yet as familiar with these industry standards.

Typographical and grammatical errors were among the most common problems with the infographics, partly due to the fact that the students are native Slovenian speakers, but the infographics had to be made in English. The most common errors included the selection of inadequate fonts and font sizes (Figure 2), which meant that the text was often too small to be displayed effectively or the contrast amount was poor.

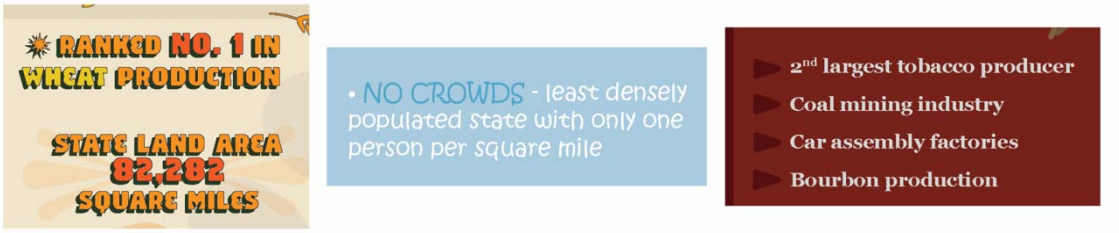


Figure 2: Examples of inadequate typography

Text alignment was also noticeably inconsistent, with inadequate word breaks and poorly structured indents further contributing to the overall lack of cohesion in the layout (Figure 3). In some cases, students did not place graphic elements properly next to the text, so that they occasionally obscured parts of the content (Figure 4). This problem was largely because most of the illustrations were not created by the students but taken from the Internet. Due to a lack of technical knowledge and attention to details, many students were not capable to select appropriate file formats for the graphics, resulting in some images not supporting transparency, which led to overlapping text and graphic illustrations. Quite a few infographics were placed too close to the edge, ignoring the bleed (Figure 5).

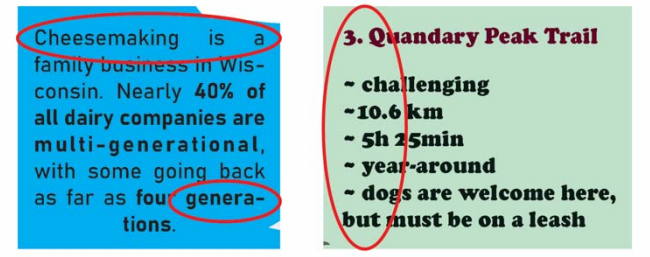


Figure 3: Examples of inadequate text alignment and hyphenation



Figure 4: Example of inadequate layout



Figure 5: Example of inadequate content placement in regard to the margin

There were fewer problems with the choice of images than with the placement of the text. As already mentioned, the students mainly searched for the visual material on the internet and endeavoured to match the style of the pre-designed motifs of the state name, but they did not always succeed (Figure 6).

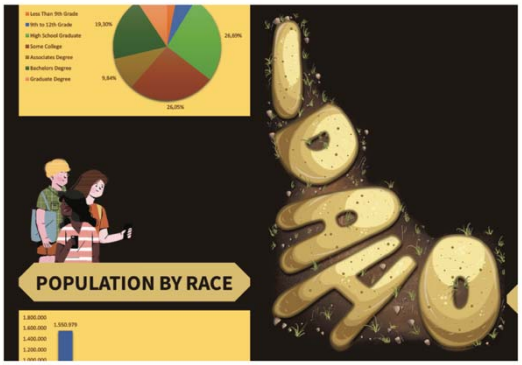


Figure 6: Example of a poorly choice illustration that does not correspond to the pre-designed motifs of state style

In addition, there were instances where the images were improperly cropped (e.g., square cropped river), lacked uniformity in size (e.g., the disproportionate scaling of animals such as the bison, bear, and beaver) and style (e.g., shopping chart, heart and canoe), and in some cases were rendered with a lack of detail or precision (e.g., watermelon) (Figure 7).



Figure 7: Examples of poorly chosen illustrations

Despite the challenges mentioned above, the students performed remarkably well. They created 16 different and highly engaging infographics that provided a compelling overview of the different US states, combining written content with visual elements. Some chose a minimal colour palette, while others opted for vibrant and colourful designs (Figure 8). All but one group of students showed a clear understanding of the task. The only omission from this group was that they did not include the given motif of the state name in their infographic. In general, they adhered to the guidelines for the use of text, which was kept to a minimum and mainly supplemented by illustrations and other graphic elements. It was also recommended to present the text in sentence-free formats, which was followed by all but one group (in addition to the already mentioned one).

The students had no major difficulties in preparing the files for printing and online use. Since vector-based illustrations were used, resolution problems were avoided. However, there were minor challenges, mainly due to graphic material from the internet that did not support transparency. When saving the infographics in PNG format for online publication and in PDF/X format for printing, some students forgot to convert the colour mode from RGB to CMYK and vice versa. Also, some forgot to add bleed marks and crop marks, which are essential for print.



Figure 8: Exhibition of 16 infographics evaluated with "Post-it method"

In a final step, the students were asked to evaluate both their own work and that of their peers. To assist them, they were given detailed instructions describing the essential elements of effective infographic design. These guidelines emphasised the importance of choosing appropriate typeface style and font size, the strategic placement of key elements within the chosen layout and the importance of harmonising text and visuals to create a coherent and balanced overall presentation. As already mentioned, the assessment was carried out using the "Post-it method", with each student marking their best infographic with a green post-it notes and the one they thought was weakest with a red post-it notes. As expected, the selection of students differed somewhat from the mentor's assessment. Factors such as knowledge, experience, familiarity with proper graphic design process, graphic prepress, and personal visual preferences undoubtedly influenced these differences. The students preferred infographics that were more colourful, with little text and eye-catching graphic elements (infographics of the states of Arizona and Montana). They reasoned that these infographics most effectively emphasised the content using well-chosen illustrations. However, the mentor felt that part of the students' preference for a particular infographic was due to the vibrant, pre-designed motif of the Montana state name – a rainbow-coloured design highlighted in the centre of the layout. The students' choice for the weakest infographic also differed from the mentor's assessment. They chose the infographic of the state of Wisconsin as the worst, even though it was not the weakest in terms of design or content. The mentor surmised that this choice was likely due to the authors' decision to focus solely on one characteristic of the state - its association with cheese and beer products. While this focus was interesting, it did not fulfil the broader task of presenting several important and recognisable features of the state, which may have contributed to the lower score.

4. CONCLUSIONS

The "*Typography World Map*" project further explored the importance of visual processing through a project collaboration that emphasised the intersection between education and graphic technology. This project demonstrated how effective visual design can simplify complex data and make it more accessible and engaging for different audiences. Using a consistency in typeface style selection and information design for the different U.S. states allowed students to create cohesive, visually appealing infographics that reflected each state's unique characteristics. Immersing students in research about their chosen states provided them with a comprehensive understanding of the cultural, social, linguistic, and natural elements that make up these regions. By examining real-world events and representative features, students were able to create data visualisations that not only convey statistical data, but also capture the essence of each state or country. Their work shows that design and visual elements can play an important role in conveying nuanced information in a way that is both informative and aesthetically pleasing.

The project results, including the visual motifs, infographics and colour schemes, showed how research findings can be effectively translated into visual communication design. The unique characteristics of each state or country were expressed through the design choices, highlighting the importance of thoughtful, research-driven approaches to data visualisation. This approach emphasises that successful information design is not just about presenting data, but also about engaging the audience through a clear, creative and meaningful representation of subject's identity.

This project therefore underlines the crucial importance of visual perception and data visualisation in modern information design. By combining technical skills and creative empathy, the students have shown how visual elements can enhance the presentation of complex information to enable better understanding and engagement. Furthermore, the project is a testament to the value of interdisciplinary collaboration and the role of visual literacy in effective data communication.

6. AKNOWLEDGMENTS

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DEVELOPMENT OF FEMALE ARTIST IDENTITY IN THE 19TH CENTURY: AN EXAMINATION IN THE CONTEXT OF PRINT ART

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Abstract: *The 19th century stands as a pivotal period in art history, marked by significant strides in both artistic expression and the struggle for women's rights. Women encountered various obstacles as they endeavoured to carve out their identities, seeking greater recognition and acceptance within the artistic sphere. However, this journey was fraught with substantial impediments to women's artistic and educational development. Initially, during the first half of the 19th century, access to art education for women was severely restricted. Often deprived of formal artistic training, they were typically relegated to home or private tutoring. This limitation significantly hindered women's efforts to establish themselves in the art world. Moreover, upon entering the realm of art, women faced societal resistance. A considerable portion of society questioned, and even outright rejected, the notion of women actively participating in the art world. Nevertheless, certain progressive artists and advocates endeavoured to strengthen the identities of female painters and secure their recognition. Over time, particularly in the latter half of the 19th century, educational opportunities expanded for some women, leading to their admission into art schools. This represented a significant step in enabling female painters to develop their artistic talents and find their expressive voices. Female painters often utilized their art to advance the cause of women's rights. Through their works, they sought to promote social change and emphasize the strength and worth of women. Consequently, female painters frequently collaborated with feminist movements. In this context, female painters typically focused on female experiences in their works. Themes such as gender roles, family dynamics, nature, and the female body were commonly explored. Additionally, female painters developed various techniques and styles to articulate their emotions and thoughts.*
This paper will focus on the growing interest in new techniques and styles emerging at the beginning of the 20th century, specifically focusing on Western female painters. Furthermore, it will examine the interaction between the development of the Western female artist identity and the traditional Japanese printmaking art, which holds significant prominence in Eastern art.

Key words: 19th Century Women Artists, Printmaking, Ukiyo-e

1. INTRODUCTION

The late 19th and early 20th centuries witnessed the birth of modern art. The modernization of art represented an innovative period that questioned traditional aesthetic understandings and social norms. Movements such as Impressionism, Post-Impressionism, Cubism, and Abstract Art challenged the traditional boundaries of art and introduced new aesthetic approaches. Women painters played important roles in this modernization process. However, their contributions during this period have generally been less recognized than those of male artists. This can be attributed to the obstacles they faced in accessing art education and professional opportunities. During that time, women were generally not admitted to formal art schools, and many women artists had difficulty receiving education in male-dominated art academies. In other words, women painters faced limited access to artistic education, professional networks, and exhibition opportunities. From Seurat's era until the 20th century, academic environments where artists found space for their early work were typically studios, where detailed drawings were made and discussed from nude models. These workspaces provided formal academic education supporting talented artists' pedagogy and connections (Nochlin, 2015).
To overcome such obstacles, women painters sought to establish a presence in the art world by creating their own studios and organizing independent exhibitions. In this context, they discovered their own identities and social roles through artistic expression. Women painters, in particular, produced works that questioned both women's identity and their social roles. These works reflect women's experiences, emotions, and their relationships with societal expectations. Frida Kahlo is one of the most important female representatives of modern art. Kahlo's unique style and autobiographical themes offered an artistic form of expression for women's identity. Her note in her work "Broken Column" (Figure 1) that says, "This body does not belong to me," reflects an understanding of art that questions both her

ORCID number is provided at the end of the paper.

personal and social identity. These and similar works by Kahlo represent an important step toward the artistic representation of women's identity (Souter, 2012). Frida Kahlo's autobiographical and symbolic works, Georgia O'Keeffe's reflections on nature and female identity, and Judy Chicago's feminist art projects are all significant examples of these themes in the art world.

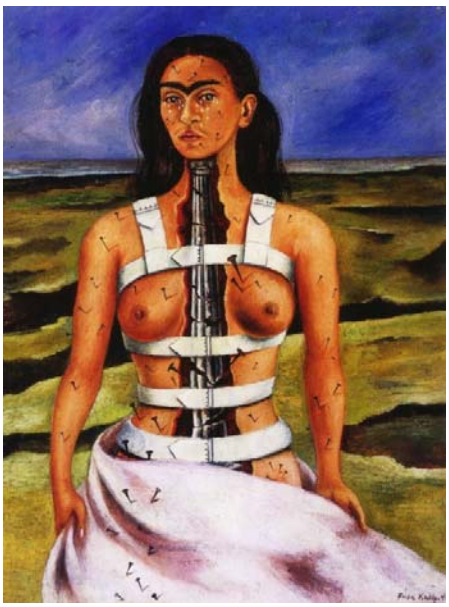


Figure 1: Simulation results

Within the modernization movement, feminist movements had a significant impact on the representation of women painters in the art world. The feminist movements of the 1960s and 1970s used art as an important tool to make women painters' voices heard and to draw attention to gender inequality. The feminist art movements that emerged during this period advocated for the rights of women painters and brought the issue of gender inequality to the forefront of the art world. Judy Chicago's The Dinner Party (1974–1979) is an iconic feminist artwork that addresses women's history and gender inequality. Chicago said about her work, "I wanted to transform women's history and cultural heritage into an artistic expression" (Gerhard, 2013). Women artists faced many challenges in gaining recognition in the art market and selling their works. While male artists generally enjoyed more exhibition opportunities and commercial success, women artists were often marginalized. This inequality resulted in female painters receiving less recognition in the art market, and their works being sold at lower prices.

In response to this situation, women painters have developed various strategies to gain greater visibility in the art market. They have established women artist groups and collectives and organized their projects and exhibitions. These independent movements have helped women painters secure a stronger position in the art world. Additionally, many contemporary women artists effectively use digital platforms and social media to promote their work and advance their careers. The roles of women artists in the modernization process, the representation of women's identity in the art world, and their struggles in the art market hold significant importance in the evolution of art. The challenges women painters face illustrates how gender inequality manifests in the art world, while also showcasing how these artists have established a strong and independent presence in the market. The artistic production of women painters is considered an important form of expression that challenges gender norms and emphasizes women's identity. In this context, the contributions of women artists have helped create a more egalitarian and inclusive environment in the art world (Öztürk, 2020).

The influence of Japanese art on the West began in 1854 when Japan opened up to foreign trade. Japanese prints (ukiyo-e) were greatly admired by Western artists and soon became fashionable in art circles. Western artists were captivated by the innovative presentation, simple aesthetics, use of colour, and abstract compositions of Japanese prints. Female painters, in particular, saw the opportunities offered by this new artistic language as a significant area of freedom. Japanese aesthetics challenged the naturalism and academic rules of traditional Western art, contributing to the development of a freer and more experimental artistic language. This shift also created important opportunities for female painters. Since women in the West had limited access to art education and the professional art world, the

alternative approaches offered by Japanese art enriched their forms of expression. For example, American painter Mary Cassatt was influenced by Japanese print art and approached female figures, in particular, from a different perspective. The simplicity and tranquillity of Japanese art allowed Cassatt to depict the daily lives of women from a more subjective point of view in her works. Art critic Linda Nochlin explains this influence in Cassatt's work as follows: "Cassatt questioned the traditional image of women by depicting their domestic lives and intimate moments, drawing inspiration from Japanese art (Lochlin, 2015).

2. METHODS

In this paper, qualitative research based on documents and records in field studies has been included. Scanning methods of various sources, such as professional books and periodicals, whether in written or digital form, were employed. The study was created by gathering data obtained through impressions and observations based on work experience acquired in previous years.

3. THE INTERACTION OF WESTERN WOMEN PAINTERS WITH UKIYO-E

Traditional Japanese printmaking has been one of the significant aesthetic movements that deeply influenced Western art, especially in the late 19th and early 20th centuries. Japanese printmaking (Ukiyo-e), in particular, contributed to the birth of a new artistic movement in Europe known as Japanism. This movement gained momentum when Western painters discovered Japanese art, especially Ukiyo-e. The minimal compositions, bold use of colour, and emphasis on patterns in Japanese art opened new horizons for many Western artists. Western women painters were also profoundly influenced by this interaction. Japanese aesthetics offered women painters an innovative perspective, both technically and aesthetically, allowing them to develop a more personal and original artistic language by distancing themselves from traditional art norms. This influence played an important role in shaping the artistic identities of women artists, who were often marginalized and overlooked in art history. Japanese prints (Ukiyo-e) were greatly admired by Western artists and soon became fashionable in art circles. Western painters were drawn to the simple aesthetics of Japanese prints, their use of flat colours, and abstract compositions. Women artists, in particular, viewed the possibilities offered by this new artistic language as a significant area of freedom. Japanese aesthetics provided valuable opportunities for women artists by contributing to the development of a freer and more experimental artistic language that challenged the naturalism and academic rules of traditional Western art.

Traditional Japanese printmaking was one of the important aesthetic movements that deeply influenced Western art in the late 19th and early 20th centuries. Japanese printmaking (Ukiyo-e), in particular, contributed to the birth of a new artistic movement in Europe and inspired an art movement called Japanism. This movement gained momentum when Western painters discovered Japanese art, especially Ukiyo-e. The minimal compositions, bold use of colour, and understanding of patterns in Japanese art opened new horizons for many Western artists. Among those deeply influenced by this interaction were Western women painters. Japanese aesthetics provided women painters with an innovative perspective both technically and aesthetically, enabling them to move away from traditional art norms and develop a more personal and original language. This influence played a particularly significant role in shaping the artistic identities of women artists who had been marginalized and overlooked in art history. Japanese prints evoked great admiration among Western artists and quickly became fashionable in art circles. Western painters discovered the simplicity, flat colour usage, and abstract compositions of Japanese prints. Women artists, in particular, viewed the possibilities offered by this new artistic language as a great realm of freedom. Japanese aesthetics provided important opportunities for women artists by contributing to the formation of a more liberated and experimental artistic language that challenged the naturalism and academic rules of traditional Western art.

The influence of Japanese printmaking on Western women artists was not only aesthetic but also technical. Women artists began incorporating techniques seen in Japanese art, such as simplified forms, flat colour use, and the effective use of empty spaces, into their own works. These techniques added a new depth to their creations, leading them towards abstraction, symbolism, and minimalist approaches. Nature themes observed in Japanese art also resonated with Western women artists, making natural elements like landscapes, plants, and animals an important part of their works. Moreover, the more authentic and everyday depictions of female figures in Japanese art opened new thematic doors for Western women painters.

The influence of Japanese printmaking on Western women artists went beyond the technical innovations and aesthetic understanding it brought to their art. It also empowered them to challenge gender roles and express their artistic identities on a more personal level. This interaction marked a significant turning point that reshaped the position of women in Western art.

3.1 Mary Cassatt and Japanese Aesthetics

The 1850s marked when Japan opened up to foreign trade and Western art discovered Japanese art, leading to significant influences. The Japanese Art Exhibition held in Paris in 1890 profoundly impacted Western artists, including Mary Cassatt, who was greatly influenced by this exhibition. Cassatt explored elements of Japanese art such as its simple and asymmetrical compositions, flat colour areas, and abstract forms, incorporating these aesthetic aspects into her work. The simplicity and directness of Japanese prints, particularly ukiyo-e, significantly impacted her graphic works. Mary Cassatt, inspired by Japanese print art, deepened her art through this influence. After encountering Japanese art, Cassatt's aesthetic approach and compositions underwent a notable transformation. By employing techniques of coloured woodblock printing in her graphic art, she adapted the spirit of Japanese prints into her work. Depicting the daily lives of women and children, Cassatt developed a minimalist and simplified visual language inspired by Japanese prints, transforming her art both technically and thematically. According to art historian Nancy Mowll Mathews, Cassatt adopted the techniques and aesthetics of Japanese print art, developing a more straightforward and minimalist approach in her compositions. The influence of Japanese art was profound in her work and marked a significant turning point in her career (Mathews, 1994).

Mary Cassatt is especially known for her depictions of the daily lives of women and children. The portrayal of simple and ordinary moments from daily life, commonly seen in Japanese prints, resonated with Cassatt’s artistic themes. In Japanese art, women were often depicted in tea ceremonies, daily chores, or interactions with their children, and these scenes were depicted with simple compositions and plain lines. By adopting this aesthetic approach, Cassatt’s work can be seen as focusing more on the reality and naturalness of women's lives, rather than idealizing their daily existence as seen in Western art. The theme of motherhood, frequently featured in Japanese prints, also holds a significant place in Cassatt’s art. For example, one of Cassatt's most famous works, "The Child's Bath" (1893) (Figure 2), strongly reflects a Japanese influence in its use of simple compositions and the minimalist presentation of figures. Art historian Katrina Gulliver explains this influence as follows: "Cassatt used the simple and asymmetrical perspectives she saw in Japanese prints to imbue her depictions of women and children with an emotionally charged intimacy." (Gulliver, 2012).



Figure 2: Mary Cassatt - The Child's Bath, 1893, Art Institute of Chicago, Chicago (Art Institute Chicago, 2024)

The artist, who also transferred the technical possibilities of Japanese prints to her graphic works, especially the woodblock printing technique became a method frequently used by Cassatt in her graphic works. The sharp and distinct lines in Japanese prints provided both an aesthetic and technical innovation in Cassatt's female and child figures. The use of colours in large flat areas emphasized the movement and emotion in the figures. The minimal use of lines in Japanese art gave Cassatt's female figures a naturalness and delicacy. Cassatt's biographer Adelyn D. Breeskin praised Cassatt's prints as "her most original contribution… adding a new chapter to the history of graphic arts … technically, as colour prints they have never been surpassed" (Lesso, 2019).
This aesthetic and technical understanding, which the artist developed through inspiration from Japanese printmaking, played a major role in the formation of her artistic identity. Through Japanese art, Cassatt developed a style that challenged the conventions of traditional Western art, allowing her to express the role of women and children in her art in a more meaningful and profound way. The aesthetic simplicity and technical finesse of Japanese printmaking form the basis of Cassatt's innovative approach to female figures and themes of motherhood. With this inspiration from Japanese art, Cassatt evolved her artistic identity towards a modern interpretation of art (Mathews, 1994).

3.2 Berthe Morisot and the Artistic Influences of Ukiyo-e

Berthe Morisot is another significant Western female artist influenced by Japanese art. The nature depictions and aesthetic approach seen in Japanese prints are evident in Morisot's work on nature and human figures. The simple and elegant compositions offered by Japanese art enabled Morisot to adopt an innovative approach to the use of light and colour. Although Morisot did not directly use Japanese print art, the influence of Japanese art in Europe can be seen indirectly in her work. The simplicity of Morisot's figures, the simplicity of her compositions, and her elegant portrayal of natural life align with the minimalist aesthetics of Japanese art. The impact of Japanese print art on Western artists has left a profound and lasting mark on Western art. With Japan opening up to foreign trade in the 1850s, Japanese art, particularly woodblock prints known as ukiyo-e, generated considerable admiration in the Western art world, especially in Paris. Japanese aesthetics challenged conventional Western perspectives and compositional rules, making simpler and more symbolic forms of expression possible. Although Morisot did not encounter Japanese art directly while working alongside artists like Claude Monet, Édouard Manet, and Pierre-Auguste Renoir in the late 19th century, the influence of this art on the Impressionist community is undeniable. Characteristic features of Japanese print art, such as flat compositions, simple lines, and the harmonious yet minimalist presentation of figures, are also evident in Morisot's depictions of women (Figure 3).



Figure 3: Berthe Morisot, La Coiffure, 1894, Museo Nacional de Bellas Artes (Artvee, 2024)

Art historian Linda Nochlin comments on the influence of Japanese art on the Impressionists: "The aesthetic revolution created by Japanese art in the West significantly contributed to the Impressionists' liberated compositions. This influence was not limited to figures like Manet and Monet; it is also evident in Berthe Morisot's elegant figure studies" (Lochlin, 2015). Throughout her artistic career, Berthe Morisot primarily focused on women, children, and scenes of everyday life. Morisot's depictions of female figures are portrayed like those in Japanese prints—simple and elegant. These figures, without being overwhelmed by details, focus more on an emotional atmosphere and a minimalist aesthetic. The characteristic feature of Japanese print art, presenting figures simply and naturally, can also be felt in Morisot's works. For instance, the frequent use of plain backgrounds in Morisot's paintings of women allows for their natural and graceful representation. This approach may reflect a compositional understanding inspired by the minimalism of Japanese print art. As with Japanese prints, Morisot's works maintain a simple relationship between the figures and the background, highlighting the figures prominently. Art historian Griselda Pollock expresses this influence as follows: "The simplicity and emotional intensity of Berthe Morisot's female figures can be interpreted as an indirect effect of Japanese print art. The innovations brought by Japanese aesthetics to Western art are evident in Morisot's refined and minimalist style" (Pollock, 1988).

The elegance of female figures in Japanese art had a notable impact on Impressionist female painters. In Japanese prints, female figures are often depicted in their natural states, as part of their daily lives. These depictions focus more on their reality rather than idealizing them. This approach allowed Berthe Morisot to present female figures more realistically and intimately in her work. T.J. Clark expresses this situation as follows: "The natural and simple portrayal of female figures in Japanese art provided Impressionist women painters like Morisot with new freedoms both technically and thematically. These female figures are far removed from the idealized images found in traditional Western art" (Clark, 1986). As an artist frequently depicting women's daily lives within the home, Morisot captured a simplicity and naturalness akin to the aesthetic understanding of Japanese print art. Her depictions of women and children are presented in an emotional yet simple manner, adding aesthetic depth for the viewer. While we cannot say that Berthe Morisot developed a direct graphic technique from Japanese print art, the extensive use of flat colour in Japanese prints may have had an indirect influence on Morisot's brushstrokes. The fine outlines surrounding figures and broad colour areas in Japanese print art can be compared to Morisot's approach to creating spaces around female figures with her Impressionist brushstrokes. By integrating figures with their surroundings through the Impressionist use of light and colour, Morisot demonstrates an aesthetic approach closely related to the minimalism of Japanese print art.

3.3 Lilian May Miller and her interaction with Asian Culture

Lilian May Miller was a contemporary American artist born in Tokyo, who established her place in the art world with her imagery. She signed her paintings with a monogram and often participated in exhibitions wearing traditional kimonos, drawing significant influence from ukiyo-e art. Unlike other Western female painters who lived in Japan, such as Helen Hyde, Elizabeth Keith, and Bertha Lum, Miller is recorded in history as the only female painter born in the Far East. Her works reflect the technical and aesthetic elements of Japanese print art. Miller combined the minimalist composition and colour usage offered by ukiyo-e with Western painting techniques, carving out a unique position in the modern art world. Her ability to present the simple yet profound themes of nature and human figures from Japanese print art is a standout feature of her work. In her prints, Miller drew inspiration from Shin-hanga printmaking, incorporating images of people and landscapes from her time in Japan and Korea (Figure 4). Her artistic presentation includes lyrical drawings, watercolours, and woodblock prints. Unlike the Shin-hanga movement, Miller personally prepared and printed all stages of her work and signed her paintings with a monogram she created herself (Frost, 2017).



Figure 4: Lilian May Miller. 1928. Yağmur Çiçekleri, Ahşap Baskı, (Ukiyo-e Search, 2024)

In ukiyo-e, a particular perspective and symmetrical arrangements are often prominent, with figures and landscapes presented in a simple and direct manner. Lilian May Miller adopted this aesthetic structure in her works, combining the symmetrical arrangements and perspectives of Japanese art with the more detailed and colourful approach of Western art. In ukiyo-e art, colours carry symbolic and emotional meanings. The brightness and simple application of colours achieved through woodblock printing offer a uniqueness previously unseen in Western art. Miller skillfully adapted this use of colour and minimalism into her own art. Particularly in her landscape paintings, the broad and flat colour areas characteristic of Japanese print art stand out. This highlights the significant role of Japanese aesthetics in Miller's artistic identity. The artist, who blends the simplicity of ukiyo-e with Western detail, is said to have used the power of symmetrical arrangement and perspective impeccably in her landscape paintings. Another critic, Arthur Kimura, notes Miller's success in colour usage, stating that she combines the minimalism of Japanese print art with the abstract expressionist language of modern art. "Her colour palette evokes the simple yet emotionally intense qualities of Ukiyo-e" (Artsper Magazine, 2020).

Lilian May Miller's art frequently features figures and nature themes inspired by Japanese ukiyo-e art. In Japanese prints, human figures and nature depictions are often presented with a simple and symmetrical approach. Miller carried the figurative attitude and the refined portrayal of nature from ukiyo-e into modern art through the themes she used in her works. The simple nature depictions in Japanese art took on new meanings in Miller's paintings, transforming natural elements into a means of expressing her inner world. Inspired by the elegant nature depictions of Japanese art, Miller created minimalist yet emotionally intense narratives, making nature not just a backdrop but also a representation of a spiritual journey. Like other Western contemporary artists, the symbolic power of Japanese art played a significant role in Lilian May Miller's artistic development. In ukiyo-e, figures attract attention not only through their appearance but also through their symbolic meanings. Miller adapted this symbolism from Japanese art into her own symbolist narrative, using direct symbols to express spiritual and emotional depth in her works. Thus, the figures and landscapes in Lilian May Miller's art, which use the symbolic power of Japanese print art as a language for spiritual expression, are noted to be imbued with not only aesthetic qualities but also profound symbolic meanings (Brown, 1999).

4. CONCLUSIONS

In conclusion, Japanese print art had a profound impact on Western female painters at the end of the 19th century and the beginning of the 20th century. The influence of Japanese print art on Western female painters shaped their artistic identities and modes of expression. Japanese aesthetics provided female painters with both technical and stylistic innovations, allowing them to develop a more personal and unique language, moving away from traditional artistic norms. The effect of Japanese print art on Western female painters highlights the role of cultural interactions in shaping artistic identities. This

interaction fostered an understanding that transcended cultural boundaries and led to significant changes in the artists' artistic production and personal identities. Female painters such as Mary Cassatt, Berthe Morisot, and Lilian May Miller embraced the aesthetic and technical characteristics of Japanese print art, reconstructing their artistic identities. This new identity created a space for freedom, contributing to the development of their art in a simple, emotional, and elegant manner. The simple narrative, bold compositions, and minimalist approach offered by Japanese art allowed Western female painters to move away from academic norms and develop more original artistic expressions. Moreover, for Western female painters, Japanese art was not only a source of inspiration but also a means of liberation against gender inequality in art. These artists, through Japonism, broke traditional moulds and pursued a more independent path in art. The aesthetic revolution of Japanese art in the West created a new realm of freedom for female painters, as it did for Impressionist artists, and allowed female painters to redefine their place in the art world.

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EXPLORING GUIDANCE AND SIGNING SYSTEMS IN ENVIRONMENTAL GRAPHIC DESIGN AS INFORMATIONAL DESIGN: A STUDY USING GRAPHIC DESIGN EXAMPLES

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Abstract: *Knowledge means power. Having knowledge has empowered human beings and provided new opportunities throughout history. Nowadays, with technological developments, accessing information has become easy for everyone.*
"Information Design" has emerged as an interdisciplinary field facilitating efficient access to necessary information and transforming complex data into comprehensible formats for broad audiences. Its primary objective is to ensure accessibility and understanding of intricate information. Currently, information design actively guides and simplifies information transfer through visual elements such as guidance and marking systems, symbols, graphics, pictograms, maps, panels, and typography.
Environmental graphic design encompasses the planning, design, and presentation of graphic elements within communication systems deployed in both natural and constructed environments. This discipline encompasses guidance systems, markings, display designs, corporate identity graphics, urban design, pictogram design, store design, mapping, and thematic landscaping.
Environmental graphic design has increasingly integrated into everyday life through the implementation of guidance and marking systems. Guidance designs enhance efficiency, create positive impressions, and foster a sense of safety in unfamiliar environments. Meanwhile, marking designs serve as visual indicators directing individuals towards their destinations.
Presently, elements such as information, guidance, and signage facilitate communication between urban environments and inhabitants. Beyond their primary roles in guiding, informing, and delineating within cities, these elements play a crucial role in enhancing urban identity, improving legibility and coherence within the cityscape, and fostering a harmonious relationship between people and their urban surroundings.
This study focuses on typography, a fundamental aspect of information design. Through an analysis of information, guidance, and marking systems, it becomes evident that elements such as signs, directional cues, symbols, pictograms, and traffic signs, integral to environmental graphic design, are closely interconnected with typography.
This study conducted a thorough review of sources to ensure the provision of original and comprehensive content. The research primarily utilized printed visual sources, augmented by archival research, internet and library databases, books, magazines, articles, and theses. Findings were presented through detailed explanations, quotations, comparisons, and identification of common themes.
This article comprises five stages. The first stage introduces the study, encompassing definitions of communication and graphic design, and an exploration of the concept of perception. The second stage defines the relationship between urban spaces and information design, discussing contemporary urban dynamics, urban identity, the intersection of urban spaces with graphic design, visual elements in urban environments, and the role of environmental graphic design. In the third stage, the study explores the role of typography in information design within urban contexts, defining information design principles, application areas, components such as typography, pictograms, symbols, emblems, and signs, and discussing criteria for readability and perceptibility in typographic analysis within information design. The fourth stage focuses on a typographic evaluation of routing systems through illustrative examples. Case studies of exemplary institutional guidance systems are examined, and recommendations for enhancing these systems are presented using tables and graphs. Finally, the study concludes with a summary of findings, evaluations, and proposed solutions.

Key words: Information design, graphic design, environmental graphic design, architecture, interior design, exterior design, pictograms, signs, indicators, wayfinding, guidance systems

ORCID number is provided at the end of the paper.

1. INTRODUCTION

Possession of knowledge has historically empowered humanity and provided new opportunities. Today, with technological advancements, access to information has become easy for everyone. However, as the amount of accessible information increases day by day, individuals are faced with the necessity of selecting the specific information they wish to access among a vast array of data. Consequently, "Information Design" has emerged as an interdisciplinary field that facilitates quick and efficient access to needed information by transforming data into forms understandable by the masses. The use of informational, directional, and signage elements has gained even more significance in modern cities, particularly in metropolises with increasing numbers of vehicles and populations. The planning, design, and presentation of graphic elements contained within communication systems used in both natural and man-made environments is referred to as environmental graphic design.

In our era, as contemporary and developed cities continue to expand over larger areas and the population living within these areas increases, modern cities have become increasingly complex. As a result, the role of information design in ensuring the accurate and efficient direction of information has become critically important. In our country, with the changes in socio-economic conditions, the visibility and effectiveness of information design have also increased.

The human being is constantly in communication and interaction with their environment. This process, which can be referred to as the exchange of information, encompasses various concepts. These concepts include motives and needs, which are the sources of human behavior, perception, which refers to the understanding and recognition of the environment, and cognition, which involves processes such as gathering, storing, organizing, reconstructing information, and recalling images. Today, information has become more accessible compared to previous times. Possessing information and being able to use it efficiently and swiftly facilitates our lives and increases the productivity of our experiences. In this era, where we can easily say we live under a bombardment of information, selecting the necessary information becomes crucial. The environment always contains more information than a person's cognitive capacity can process. Therefore, individuals must select from among the information that exceeds their cognitive capacity. The primary goal of information design is to make complex information understandable and accessible. At this stage, information design plays an active role in guiding individuals and assumes the responsibility of conveying information in a clear and accessible manner.

Zillioğlu emphasizes the importance of thoroughly understanding the communication process and its stages for effective comm-unication, and outlines these stages as follows:

In order to establish effective communication, it is essential to thoroughly understand the communication process and its stages. This process, referred to as the "Bullseye Model" (Figure 1), consists of five stages: sender, message, communication channel (media), receiver (target audience), and feedback. The initiating element of the communication process is the "sender" (Zillioğlu, 2000).

As seen in the figure below, the target audience to whom the message is conveyed constitutes the "receiver" stage in this model. The final stage of the communication process is "feedback." This stage is concerned with informing the sender about whether or not the message has been perceived by the receiver.

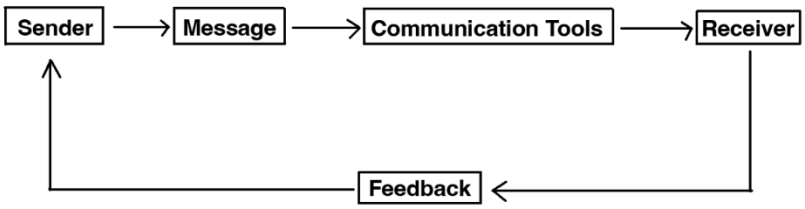


Figure 1: Bullseye Model"

Graphic Design is defined as a visual tool that presents the intended subject in an effective, informative, and aesthetic manner. Perception is the process by which stimuli recorded by the sensory organs are organized and interpreted by the brain, thereby becoming meaningful. It is a complex phenomenon formed through various mental processes, which constitutes the basis of human communication with the environment, allowing individuals to acquire information about their surroundings and make use of it. The term "graphic" refers to concepts related to visually perceived objects, namely images. Communication, on

the other hand, is the exchange of any kind of information between people. Visual communication can be defined as the exchange of information between individuals through images, without the need for verbal language—in other words, the exchange of information composed of images. Among all forms of communication, "visual communication," which occurs through sight, is the most effective and significant. Visual communication is a universal form of communication that enables people to communicate via symbols and signs. In environments where speech is not possible, "visual communication" is the only form of communication that allows us to connect with our surroundings. According to J. Bowers, in graphic design, the content of messages should be organized according to a specific structure. In graphic design, messages are the elements that enable the transmission of information between sender and receiver: "Messages can be created solely from elements such as colors, symbols, letters, or photographic images. Individually or together, these elements establish communication between the sender and the receiver, facilitating the transfer of ideas, concepts, and information." (Bowers, 1999)

An individual's ability to perceive simple and complex messages from their environment, adapt to environmental conditions, and learn and utilize their surroundings depends on these factors. This is only possible when the stimuli in the environment are accurate, sufficient, and perceivable. A person's ability to constantly monitor and perceive their surroundings is related to their capacity to select messages with related and similar characteristics from among the bombardment of intense information. This is referred to as "selective perception." Just as a person can easily perceive a single object or form in the environment, they will also more readily perceive objects or forms that form an organization, compared to those that are complex or disorganized. In graphic design, unity is achieved by arranging all design elements in relation to each other to create a sense of completeness. The viewer always seeks unity in a message; otherwise, they lose interest in the design. The human eye and brain strive to make sense of everything they see. To do so, they complete unfinished forms, group similar ones, and attempt to establish a figure-ground relationship. Wayfinding, informational, and signage systems-key aspects of environmental graphic design, one of the most important subcategories of information design-must ensure the aforementioned elements in order to establish an accurate and efficient wayfinding and informational system. The selection and use of typography, one of the graphic elements, will significantly affect the success and functionality of this system. When creating a design, the choice of font and font family, the point size, weight, and spacing, the color, its contrast with the background color, its relationship with the environment, and its alignment with corporate identity will be the most decisive factors.

1.1 Problem

The effective and efficient use of information design relies on fundamental graphic elements that ensure clarity and functionality. For institutions to establish effective communication, it is essential that they reflect their identity in a distinctive manner. Among the institutions that prioritize corporate identity and strive to create typographic consistency, universities are among the most prominent.

In this study, guidance and information systems for indoor and outdoor signage systems, particularly in large and crowded spaces of Turkish and foreign university campuses, have been examined through their design guides. An exemplary model has been developed based on Istanbul Technical University.

Due to the lack of a study or systematic proposal establishing a standardized system for signage and wayfinding in universities in Turkey, there was a need to conduct such research. The main problem addressed by this study is to determine how an information design system should be structured to ensure that the wayfinding and information design systems used in university campuses are more functional, effective, and visually cohesive, by analyzing them from the perspective of graphic design elements and communication.

This study will also address typography, which is a significant aspect within the broader scope of information design. The examination of wayfinding, signage systems, and environmental graphic design reveals that various details such as signs, wayfinding systems, symbols, pictograms, and traffic signs are closely related to typography.

The study focuses on the role of typography in information design across university campuses at the urban and spatial scale, with a proposed model titled "The Role of Typography in Information Design in University Campuses: A Proposed Model."

The general aim of the research is to contribute to future studies by analyzing the graphic design elements and communication aspects of wayfinding signage, nameplates, and other informational design elements that enable students, faculty, administrative staff, and visitors to easily navigate university campuses. During the course of this research, the signage and wayfinding system manuals of selected foreign

universities for both indoor and outdoor spaces were examined, and it was observed that there is a significant gap in this field in Turkey. The aim is to establish manuals for wayfinding and signage systems for every university in Turkey, thus ensuring a system aligned with each institution's corporate identity.
In line with this goal, the following questions will be explored:

- Are the quantity and dimensions of the informational design elements in university campuses adequate?
- Do these informational design elements convey information in a functional and comprehensible way?
- Do these informational design elements reflect the institution's corporate identity?
- Do these elements maintain visual integrity?
- Are the placement locations of these informational design elements chosen correctly?
- Are there sufficient numbers of these elements in university campuses?
- Are these informational design elements readable and perceivable from a distance?
- Is there a significant difference between public and private universities in terms of user perceptions of the informational designs?
- Do the colors used capture the users' attention?
- According to users, do the symbols, signage, and colors in university campuses, particularly at turnstiles and elevators, provide sufficient information for people with disabilities to navigate?
- Do users believe that the ground graphics, directional signs, and information boards in university campuses provide adequate information?
- Do the symbols, typography, and colors used in all the stops draw attention through their design?
- Do universities have standardized signage and wayfinding manuals that are designed in line with their corporate identity?

The significance of this research lies in its aim to establish a standard for the use of information design in university campuses, making it the first study on this subject. By addressing information design from the perspective of graphic design elements and communication in university campuses, the research is expected to contribute to solving issues encountered in this area. Furthermore, it is anticipated that the findings will benefit users and university administrators by facilitating social life, enhancing information transfer, and providing accurate wayfinding. The recommendations to be presented regarding how information design products should be structured will highlight the importance of this topic.
The study observed that the Standard Wayfinding and Signage Manuals of American universities examined during the research could serve as a model for Turkish universities. This research is limited to the campuses of Istanbul Technical University, Marmara University, Kadir Has University, and Sabancı University, located in Istanbul, Turkey. In the final stage of the study, Istanbul Technical University was selected as the exemplary model.

1.2 Methods

By examining the wayfinding and signage manuals used in the United States, it has been determined that there is a need for standardized manuals for each institution in Turkey. A comparative model study was conducted based on Istanbul Technical University (ITU). As a result, a two-part standard manual, covering both indoor and outdoor spaces of the ITU campus, was designed.
The research scope involved examining eight universities in the United States, with the two best institutions selected as model examples. Two public and two private universities in Istanbul were also selected for comparison. The study found that such work had not been previously conducted at any university in Turkey. Since the research describes an existing situation within its given conditions, a descriptive method was chosen. Accordingly, a fieldwork model was preferred due to its relevance to the research objective and subject matter.
To collect data, the manuals of American universities were accessed and analyzed online. Interviews were conducted with representatives of universities in Turkey, and physical visits were made to two public and two private universities in Istanbul. Photographs were taken, and the physical spaces were examined to identify deficiencies and issues in the universities' wayfinding and signage systems.
This article consists of four sections. The first section is the introduction, where the problem statement, research objective, significance, methodology, assumptions, limitations, definitions, and method are explained.

In the second section, the relationship between urban space and information design is defined. It explores the modern relationship between urban space, urban identity, and the connection between urban space and graphic design, including the visual elements and environmental graphic design within urban spaces.
The third section discusses the role of typography in information design at the urban space scale and defines the concept of information design. The principles of information design are elaborated upon, along with its areas of application and components, such as typography, pictograms, symbols, emblems, and signs. Criteria for legibility and perceptibility in typographic analyses within information design are also explained.
The fourth section evaluates wayfinding systems in universities from a typographic perspective. The wayfinding systems of the model universities are analyzed, and suggestions for improving the wayfinding systems of universities in Istanbul, Turkey, are presented in tables. Following this, conclusions are drawn, and evaluations and solution proposals related to the topic are provided.

2. RELATIONSHIP BETWEEN URBAN SPACE AND INFORMATION DESIGN

People spend a significant portion of their daily lives in urban spaces, living within architectural environments. The spaces in which they reside influence their lifestyles and behaviors. Louis Wirth defines a city as "a relatively large, dense, and permanent settlement of socially heterogeneous individuals (Wirth, 2002). Public spaces, from streets to squares and parks, constitute the most essential parts of cities. Therefore, the quality of public spaces, particularly streets and squares, plays a crucial role in shaping a city's identity. Public spaces have historically played an important role in the formation of cities. As stated, "Individuals sustain their socio-cultural lives through the experiences and activities within outdoor spaces as part of the urban physical environment. In this sense, the structuring of society occurs in open public spaces, where the relationship between individuals and society is supported by the physical environment." (Erdönmez, 2005).

2.1 The T-Relationship Between Urban Space In Contemporary Context

Since the 1970s and 1980s, with the rapid rise of globalization and the accompanying transformations in the economic structure, urban public spaces have emerged in various forms such as shopping malls, theme parks, supermarkets, and fast food restaurants. Today, identical consumption habits and the lifestyles that result from them are found in cities and metropolises around the world. Modern cities are increasingly becoming centers of consumption.

2.2 Urban Identity

Every city has its own unique architectural structure, lifestyle, or in other words, identity. The core values of urban identity are shaped by historical and cultural heritage. The impact of social and spatial changes over time on the inhabitants forms the identity of a city. A city is a settlement system with its own unique characteristics, enabling the resolution of complex societal issues that cannot be addressed by individual efforts. Urban identity is shaped through the standardization, homogenization, and regulation of the visible material elements of culture such as the architectural fabric, street furniture, and urban landscape. Additionally, cities are structured to meet the entertainment, arts, sports, and other needs of the social groups living within them.
By designing the city as a living space with elements such as buildings, landscaped areas, transportation systems, and pictograms, the suitability of this space for use, its functionality, and its contribution to the organization of daily life are ensured. As a result, a visual identity of the city emerges. As previously explained, the city's visual identity is the creation of all the visual elements that communicate with the external world around a design concept, based on the city's physical presence within its geographical context.

2.3 Relationship Between Urban Space and Graphics

For people living in modern cities, completely losing their way is perhaps a rare occurrence. The presence of other individuals and urban elements—such as maps, street names, road signs, and bus stop signs—make it nearly impossible for a person to be entirely disoriented. It is at this point that the importance of information design in urban spaces becomes evident.

2.4 Visual Elements in Urban Space

The messages conveyed to an individual from their surroundings help them understand and navigate the space, facilitating movement within it. A person meets their needs such as transportation, relaxation, acquiring information, and shopping through visual images in the environment, in other words, through graphics. Graphics are communication elements. Therefore, the visual communication tools present in urban life make the environment more accessible. The spaces in cities, which are the smallest units where life unfolds for urban dwellers, represent a multidimensional view of the experienced and perceived environment. The urban setting or urban fabric consists of spaces, and these spaces are composed of city elements. Environmental graphics, which facilitate communication within the built environment, create a sense of place using two- or three-dimensional graphics, forms, and signs. Furthermore, environmental graphics enhance the appreciation of the environment and strengthen the local identity of the space. Through environmental graphics, which inform individuals of the time and place, not only physical but also social problems are addressed.

"Environmental graphic design," which is a discipline within information design, is a field that inherently intersects with various other disciplines. The Society of Environmental Graphic Design (SEGD) defines environmental graphic design as follows: "Environmental graphic design encompasses various design disciplines such as graphic design, architecture, interior design, and industrial design, all of which focus on the visual aspect of wayfinding, communication identity, information dissemination, and shaping the perception of space."

"According to Deborah Sussman, founder of the renowned environmental graphic design firm Sussman & Prejza in the United States, environmental graphic design is the natural evolution where fine arts transform into visual communication and a sense of environmental work." (Teresa-Steven, 2002)

Applications of Environmental Graphic Design encompass outdoor graphic design, wayfinding systems, signage design, exhibition designs, pictogram design, mapping and thematic environmental arrangements, vehicle graphics design, event designs, point-of-sale graphics, clothing graphics design, and corporate identity graphics. Environmental graphic designs are typically applied to institutional spaces such as universities, hospitals, shopping centers, museums, parks, and sports facilities. Examples of environmental graphic design elements, which can be designed using temporary or permanent materials, include flags, signs, signposts, booths, exhibition graphics, advertisements, and billboards.

As an essential component of Environmental Graphic Design, wayfinding and signage design refer to the visual design that helps users navigate and locate their destinations in indoor or outdoor spaces. Signage design is a visual system indicating the point reached. The existence of wayfinding design enhances efficiency, creates a positive impression of the space, and provides users with a sense of security in unfamiliar environments. Wayfinding design creates visual elements aimed at guiding the user in a particular direction, often utilizing directional arrows. Signage design, on the other hand, refers to visual markers that indicate the destination. For instance, a sign at the end of a long corridor showing the unit reached is an example of signage. Entrance signs, door signs, intermediate maps, and lists all fall under the category of signage. Both wayfinding and signage design are integral parts of environmental graphic design and contribute to corporate identity design. Signage systems, as part of environmental graphics, serve functions such as providing information, facilitating the user's adaptation to the space, giving the space an identity, directing the user within the space, and contributing to the decor.

3. THE ROLE OF TYPOGRAPHY IN INFORMATION DESIGN AT THE URBAN SPACE SCALE

The role of typography used in informational design at the urban space scale will be examined in this section. Typography is one of the main subjects of graphic design. Accordingly, the focus will be on the place of typography within informational design in the context of urban spaces.

3.1 The Concept and Definitions of Information Design

“According to the International Institute for Information Design, information is data that can be accessed and utilized by people. Design, on the other hand, involves identifying the problem and creating drawings or plans that detail the technical characteristics and descriptions of the product, which will be presented through the designer’s qualified creativity. Information Design is the process of determining, planning, and

shaping the content of a message and the medium through which it will be delivered, in accordance with the specified needs of the users" (Durmaz & Ergüven, 2009).
Information design also plays a guiding role in creating a happier and healthier world. The resulting product is universally effective and aesthetically pleasing. Today, when referring to information design, it is commonly understood as the aesthetic graphic design of informational material. Information design is a contemporary design field that spans a wide range of areas, from informational graphics to wayfinding design, from pictogram design to signage system design.
"Information design can utilize all elements inherent in graphic design, such as line, shape, colour, balance, space, void, typography, and photography. Depending on its function, it must take into account the socio-cultural characteristics, psychology, habits, and perceptions of the target audience; spatial data such as sound, light, size, and distance, as well as ergonomics; and the use of technological capabilities" (Oral, 2009).
Wayfinding signs, which are part of information design, are essential visual markers that guide users, especially in traffic, at main entrances, and on both indoor and outdoor building signage. In addition to being accurate, clear, and easy to understand, these wayfinding signs should convey information correctly while also reflecting the institution's identity. The colour, typography, and form that comprise the visual design language must align with the institution's visual identity. Graphic design elements such as typography, colour, and form, which are used in information design, play a crucial role in giving a space its identity. When transferring information, criteria such as legibility, simplicity, clarity, and consistency with the institution's identity should be taken into account. The components of information design include typography, pictograms, ideograms, symbols, emblems, and signs.
"Typography, which has been defined in various ways throughout its development, can be understood in contemporary typography (especially since the 1980s, when computers began to permeate all environments) as both the visual, functional, and aesthetic arrangement of letters and other textual-visual communication elements, as well as the design language and concept created with these elements" (Sarıkavak, 2004).
Due to its communicative function, readability must be prioritized in typography, and communication should never become unclear for the sake of aesthetic concerns. The primary function of typography, one of the elements of graphic communication, is 'to be read.' A typographic arrangement that ensures readability is always successful. Geometric or non-geometric elements, lines, shapes, spots, sections, letters, and numbers are the main components of typography'. A sequence of typographic characters consisting of letters, numbers, punctuation marks, and other symbols is called a 'font.' Letters are symbols that correspond to the sounds we use in spoken language and possess specific forms. A complete set, composed of uppercase and lowercase letters, numbers, punctuation marks, and mathematical symbols, which has been finalized and made available for use, is referred to as a 'typeface.
The primary visual elements used in information design include wayfinding and signage systems, symbols, graphics, pictograms, maps, panels, and typography designs. A pictogram is a form of visual writing created in a simplified manner with symbols to visually represent a concept or idea. Pictograms are graphic symbols that facilitate international communication and express an object or the meaning of those objects. Since a universal language is used in pictograms, they must be designed in a simple manner that can be understood by people of all ages and cultures. Symbols are signs that represent a specific person, object, group, idea, or a particular combination of these. Visual symbols, which enable communication, are visual and auditory phenomena that convey more than what is directly shown. The use of symbols aims to facilitate communication and information sharing, while also striving to establish a universal common language. 'They are icons that provide identity to organizations that produce products or services, created with abstract or objective images or letters, and do not possess the properties of words' (Becer, 2005). 'Signs are symbolic elements that represent events or objects. In other words, signs are linguistic elements, gestures, or facial expressions used to express a thought or indicate a request or command' (Larousse Encyclopedia, 1971).

3.2 Criteria for Readability and Legibility in Information Design

"Readability is a term used to describe the quality sought in typefaces, words, book pages, posters, signage, and many other forms (Ruder, 1967).
The perceptibility and readability of a typographic design indicate that it is fulfilling its function as a communication tool. Readability varies based on the application of rules regarding spacing, line length, and the time required for reading and comprehension. Therefore, typographic arrangements in informational

design should be made with these concepts in mind. In both indoor and outdoor spaces, a typographic layout that is difficult to read affects the perception time in informational design.
One of the most significant factors influencing readability is spacing. Spacing is one of the fundamental elements of a good typographic design. The design rules that must be applied to letters, words, lines, paragraphs, columns, headings, and subheadings also encompass the surrounding space.
The literal meaning of spacing is "space," "gap," or "distance." It is a term used in the visual arts and graphic design, particularly in typography. Generally, "spacing" refers to the appropriate gaps left between letters, words, lines, and paragraphs (Carter-Day-Meggs, 2002).
Another criterion of readability is contrast. Contrast is one of the most basic principles of typography and design. The ease of perceiving and reading a typeface depends on a series of contrasting values such as dark-light, circular-straight, narrow-wide, vertical-horizontal, thick-thin, large-small, symmetrical-asymmetrical, and static-dynamic. In a signage system, the readability of the typeface applied—ensuring that users can access information correctly—is also important in terms of readability.

4. EVALUATION OF WAYFINDING SYSTEMS FROM A TYPOGRAPHIC PERSPECTIVE THROUGH THE EXAMPLE OF UNIVERSITIES

University campuses have been chosen as examples for examining typographic arrangements in informational design at both urban and spatial scales. One of the main reasons for focusing on university campuses among all examples is that they encompass both urban and spatial dimensions. In this context, examples will be grouped under main categories, classified as either international or national, and the wayfinding systems of these examples will be analyzed comparatively based on a specific classification system. During this analysis, the deficiencies identified in the national examples will be highlighted, and recommendations for addressing these shortcomings will be provided. Data on international examples will be gathered from the literature, while field studies will be conducted for the national examples. In the initial phase, a literature review will be conducted to develop a classification system.

4.1 Classification of University Guidance Systems

In conducting a literature review on the classification of wayfinding systems at the international level, the campus wayfinding system guides of the following universities were examined: Duke University, University of Michigan, North Carolina State University, The Ohio State University, The University of Texas at Austin, University of California San Francisco, The University of British Columbia, University of Miami, University of Guelph, University of Nebraska-Lincoln, University of Minnesota, Utah State University, and York University. The analysis revealed that the wayfinding systems of York University and the University of Nebraska serve as exemplary models, as they encompass all subgroups of a comprehensive wayfinding system.
From a typographic perspective, the wayfinding system guides of York University and the University of Nebraska are considered good examples due to several characteristics: readability, perceptibility, alignment with institutional identity, clarity in delivering necessary information to users, accessibility to people from all languages and cultures, the establishment of a unified graphic language throughout the entire campus, and a consistent visual and typographic harmony.
At this stage of the thesis, the wayfinding systems of four different universities in Turkey, two public and two private (foundation) universities, were selected for analysis. These universities are as follows:

1. Public Universities:
    a. Istanbul Technical University
    b. Marmara University
2. Foundation Universities:
    a. Kadir Has University
    b. Sabancı University"

It has been identified that the interior signage system at Istanbul Technical University (ITU) contains numerous problems. Similarly, it was found that Marmara University has similar issues, and the informational and room signage systems were deemed inadequate. ITU's Ayazağa campus is spread across a large area and consists of a vast, crowded, and multi-unit structure. Therefore, the outdoor wayfinding systems are of significant importance. However, fieldwork has revealed that there is no wayfinding system in this large area that adequately and functionally serves both pedestrians and vehicles. Additionally, it was observed that ITU's various campuses do not share a unified design or visual language in terms of the

wayfinding system. Design decisions regarding the graphics, colors, fonts, font sizes, and spacing adjustments were found to be incorrect. As a result, the existing wayfinding system lacks the necessary functionality for both pedestrian and vehicular traffic. Similar problems were also identified in the wayfinding systems of Marmara University and Kadir Has University, which were taken as model examples. Kadir Has University's informational and room signage systems were found to be insufficient. Fieldwork revealed that the implemented wayfinding systems differ across the various campuses. Among these, the Balat Main Campus had the best system, but even there, the wayfinding system was incomplete and did not cover all units within the campus. Pedestrian wayfinding ends abruptly at certain points, and foreign visitors are unable to navigate to their desired locations using the system. Furthermore, the wayfinding system at Kadir Has University fails to adhere to the institution's corporate identity, especially in terms of color. In addition to being non-functional, it also suffers from readability and perceptibility issues. Specifically, the choice of font characters, font sizes, and spacing adjustments were not made correctly. The locations of the signs were also found to be poorly selected.

Sabancı University's main advantage over the other universities in terms of its wayfinding system is that it operates on a single campus. Upon examining Sabancı University, it was found that many signs are sufficient, yet they are not functional. The signs are difficult to notice in their current locations, and their readability is low due to inappropriate font types and sizes. However, compared to the other examples, Sabancı University has far fewer deficiencies in its wayfinding system. The form and size of the wayfinding system were not adequately designed for the large area, resulting in perceptibility issues. It was also determined that incorrect choices were made regarding the graphics, colors, font types, font sizes, and spacing settings, causing readability problems. As a result, the existing wayfinding system lacks the necessary functionality for both pedestrian and vehicular traffic.

When comparing the interior wayfinding systems of two public and two private (foundation) universities with campuses in Istanbul, it was found that the foundation universities had a more systematic approach to design than the public universities. Nevertheless, deficiencies were identified in the wayfinding systems of the foundation universities as well. Comparing the outdoor wayfinding systems revealed that both public and foundation universities share similar problems. It appears that universities generally place more emphasis on their interior spaces when establishing wayfinding systems, while giving less consideration to the exterior spaces. When comparing the wayfinding systems of the selected Turkish and international universities, significant differences were found between them. Additionally, it was observed that international universities possess wayfinding system guides that go beyond their corporate identity guidelines, providing detailed information and adhering to these guides when implementing and developing their wayfinding systems as needed.

Based on the identified problems, a two-part sample design model, focusing on both indoor and outdoor signage systems, was created for university campuses using ITU as a case study. In the sample designs, the use of institutional colors and the selection of the "DIN" font family, including the appropriate font weights, font sizes, letter, word, and line spacing, resulted in an effective and functional design model. The wayfinding and informational signage within the design, through the correct selection of typographic and graphic elements, ensures ease and clarity in both readability and legibility.

4.2. Examination of the Wayfinding Systems of Selected Turkish and International Universities as Example Models

The selected universities will be analyzed under two categories, with two examples for each category. These two categories are public universities and foundation (private) universities.

4.2.1 Public Universities

Two examples of public universities have been selected: Istanbul Technical University (ITU) (Figure 2) and Marmara University (Figure 3).

4.2.1.1 Istanbul Technical University (ITU)"

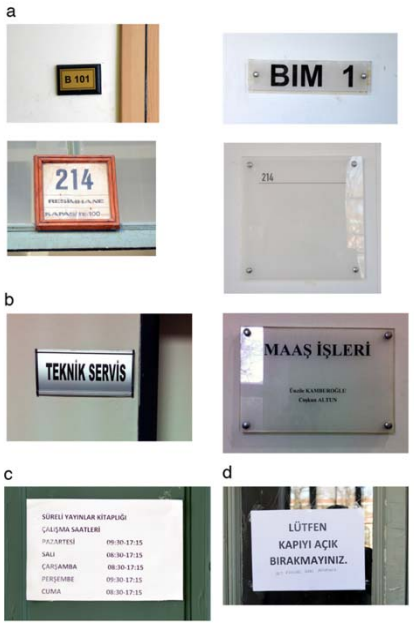


Figure 2: The study of examples related to the examination of İ.T.Ü's guidance systems

Upon examining ITU's wayfinding systems, it was observed that there is no visible institutional visual coherence in the door signage (a, b) and informational signs (c, d), as shown.

4.2.1.2 Marmara University



Figure 3: Examples related to the examination of Marmara University's guidance systems

An examination of the wayfinding systems at Marmara University's campuses revealed that the door signage and informational signs (a), departmental informational signs (b), outdoor wayfinding designs (c), and general use area signage, including restrooms, lack sufficient graphic and typographic elements. These signs fail to establish an institutional visual coherence, resulting in readability and legibility problems.

4.2.2 Private Universities

Two examples of foundation universities have been selected: Kadir Has University (Figure 4) and Sabancı University (Figure 5).

4.2.2.1 Kadir Has University”



Figure 4: Examples of the Examination of Kadir Has University's Wayfinding Systems

An examination of the wayfinding systems at Kadir Has University revealed that the door signage and informational signs (a), elevator wayfinding (b), indoor wayfinding designs (c), and general use area signage, including restrooms, lack sufficient graphic and typographic elements. These signs fail to establish an institutional visual coherence, resulting in readability and legibility problems.

4.2.2.2 Sabancı University



Figure 5: Examples of the Examination of Sabancı University's Wayfinding Systems

An examination of Sabancı University's wayfinding systems revealed issues with parking and outdoor signage (a), exterior building identification signage (b), and warning signs, such as the 'No Smoking' pictogram, which was designed in the university's corporate color, resulting in a major mistake. By not using the necessary red color for the warning sign, it failed to create the required cautionary effect. Additionally, it was observed that door signage for two professors with the same title had different visual designs.

4.2.3 Comparison of ITU Informational Designs Based on Deficiencies and Proposed Model

The comparison of the informational designs of Istanbul Technical University based on deficiencies and the proposed model is conducted under the following headings.

4.2.3.1 Door Signage for University Employees Identification

The previous state of the door and door signage was characterized by graphic confusion, rendering it ineffective due to the incomprehensibility of the typographic and graphic design elements used. A solution to this problem has been proposed above. As demonstrated in the example model for Istanbul Technical University (ITU), a Wayfinding and Signage Guide has been prepared, standardizing all aspects.



Figure 6: Comparisons Between the Design and Previous Examples Associated with İ.T.Ü.

4.2.3.2 Indoor Wayfinding Signage for Pedestrians

It has been determined that wayfinding signage related to indoor areas is not utilized in large spaces such as university campuses.



Figure 7: Comparisons Between the Design and Previous Examples Associated with İ.T.Ü.

4.2.3.4 Wayfinding Signage for Campus Outdoor Signage System

The use of wayfinding signage located outside university campuses is very important. Special attention should be given to these elements, particularly in large campuses. Pedestrians, especially foreign visitors, have a strong need for these wayfinding signs.



Figure 8: Comparisons Between the Design and Previous Examples Associated with İ.T.Ü.

4.2.3.5 Building Entrance Signage for Outside

The use of exterior building entrance signage in outdoor spaces is a crucial criterion. People want to know what a space is when seen from the outside. Information regarding these spaces should be arranged in a way that can be easily read, particularly for foreign visitors. In order to improve the wayfinding systems of universities, it is essential to collaborate with a professional team consisting of graphic designers, architects, interior designers, landscape architects, and industrial product designers. The "Wayfinding System Guide" that this team should base its work on must consist of two sections: one for interior spaces and one for exterior spaces. The designed wayfinding system guide must be prepared in detail, both technically and in terms of design, and include comprehensive information. The guide must primarily reflect a design language that aligns with the institution's identity and should be detailed with consideration of all university campuses. Furthermore, the design criteria, which include graphics, illustrations, maps, plans, sketches, colors, the form and format of the signs, materials, fonts and font families, font sizes, spacing, and color choices, should be addressed as a whole and should meet both functional and aesthetic requirements.

In this context, as part of this thesis, a "Wayfinding System Guide" has been developed for both interior and exterior spaces aimed at improving the wayfinding systems of universities in Turkey, particularly in Istanbul. Comparisons have been made using visual examples from Istanbul Technical University's (İ.T.Ü.) informational designs, and solutions to identified deficiencies have been explained alongside the provided designs. In the fourth chapter, the wayfinding systems of two foundation and two public universities in Turkey have been classified based on research and studies. The shortcomings of the wayfinding systems of selected Turkish and foreign universities, taken as model examples, have been clearly identified using visual comparisons.



Figure 9: Comparisons Between the Design and Previous Examples Associated with İ.T.Ü.

5. CONCLUSION

In today's world, accessing information has become much easier due to advanced technological capabilities. Consequently, within the growing density of information, the field of "information design" has emerged, aiming to process raw data and transform it into a form that the target audience can easily comprehend. Due to its communication function, legibility and readability in typography should be prioritized, and the communication process should never lose clarity. One of the primary elements of graphic communication, typography's main function is to be "read." A typographic design that is perceivable and readable fulfills its function as a communication tool. Readability varies according to the application of rules such as spacing, line length, and reading time. Typography is the most critical element of any information design. In typographic arrangements used in information design, readability and clarity should be established by selecting typefaces, the space in which they are used, distance, and the message to be conveyed. Additionally, legibility is not solely about the readability of the typeface. Elements such as margins, columns, material selection, and color also affect legibility. Readers should be able to perceive written information with minimal effort and difficulty. To ensure readability in information design, typographic design must be crafted to be more attractive, exciting, and creative in tone, with a stronger sense of color and space, thereby enhancing its legibility.

It is recommended that national-level guides be prepared for different environments-such as universities, airports, hospitals, and metro systems-that teams working on information design can use to follow a more informed process during the project development stage. Within the scope of this thesis, a Wayfinding and Signage System guide, consisting of two parts-interior and exterior signage systems-has been created specifically for universities. Through this guide, it will be possible to improve the existing wayfinding systems on university campuses. This study will also serve as an example for conducting similar work in other environments.

The following conclusions have been reached through this study:

Based on the research and analyses conducted, it has been observed that the design elements comprising the wayfinding, informational, and signage systems in university campuses-such as the forms and shapes of directional and informational signs, symbols, text, and colors-used in the studied Turkish university campuses do not possess striking or original forms and visuals. There are issues with the selection of areas where informational design elements are placed on campuses. One of the most notable problems is whether the informational design elements on university campuses are perceivable and legible from long distances.

It was also found that the informational design elements on university campuses do not always function effectively in conveying information in a comprehensible and functional manner, leading to problems. Additionally, the lack of wayfinding and informational designs on campuses means that the necessary information is often inaccessible.

The design elements that constitute the wayfinding, informational, and signage systems on university campuses do not achieve visual coherence. Moreover, the number of informational and directional design elements on university campuses is insufficient, and their trackability is limited. For disabled individuals, symbols, signs, and colors used on campuses are limited in assisting them in navigating turnstile access, entrances and exits, and elevators to reach their destinations.

Symbols (elevator signs, turnstile signs, entrance and exit signs), text (building identification names, stop and street signs), and colors (safety signs, faculty colors, elevators) used across all campuses do not feature attention-grabbing designs.

Despite the existence of institutional identity guidelines in some universities, it was found that there are no standardized wayfinding and signage guides created with a design language that aligns with these institutional identities. Even when institutional colors are used, the colors selected during the design process for backgrounds and design elements do not always attract users' attention, and environmental factors were not considered in these designs.

There are significant differences in the design elements used in the wayfinding, informational, and signage systems between public and private university campuses, and the differences generally favor private universities.

As a result, an exemplary model was developed based on the Istanbul Technical University (ITU) sampling. The design employed institutional colors and the selected "DIN" font family, carefully incorporating font weights, font sizes, and precise spacing between letters, words, and lines. This led to the creation of an effective and functional design model. The wayfinding and informational signs within the design are easy to read and understand, thanks to the proper selection of typographic and graphic elements.

Based on the research data and findings, several recommendations were made for practitioners. Informational graphics should be used in appropriate locations and in sufficient numbers to facilitate easier communication for users within university campuses.

Additionally, it is crucial to establish a sense of institutional identity. The design should best represent the institution’s identity by ensuring visual cohesion in its colors, forms, and font family.

Informational designers should prioritize clarity, comprehensibility, and originality in their designs, with typographic elements playing a key role in achieving these qualities.

Campus maps are particularly important and should be placed in high-traffic areas to assist users in finding their way. Directional signs are another critical design element for wayfinding.

Informational designs, especially at public transportation points and entrances/exits, are vital for providing guidance and information to visitors.

The continuity of visual unity should be maintained across all design elements through the consistent use of colors, shapes, pictograms, and text.

Just as the university campuses studied in this research require institutional identity designs, they should also have wayfinding, informational, and signage system guidelines for both interior and exterior spaces.

The successful design outcomes from the model developed for Istanbul Technical University highlight key design principles that should be considered for all public and private universities in Turkey, making this model a valuable example of effective design.

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CHAMPAGNE PACKAGING DESIGN WITH BRAND AWARENESS AND USER-CENTRIC CRITERIA: A CASE STUDY

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Abstract: *A holistic approach to product design is a design mindset that creates desirable products but also fulfills stakeholders' needs and considers production limitations. Design is more than aesthetic results and takes into consideration a great number of topics such as the sustainability of the product by using the best practices in material resources, examining the parameters of the industrial production and the re-usability of the product. Additionally, the strategy of holistic design aims to extend the product's life cycle beyond its initial use, making it self-promoting and attractive to customers, while enhancing the company's brand image to gain a competitive edge. Ultimately, each experience associated with a product, whether it's a tangible item or a service, is deliberately crafted with the user in mind. The proposed paper uses a holistic design approach for luxury secondary metallic champagne packaging, highlights the importance of the correct data gathering and analysis from research, and then translates to parameters and limitations that they will embed into the design decisions delivering the final product. In conclusion, the paper presents various methodologies and cutting-edge tools to generate rendered representations of the product, ensuring effective communication with all relevant stakeholders.*

Keywords: Holistic product design, user experience, sustainability, re-use, product life cycle, CAD, metallic packages, packaging, branding

1. INTRODUCTION

Packaging design is not only an aesthetic approach of a container but also a product to attract consumer's attention and call them to purchase the product (Dobras, Manavis & Kyratsis, 2021). Nowadays, packaging design principles enhance brand awareness and create a communication channel between the customer and the company (Manavis & Kyratsis, 2021). Historically, wine packaging has taken on various forms and materials according to the technological techniques and tools of each time period (Moutaftsi & Kyratsis, 2016). Despite the numerous challenges that can packaging faces from oxidation caused by wine, as well as the dominant market presence of materials like glass and plastic, metal continues to undergo ongoing research aimed at enhancing its use in wine packaging (Versari et al., 2023). The main purpose of the secondary packaging is to protect the primary bottle and contribute to brand awareness and brand loyalty. Furthermore, customers are looking for a holistic experience with a brand and their loyalty to the latter depends heavily on the experience quality a company offers (Lukehart, 2022). Moreover, matters such as sustainability and recycling have gained a lot in recent years due to climate change awareness. Customers are looking for more sustainable products with a smaller CO_2 footprint and are open to products that can have further use after their primary scope is fulfilled. Metal is an ideal material and successfully serves this purpose as it is lightweight, offers good protection, can be shaped in many forms, can be coloured or have its natural colour, has longevity, and can be easily recycled (Mousli et al., 2009).
Finally, to develop a product that delivers an exceptional user experience, we categorize all constraints and information as design data, which we then synthesize using various tools and methodologies (Manavis, 2022). This approach transforms the gathered data into opportunities for generating innovative design ideas through a comprehensive design strategy that emphasizes brand awareness, rather than viewing them as limitations or challenges. For the implementation, digital sketching tools and a pen display were utilized to create the required sketches, while CAD software and 3D rendering software were essential for 3D modelling and rendering.

2. LITERATURE SURVEY

Nowadays, a great number of studies are held regarding consumers' perception of the product, as packaged food products cannot be, usually, tasted before purchase. The findings suggest that a buyer will take under consideration both material and immaterial characteristics of the packaging to form a decision

ORCID numbers are provided at the end of the paper.

regarding the quality of the wine. Additionally, inquiries are presented about what consumers notice in packaging at first glance, the key elements to focus on for comparison with other products, and the features that prompt consumers to choose a particular item for purchase.

2.1 Consumers' perception

Rocchi & Stefani (2016) record that consumers consider numerous factors when evaluating rose wines, including the packaging colour, perceived quality, transparency, and opacity. Additionally, they pay attention to the physical attributes of the packaging, such as its size and thickness. Many consumers associate the quality of the packaging with the quality of the wine itself. Descriptive terms like "important," "polished," and "refined" are frequently used to characterize the product (Rocchi & Stefani, 2016). Moreover, the same research suggests that attention is paid by customers, to the quality of the printing, the coherence, and the proper use of graphical elements. Vilnai-Yavetz & Koren (2013) supports that the psychological part and the influence it has on consumers' purchase intention by using aesthetics and symbolism to analyze and interpret packaging design and use it as a powerful marketing tool and not only as a transportation means (Vilnai-Yavetz & Koren, 2013).

2.2 Packaging image

Packaging serves as the initial point of interaction between the consumer and the product. At this early stage, the consumer engages with the packaging through sight and touch before actually consuming the product. During this period, the product exists as an image in the consumer's mind, with all pertinent information being conveyed through the packaging's visual and tactile elements. In that direction, Orlowski et al. (2022) suggest that a non-traditional design could be precepted as more unique and innovative, capturing the consumers' attention, backed up by uniqueness theory which supports that individuals try to differentiate themselves from others and novel products provide a solution to that need with minimal social exposure (Orlowski, Lefebvre & Back, 2022).

2.3 Sustainability

Malea et al. (2020) support that consumers are already ecologically alert, and the product's environmental footprint is high on every company's agenda. Deshwal & Panjagari (2020) record that the material of metal is an excellent choice for primary and secondary packaging, as it is lightweight, can be easily processed, provides safe transportation of the product, can be easily printed or elaborated, is highly recyclable, and can offer a long life-cycle through reuse, compensating for the high cost of CO_2 emission from the metal industry. It is crucial to note that, the orientation of the design to sustainable and eco-friendly packaging can be achieved without any discounts on the luxury and uniqueness of the packaging as an item.

2.4 Brand identity

The packaging is an ideal tool for a great user experience to be achieved and build a loyal customer base for the brand (Kouveli, Tzetzis & Kyratsis, 2017). The wine market is competitive, with consumers spending just a few minutes on product selection in stores. Packaging is vital, not only for protecting the wine but also for attracting buyers and influencing purchase decisions. Effective design serves as a communication tool, impacting perceptions of brand quality, often based only on typography and graphics. Moutaftsi et al. (2016) report that a study found 66% of consumers recognize the significance of packaging for their purchased products, noting its role in both product protection and the quality of materials used. Additionally, most respondents made a direct connection between the packaging and the enclosed product (Moutaftsi & Kyratsis, 2016).

Furthermore, Hurley et al. (2017) propose a study utilizing eye-tracking technology to assess customer reactions to products in a controlled setting. Their findings indicate that customers require 5 to 7 seconds to concentrate on four key design elements: a) brand identity, b) graphic design, c) description (when applicable), and d) a claim. The aforementioned study concludes that customer engagement with packaging needs to be both immediate and effective, and designers should strive to achieve this goal (Hurley et al., 2017).

3. DESIGN METHODOLOGY

Gathering and organizing all relevant design data, while translating restrictions into usable design data, is a complex challenge. To address these challenges, creativity tools have been introduced through design thinking—a creative and empathetic, user-centred approach—and the design process, which focuses on data and business-driven methods, for generating innovative ideas. Specifically, a systemic design protocol is introduced as a guideline for all data to be recorded and advise through the project by the design team. (Manavis, 2020). The main core of the proposed case study concerns a design of a metallic secondary, self-promoting, and brand-oriented champagne packaging with sustainability, extended life cycle, ergonomics and user-centric criteria. To address this scope, a systematic design protocol was implemented to develop a spreadsheet that encompasses all research elements, serving as a reference point for the design team.

3.1 Design target and data

The design protocol (Figure 1) was a guideline for the team to register all restrictions and translate them into design opportunities. In this case study, the approach to design viewed restrictions as opportunities. The process began with establishing a main target, followed by secondary market and design goals. Market considerations included packaging aesthetics, usage occasions, quality messaging, and consumer communication.
Design goals focused on shape, material techniques, and visual graphics. This breakdown clarified needs and constraints, aiding subsequent research. The data collection phase was not linear, allowing for iterations and adjustments as new insights emerged, continually refining the design protocol.

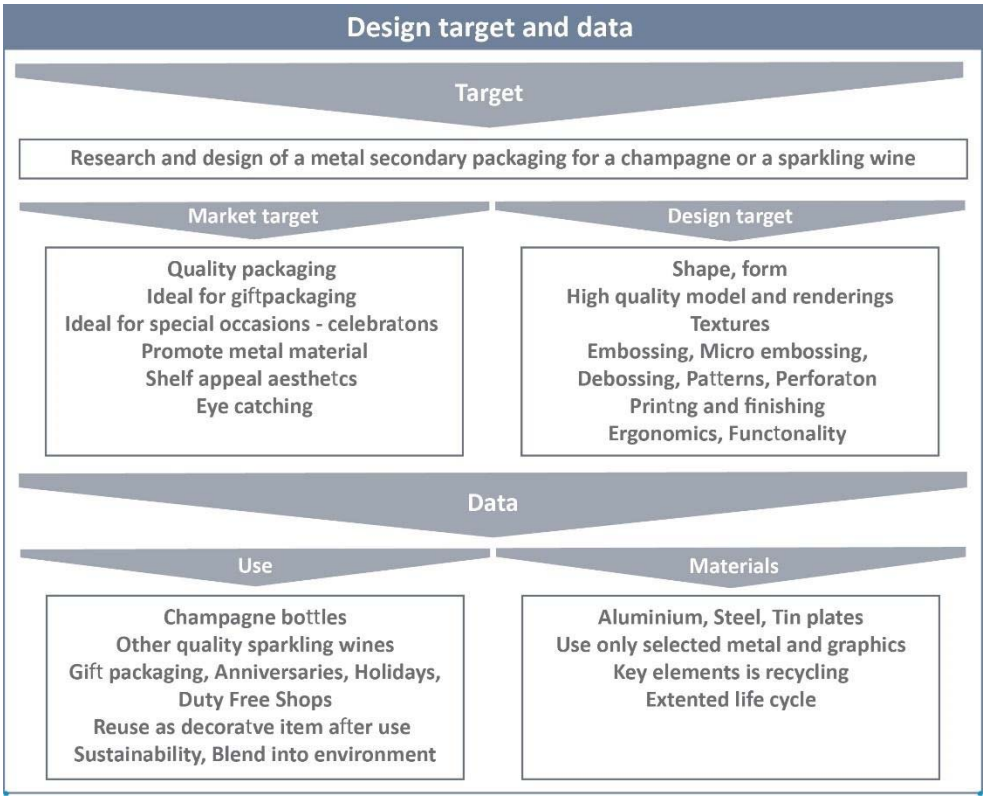


Figure 1: Design target and data

3.2 Mind-map and Mood-board

Mind-map is used to explore possible design directions more freely and abstractly (Figure 2). During this stage, it is important not to be restricted while exploring and to try to open as much as possible the way of thinking, while the main target is placed in the middle. Specifically, words from the design protocol (Figure 1) are used, either as exploration directions or as keywords, leading to further concept analysis. The selected words that are used as inspiration in the following step of ideation, are marked with a different colour.

These words are key elements that together with the mood board are translated into ideas. On the other hand, mood-board is the visual research of early forms and directions related to selected keywords from mind-map and is the second tool used during the early design research (Figure 3). Additionally, mood-board offered an optical translation of the data input and it helped start building image-based information to be used during Ideation.

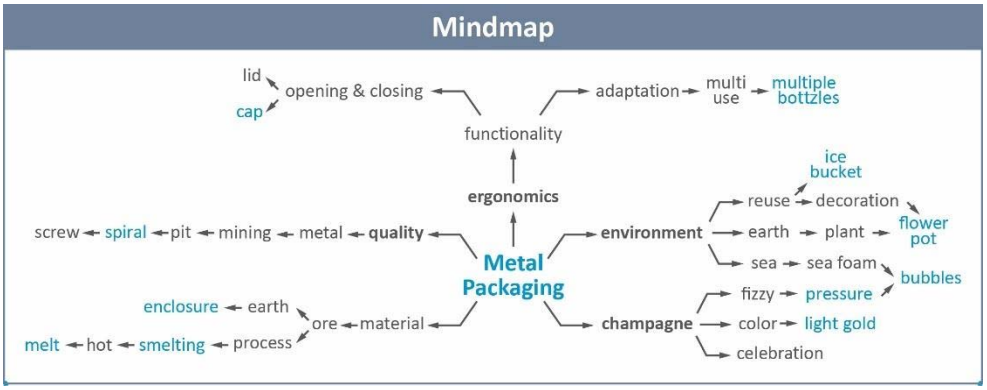


Figure 2: Mind- map

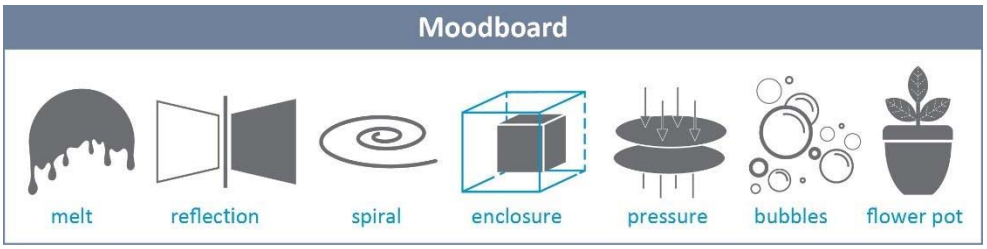


Figure 3: Mood-board

3.3 Ideation

In the ideation stage, a free-hand drawing strategy is embraced, emphasizing the importance of unrestricted thinking to generate a wide array of ideas at this phase (Figure 4). Ideation is focused in two main principles of packaging: a) the shape/form and b) the ergonomics. Specifically, more organic forms are drawn, to offer a more decorative aspect, whereas bubbles, a key element of champagne, are taken into consideration. Furthermore, an approach of different use of the packaging is explored, to offer an extended life cycle of the product and create a better and longer user experience.

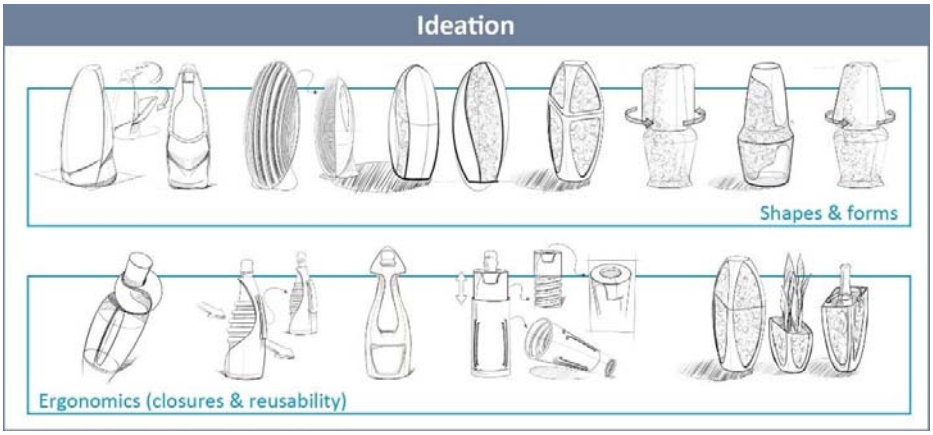


Figure 4: Ideation

3.4 The proposed design solution

By using the designs from ideation, the decision on the final packaging is made. In this stage all the data is considered, design protocol is extensively consulted during the whole process, and designs are evaluated, corrected, and brainstormed again in a repetitive manner. The final decision is made with a packaging that will reflect the form of the champagne bottle, following the literature survey that more consumers in the wine market are keen to more traditional shaped packaging. Furthermore, a more innovative concept is adopted regarding the optical part of the packaging, attempting to provide elevated brand awareness and the option for the packaging to self-distinguish from other products on the shelf.
For that scope, a metal-melting area is created by embossing, on the top and bottom of the packaging, creating an enclosure (i.e. mind-map, mood-board). In contrast, a metallic champagne colour area with bubble printing in the middle is created. In this way, the message of champagne wine enclosed in a metal container is communicated, referring to the product directly and offering product awareness without further explanations. The closing is also decided, a system that opens the packaging in two parts, upper and lower, and by screwing in, it can adjust to bottles of different heights, rendering the packaging very versatile. The final solution is rendered with digital sketching and an explanatory storyboard and usage designs are made to easily communicate the design decisions to the stakeholders, before proceeding with time-expensive 3D modelling and renderings (Figure 5).

3.5 3D C.A.D. modelling & rendering

After the final solution is approved, the Autodesk Inventor™ software is utilized to create the product in real scale. Design corrections are made to address topology issues, highlighting the importance of resolving any problems at this stage to ensure a flawless product for production. A preliminary rendering is created in neutral colours to assess the form and dimensions. This is followed by a high-resolution rendering using KEYSHOT™ software, showcasing metallic textures, colours, bubble printing, and the product's alternative use as a flowerpot, ensuring both aesthetics and functionality are met (Figure 5).

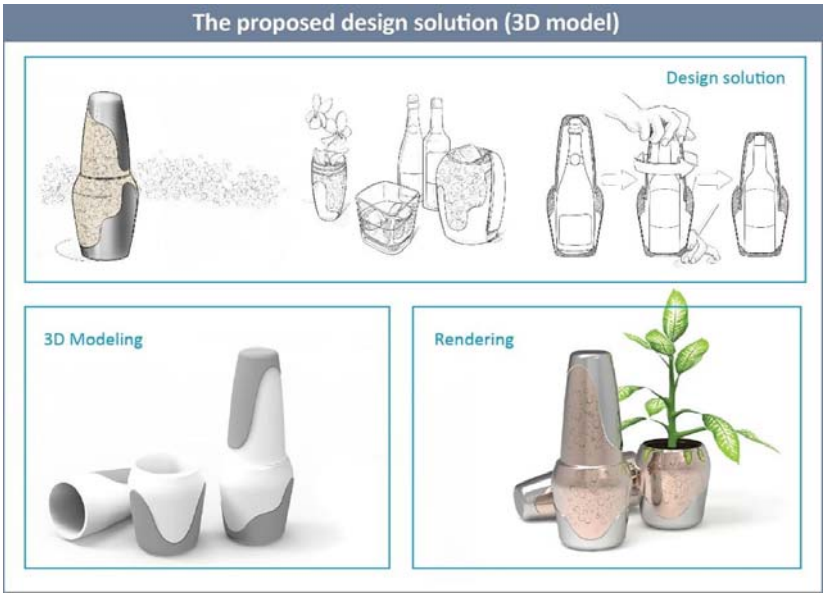


Figure 5: The proposed design solution for package

3.6 An early evaluation approach

An early evaluation of the proposed design, by using Likert scale questionnaire of five specific inquiries, was conducted, to evaluate design expectations with potential consumers' opinion. For this scope a sample of 45 individuals was used, aged 30–50-year-old, divided by gender diversity, and by different income background. The evaluation was focused on a) product awareness (score 4.1), b) attractiveness (score 4.2), c) intuitivity (score 3.7), d) usability (score 4.5), e) ergonomics (3.9) and purchase intention (3.9). In future work, the effectiveness of the design prototype (physical item) will be evaluated based on the results of the questionnaire.

4. CONCLUSIONS

The proposed paper uses a holistic design approach for luxury secondary metallic champagne packaging, highlights the importance of the correct data gathering and analysis from research, and then translates to parameters and limitations that they will embed into the design decisions delivering the final product. Furthermore, this paper proposed the importance of research in a preliminary stage, long before the designer is engaged in the standard design procedure, and the necessity to register various restrictions as early as possible, and how to translate them as design parameters. In this way, the designer is aware of several issues that might occur during the design process and production to follow. Furthermore, user and business needs are taken into consideration by focusing on ergonomics and branding standards respectively. The importance of business and user research and how to amalgamate it with aesthetics is highlighted, and the methodology on how to achieve this scope, by taking data-driven design decisions and communicating them to all the interested parties is presented.

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ENHANCING PATTERN DRAFTING AND FASHION ILLUSTRATION USING CORELDRAW AND A GRAPHICS TABLET

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Abstract: *The purpose of this study was to develop techniques for computer-aided design (CAD) in fashion using CorelDraw a vector graphics software and a graphics tablet to produce technical fashion packs. The study adopted a design-based action research method to develop digital fashion illustrations and patterns. The study sought to solve the problem common among fashion designers of integrating CAD in their operations. Results revealed that designers can create complex digital fashion illustrations easily by using the graphics tablet and CorelDraw. The techniques explored in this study can assist fashion designers and pattern makers in quickly expediting the process of digital pattern development at the least cost. Digital fashion illustrations provide a better and more accessible format for customer design communication. The steps described in the study can assist early career fashion illustrators to easily combine their traditional physical skills with technology so that they can communicate their design ideas with much ease. In conclusion, the study recommends that more effort be made to encourage technology adoption through digital drawing and illustration in the fashion industry.*

Key words: CorelDraw, fashion, illustration, design, pattern

1. INTRODUCTION

Fashion design is a multifaceted field that encompasses various aspects, from conceptualization to the final execution of garments. Fashion design has three components: style design, construction design, and process design (Xu et al., 2016). The key task in sketch design is drawing or illustrating the fashion idea either on paper or on the computer. Construction design involves the way the pattern is drafted whilst, process design refers to the way the illustrated and drafted ideas are converted in a production system. All these design processes in fashion are critical as they feed into each other in the garment manufacturing process loop. McQuillan (2020) states that pattern drafting and fashion illustration are important practices in the world of fashion design. These processes not only involve creating unique designs but also ensure that they can be accurately replicated in the manufacturing process.

Pattern drafting and fashion illustration have a long history dating back to ancient civilizations. According to Tortora and Eubank (2009), in ancient Egypt, Greece, and Rome, garments were often draped directly onto the body to create patterns. As civilizations developed, pattern drafting techniques evolved, with the Industrial Revolution bringing mass production to the fashion industry. Pattern-making in the early days of industrial manufacturing was a painstaking process involving tailors creating unique patterns according to the measurements and preferences of their clients (Virmani & Singh, 2024). Authors (Gill et al., 2024; Huang et al., 2012; Virmani & Singh, 2024) do cite that technology has changed the garment manufacturing process as, pattern-making processes have evolved to be more sophisticated and imaginative, utilising computer-aided design tools and 3D modelling to enhance pattern creation. The introduction of computers in the late 20th century led to further advancements in pattern drafting and fashion illustration, with software such as CorelDraw, Gerber, and Adobe Illustrator making the process more accessible and efficient.

According to Biliakovych et al. (2024), digital fashion is transforming conventional design, production, and marketing processes, offering the novel potential for innovation, interactivity, and personalisation. Digital tools such as virtual reality, artificial intelligence, computer graphics, blockchain technology, augmented reality, and 3D printing are continually being integrated with traditional fashion elements in the development of the fashion sector. Amos et al. (2017) and Oppong, Biney-Aidoo and Antiaye (2013) report that one such tool that has gained widespread adoption is CorelDraw, a vector-based graphic design software that has revolutionised the way designers approach pattern drafting and fashion illustration. Wang, (2020) highlights that the adoption of computer-aided design software such as CorelDraw has transformed the graphic art design industry, allowing designers to effectively translate their concepts into realistic digital graphics. According to Xu et al. (2016), CorelDraw can manipulate and edit vector-based images thus enabling designers to create intricate patterns and illustrations with greater precision and

ORCID number is provided at the end of the paper.

efficiency than traditional hand-drawn methods. The use of CorelDraw in pattern drafting and fashion illustration has not only streamlined the design process but also opened up new avenues for creativity and innovation. Fashion illustration is more aligned with the artistic impression of the fashion idea whilst pattern drafting is an engineering-based process as it involves precise calculations. Sinha (2001) highlights that the generic design process in fashion product development involves the illustration of the fashion idea and sample development through pattern drafting. Xu et al. (2016) opine that the adoption of computer-aided design (CAD) in these two processes improves efficiency and effectiveness of product development. Fashion flats, also known as technical drawings or flat sketches, serve as the blueprint for garments, showcasing proportions, details, and construction (Hagen, 2017). Traditionally, fashion flats were created in 2D form using pen and paper, but with advancements in technology, designers now have the option to utilize 3D fashion flats (Datta & Seal, 2018). Historically, 2D fashion flats have been the industry standard for designers to visualize their creations. Fashion designers would sketch their designs on paper, meticulously detailing each element of the garment and providing measurements for accuracy. This process allowed designers to convey their vision to manufacturers and pattern makers, ensuring that the final product matched the initial concept. Key figures in the history of 2D fashion flats include Rene Gruau, a renowned fashion illustrator known for his elegant and expressive sketches that captured the essence of the garments he depicted. Gruau's work inspired generations of designers to use fashion flats as a fundamental tool in the design process.

The process of fashion illustration and pattern drafting is usually executed in two stages by different individuals in most industrial setups. However, with the advent of technology, these two processes can be integrated to reduce errors in garment development. The adoption of digital methods for illustration and pattern drafting enhances efficiency, accuracy, and sustainability, reducing production time and improving pattern-making precision (Afifi et al., 2024). Small fashion design companies often face challenges in purchasing access rights to use the software requisite for illustration and pattern making such as Gerber and Clo3D as they are highly-priced. Investment in such software also comes with minimum hardware requirements that make it difficult for small production setups or freelance fashion designers to invest in CAD. The overall effect of these challenges is a lack of investment in CAD for fashion or a lack of appreciation of digital tools in fashion design.

This study seeks to explore ways of integrating fashion illustration and pattern drafting using CorelDraw and a graphics tablet (XP Pen DECO 01-V2) to optimize time and increase efficiency in clothing production. Such a method will make it easier for fashion designers to quickly sketch ideas that can be drafted into patterns as the software is affordable and does not have many hardware requirements. The focus of this study seeks to benefit small-scale companies that are into mass garment production and design.

2. LITERATURE REVIEW

2.1 Fashion sketching

There are two methods of producing fashion sketches or illustrations. The first is the traditional method of drawing by hand commonly referred to as manual fashion illustration (Liu, Zeng & Bruniaux, 2019). The second method is through the use of design software such as Adobe Illustrator or CorelDraw which can be referred to as computer-aided drafting (Marin & Bocancea, 2024). Both methods require good skills in drawing. Once a sketch has been developed the fashion idea has to be turned into a pattern. This process can also be accomplished through two methods namely, traditional hands-on pattern-making process or computer-aided pattern drafting. Industry-specific software such as Gerber Accumark, Clo 3D, Richpeace, Browzwear, OptiTex, and Tukatech can be used for the development of pattern making, marker making, grading, and virtual prototyping in the fashion industry. According to Marin (2022) and Puri (2013), digital drafting of patterns using CorelDraw enhances efficiency and accuracy, and allows for virtual simulations, promoting a shift towards digitalization in clothing manufacturing compared to traditional manual methods. Liu et al. (2022) also support use of CorelDraw in digital pattern drafting as they argue that it offers innovative artistic design, spatial expression, and efficient art creation compared to traditional methods, expanding creative possibilities in fabric design with computer technology integration.

According to Jhanji (2017), CAD for fashion can be divided into three major groups as shown in Table 1. Oppong, Biney-Aidoo and Antiaye (2013) noted that CAD has incredible tools that improve creativity and visualization of designs. CAD can make a design from scratch with colour and textures, these satisfy a creative's mind and artwork. In agreement with Chen, (2016) the use of CAD software greatly improves the working speed and efficiency as it avoids the effects of human error as compared to the manual operation

that takes much time resulting in wasted time (Amos et al., 2017). Authors (Dwivedi & Dwivedi, 2013; Tabraz, 2017) report that CAD software enables a garment to drape on a 3D scan image, which enables customers to see how the garment looks and fits before they purchase it. The virtual fit model on a 3D scan image reduces the cost and time involved in creating a physical sample or prototype. One of the key advantages of using CorelDraw for pattern drafting is the software's ability to precisely measure and scale design elements, ensuring accurate pattern development and fit.

Table 1: CAD for fashion design

		Examples	Attributes
1	CAD based software	Gerber, Clo 3D, Tukatech	Expensive, specialised,
2	Scaled down CAD software	Wild Ginger, Telestia creator	Less expensive, small companies, design houses
3	Vector graphic software	Adobe Illustrator, CorelDraw	Cheap, easy to train

Burke and Sinclair, (2015) affirmed that some designers in the fashion sector are using CorelDraw to draw mannequins and produce designs. Fashion designers construct a geometric jointed mannequin using the CorelDraw basic shape drawing tools, (ellipse, rectangle, and polygon tools) along with the trim and weld shaping options.

2.2 Application of CorelDraw in Fashion Design

Wang (2020) reports that CorelDraw has become an essential tool in fashion design education and the fashion industry at large, as it offers numerous advantages for creating detailed garment designs. One of its key strengths is that it enables clear visualisation of style structures, stitching, and fabric details, making it valuable for both students and professionals. According to Na'am, Achmadi and Ihsani (2021) integration of CorelDraw and Adobe Illustrator in fashion design curricula helps students develop technology-based skills necessary for Industry 4.0. CorelDraw is a vector-based software that allows one to create fashion illustrations that can be easily printed in different formats even when they are scaled thus providing numerous solutions quickly to the field of fashion design. Vector-based software allows high-quality output and maintains quality, which is critical for fashion presentations and marketing materials (Sugiarto et al., 2021). According to Datta and Seal (2018) traditional pattern drafting involves the manual creation of patterns, while digital pattern drafting with CorelDraw offers flexibility, efficiency, and accuracy in garment design, grading, and marker making in the garment sector. In the same vein (Puri, 2013) states that digital pattern drafting using software like CorelDraw saves time, offers more options, and enhances accuracy compared to traditional manual methods.

As digital technology continues to advance, the field of fashion illustration design has experienced a profound transformation, with CorelDraw providing the necessary technical support and creative freedom for designers to explore new avenues of expression. One of the key advantages of CorelDraw in fashion design is its ability to digitize the garment design process. The software's arbitrariness in drawing settings, unit and ratio adjustments, and file format interchangeability make it an ideal choice for digital clothing design (Trivedi, 2015). Designers can effortlessly create detailed clothing effect charts, accurately depicting the intricate stitches, fabrics, and patterns that define their designs. This digital approach not only streamlines the design process but also allows for greater experimentation and iteration, enabling designers to refine their concepts with ease. A study by Wiana (2017) concluded that there is a strong correlation (81%) between proficiency in CorelDraw and the quality of designs produced by students, highlighting its effectiveness in educational settings. Integration of computer image technology with CorelDraw has improved visual communication in fashion design, leading to more artistic and visually appealing clothing. This approach has shown a marked increase in the effectiveness of design presentations compared to traditional methods (Meng, Mok & Jin, 2012). While CorelDraw offers numerous advantages, some designers may still prefer traditional methods for their tactile and hands-on approach, which can foster creativity in ways that digital tools may not replicate.

3. METHODOLOGY

This study used the design-based action research technique. Design-based research method allows one to design, develop, and test the product or model and its applicability in responding to a design situation. According to Keskin and Kuzu (2015), design-based action research consists of four interactive phases. These phases include analysis of practical problems, developing of solutions, iterative cycles of testing and refinement of solutions in practice, and finally reflections and documentation for design principles. The four phases are similar to the design thinking process, a methodology popular in situational design problems. Townsend, Kent and Sadkowska (2019) highlight that action research allows for participatory co-design methods that foster collaborative creativity and information sharing among stakeholders. Design-based action research methodology is practical and iterative as it seeks to influence the practical decision-making process and offer possible solutions that can be evaluated. This method leads to a deeper knowledge of the underlying issues and their causes, with the researcher and the users collaboratively developing potential solutions. Additionally, it enables a more adaptable approach in both design and delivery, which may support co-design methods that generate value (Manzini, 2015). The researchers developed an instructional manual to use for drafting patterns using CorelDraw and illustration using a graphics tablet.

4. MATERIALS

CorelDraw is commonly used by creatives as it offers many advantages to designers. Just like any other software program CorelDraw also requires one to have a certain skill level for them to be able to use the software in designing. The software is easily compatible with many personal computers and has flexible subscription rates. Table 2 highlights the critical resources used for this study.

Table 2: Equipment and materials used in the project

Requirements	Purpose
Personal Computer-PC	Processing and displaying the graphic output
CorelDraw Graphics Suite 2022 v24	Vector based program used to develop graphic illustrations
Mouse	A necessary tool used to move cursor
XP Pen Deco 01 V2 Graphics Tablet	A graphic tablet used for hand drawing or hand rendered digital illustrations etc.
Open Broadcaster Software-OBS	A software program used to capture screen or record whilst developing the processes

5. RESULTS

5.1 Workspace design

To launch CorelDraw 2022 the following procedures were done, click on the start menu of the taskbar (at the bottom left corner of the screen), move cursor and select CorelDraw 2022, and double-click on CorelDraw 2022 to display. When CorelDraw 2022, is launched the application window opens and has a drawing page with various commands as shown in Figure 1. The title bar displays the title of the currently selected drawing. The toolbox is a docked bar with tools for creating, filling, and modifying objects in the drawing. The drawing page is the printable rectangular area inside the drawing window where one can do their illustrations.

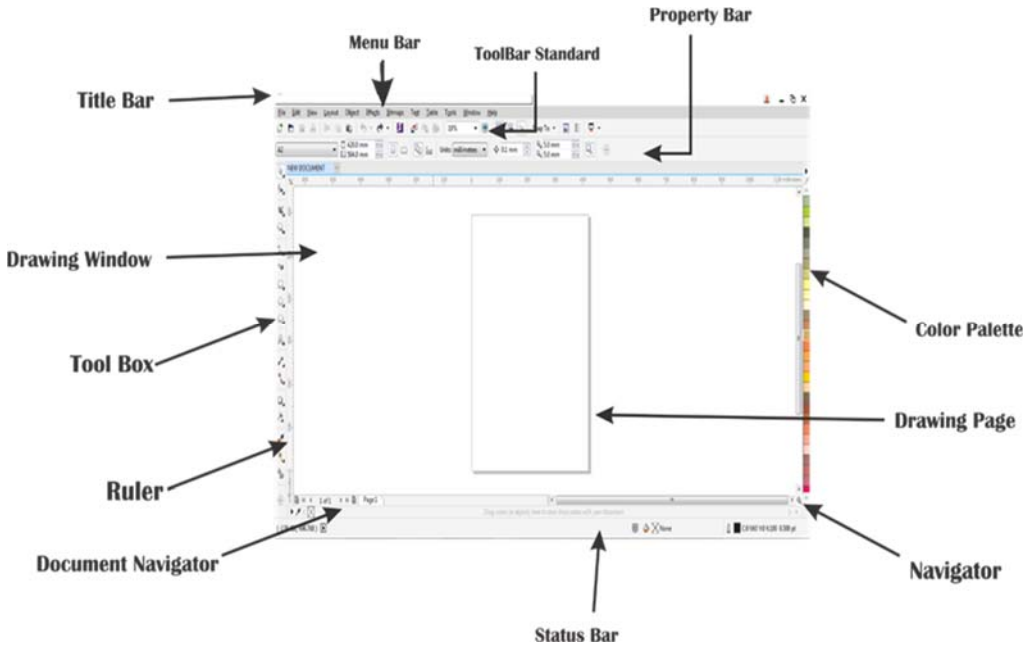


Figure 1: CorelDraw Graphics Suite 2022 v24

5.2 Developing techniques for a hand-rendered illustration

Drawing straight into a computer platform, such as CorelDraw, eliminates the need to scan hand drawn ar twork. Hand-drawn illustrations in digital graphics have a distinct and authentic appearance that distinguishes them from vector or digitally created images. This work focuses on the technique of using a graphics tablet as it produces more accurate and authentic drawings on the screen than the mouse or any other pointing device. The graphic tablet (XP pen Graphic Tablet) is recommended for beginners as it also provides a more ergonomic method of input that can reduce the repetitive strain injury caused by traditional hand drawing illustration methods. The freehand tool and the artistic media tool (CorelDraw toolbox) were used to produce detailed hand-rendered illustrations together with the graphics tablet, which has a digital pen (representing a pencil) and a digital tablet (representing a drawing pad).
Figure 2 shows the imported silhouette that was traced and illustrated on the drawing page. The inspiration for the design is also shown in the drawing window. The freehand tool on the toolbox bar was used to trace the design on top of the silhouette, using it as a guide to design as well as body shape. Freehand tool has an outline width on the property bar that can be adjusted or increased, on this illustration it was increased after tracing out the design, the silhouette was moved next to the design so as to demarcate the design, and the silhouette is shown in Figure 2.

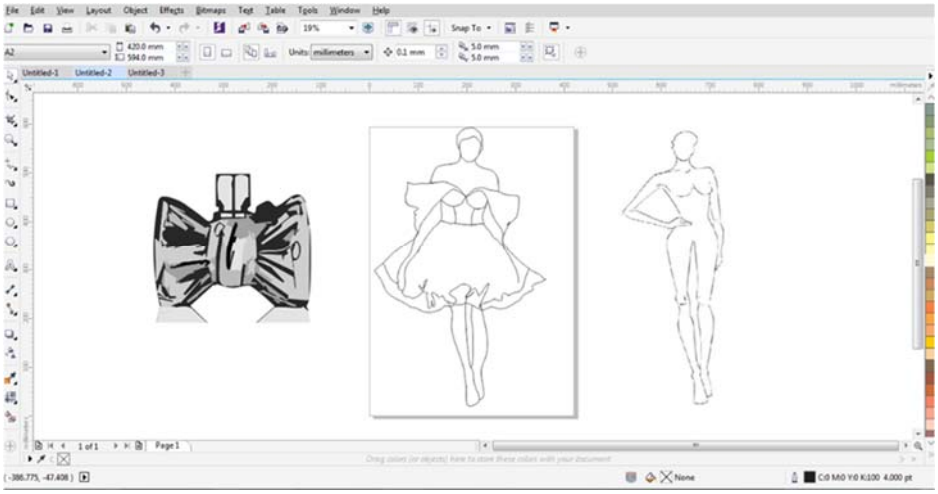


Figure 2: Preview of sketched design alongside the inspiration and the silhouette

5.3 Adding colour details to the design

This stage requires extra attention to detail as the techniques make extensive use of the artistic media tools that is the brushstroke tool and the colour palette. On the toolbox, the artistic media tool is located next to the freehand tool and the colour palette is on the right side of the centre drawing page. After clicking on the artistic media tool, the brushstroke is found on the property bar where the user changes to any artistic brush of choice. The brushstroke was used to add colour on top of the freehand tool lines, as well as to add complicated strokes to the design to produce the effect shown in Figure 3. On the toolbar, there is a fill tool which had a drop bar with two different types of fill options. The process was achieved through the following:

1. Move the cursor to the colour palette tool and add colour from the inspiration.
2. Add colour to the skin areas using the smart fill tool
3. Click on the artistic media tool, move the cursor to the property bar, and change the tool to brushstroke (using the graphic tablet).
4. Use the brushstroke to add lines and some designs on the garment
5. Click on the fill tool and select the mesh fill tool on the drop bar. Select the skirt part of the dress using the mesh fill tool and add colour to it.
6. Drag the inspiration close to the finished design.

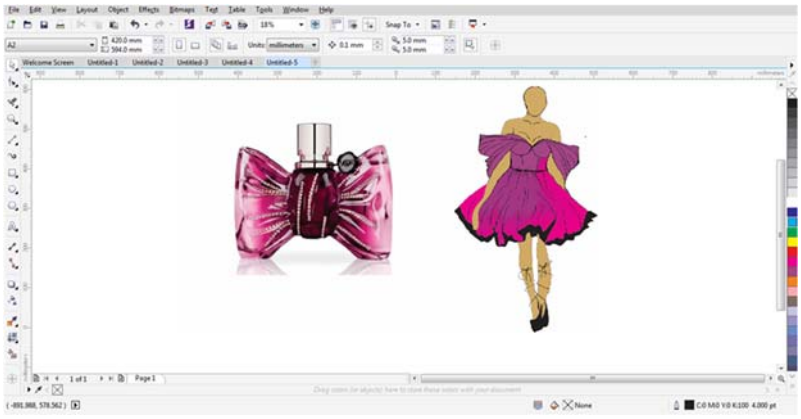


Figure 3: Adding colour to the design to match inspiration.

The illustration shown in Figure 4 was achieved through the following steps:

1. Click on the freehand tool.
2. Use the direct drawing technique to draw the outline sketch of a shirt.
3. Use the pick tool to select the artistic media tool.
4. Move the cursor to the property bar and click on the brushstroke media to highlight the freehand tool marking.
5. Use the graphic table for free-hand movement wearing the glove.

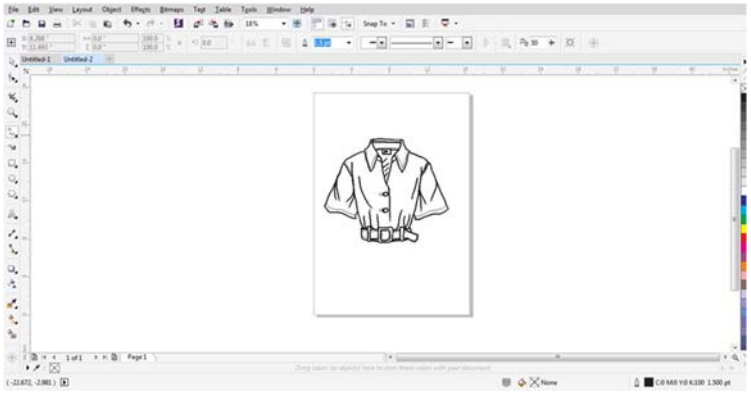


Figure 4: Shirt illustration in CorelDraw using a graphics tablet

5.4 Pattern drafting using CorelDraw

Before drafting a pattern there is a need for an illustration guide of a design that guides the pattern maker of the design to draft the exact pattern for the design. The illustration in Figure 5 was hand-drawn using the graphics tablet using the tools in CorelDraw. CorelDraw default tools were used for corset pattern development. Tools such as pick tool, rectangle tool, dimensional tool, text tool, shape tool, two point line tool were used in the development of the pattern.

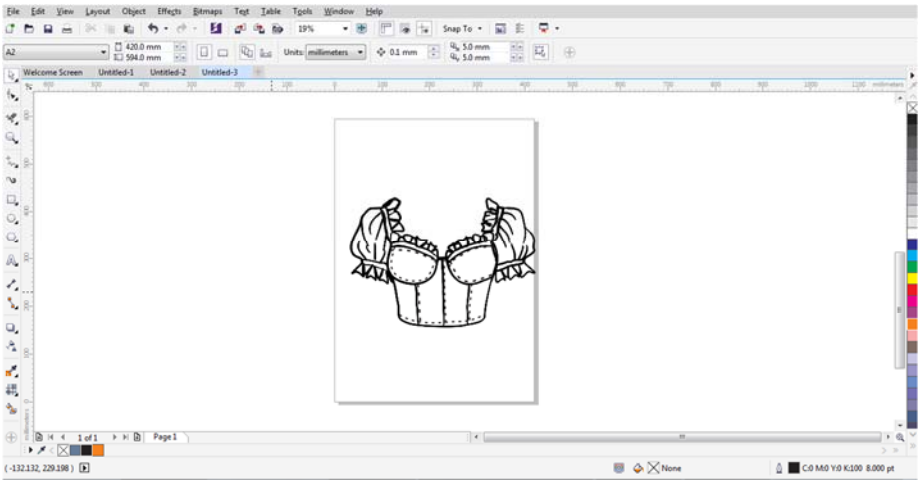


Figure 5: Female corset top design illustration

The pattern below can be used to make different types of corset tops. A corset top pattern development process began by changing the working paper size to A2 and drawing units to inches. A2 paper size was selected because it fits the corset top pattern well. The y-axis and x-axis ruler were used to guide the correct positioning of lines. At this stage, a female block full scale was used to develop a corset top of size 8. The measurements that were used for the development of the corset top of this pattern are:

- waist -24
- bust- 34
- bust point- 4
- bustier length- 14

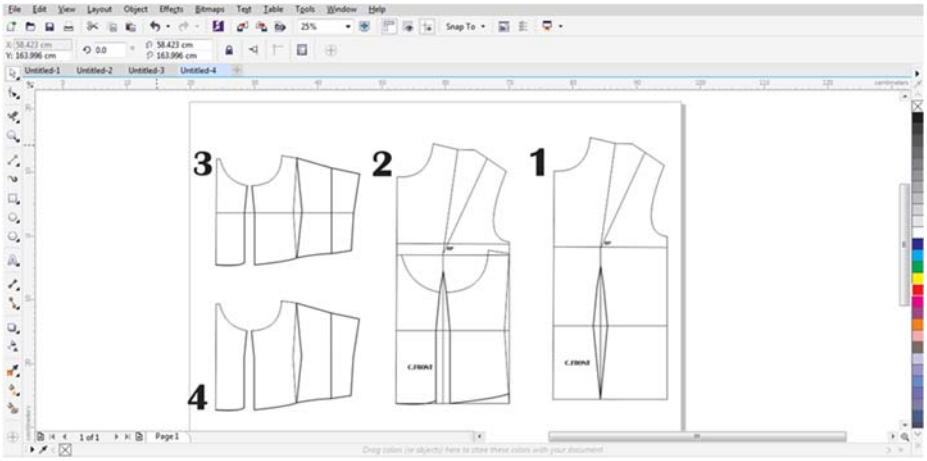


Figure 6: Pattern development of a female corset top

5.5 Developing technical pack for garment design

A technical pack or tech pack in short is similar to a standard sewing pattern envelope used in most garment manufacturing companies that produce and sell commercial patterns. A tech pack can be used as a blueprint of the final garment. The technique consists of designing from an illustration design to a pattern

ready for laying out and cutting. The artistic media tool was used to draw complicated strokes to show the garment's position and to show a realistic draping feel on the garment. The graphics tablet allowed natural drawing motion thus assisting in the drawing of complicated shapes with ease unlike as compared to the mouse. Figure 7 shows the commercial envelope that was designed using hand-rendered illustrations that were achieved using the graphic tablet as well as CorelDraw software. The envelope was made easier to design because of the techniques introduced in the study as well as the flexibility of the graphics tablet.

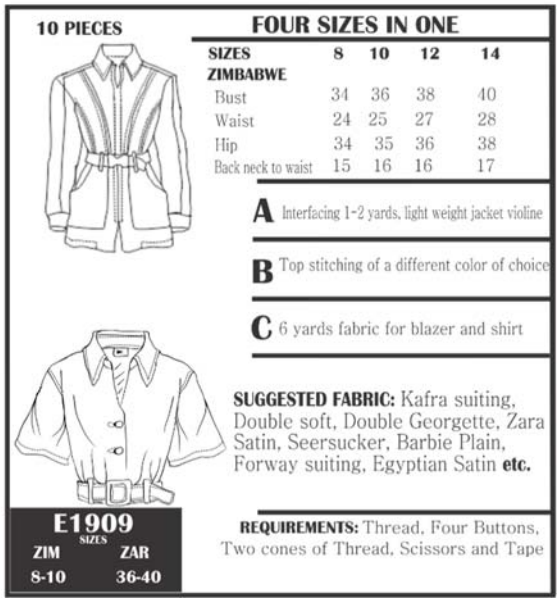


Figure 7: Commercial Sewing Pattern Envelope

6. DISCUSSION

The study explored various digital illustration techniques for fashion illustration using CorelDraw and the graphics tablet. The study sought to manipulate some CorelDraw tools to develop unique techniques that can be used to produce similar results that can be achieved through the use of commercially available fashion CAD software such as Gerber. Using the graphics tablet improved the manipulation process of the various tools within CorelDraw. The digital pen on the graphics tablet allowed the users to create unique design details that would have been hard to create using CorelDraw only. The study explored various application areas of CorelDraw in the fashion design process from illustration to the final commercial garment tech pack. Traditional methods of pattern drafting are time-consuming and may lack precision (Afifi et al., 2024; Liu et al., 2022), as they do not always account for the body-to-pattern relationship effectively, leading to fit issues. In contrast, digital drafting using CAD significantly enhances efficiency by reducing production time and increasing accuracy, allowing for more complex designs and better fit through automated processes. Moreover, digital methods such as the ones illustrated in this study facilitate innovative design possibilities, enabling the integration of various visual elements and textures that traditional fashion illustration methods cannot easily replicate.

Practically using CorelDraw allows for the precise drafting of patterns, which can be tailored to specific materials. Using CorelDraw also improves the ability to visualise and adjust patterns in real-time at a lower cost thus leading to more efficient garment design processes and improved end products similar to the findings highlighted by (Wang, 2020). Integration of technologies such as CorelDraw is critical especially for small garment manufacturing companies as it improves their product quality. CorelDraw has the ability to utilise methods that generate patterns from user-uploaded images or style drawings, ensuring that the final products match customer expectations. While CorelDraw offers robust tools for pattern drafting, challenges remain in ensuring consistency across different drafting methods, which can affect garment fit and overall design integrity. Challenges such as software integration and user accessibility must be addressed to ensure practical application in CorelDraw. The use of graphics tablets as described in this study offers an opportunity to simply improve the design output.

7. CONCLUSION

Digital fashion illustration and pattern drafting are important in the fashion design sector as they bring numerous benefits to the industry. For small companies that face financial challenges in investing in CAD systems for fashion, using the alternative of CorelDraw can be an option that is worthwhile as it has fewer financial implications. Every fashion aspect or art aspect begins with a design which makes the designing process an important component in the industry. One thing that makes designing difficult for other designers is the manual way of illustrating designs, it takes time and some are not familiar with idea development with no inspiration, but with the use of vector graphic software and the digital tablet, illustration is made easier for the designer. The digital outputs illustrated in this study reveal that using a graphics tablet and CorelDraw allows the user to create complex designs and pattern drafting whilst the user feels like they are doing it manually through hand-rendered illustrations. Businesses can adopt the methods described in this study to develop their digital patterns and illustrations with much ease at a lower cost. These digital outputs can then be easily and efficiently communicated to the production team and or clients and make the process of prototype development quicker.

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THE INFLUENCE OF SYMBOL ORIENTATION AND BORDER LINE THICKNESS ON SUBJECTS' PREFERENCES FOR ICON DESIGN

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Abstract: *This study investigates the influence of symbol orientation and border line thickness on subjects' aesthetic preferences for icon design. Iconography, a critical element in user interface design, relies heavily on visual clarity and aesthetic appeal. Not only shape but also colour and colour combinations influence and make more complex icon design. That implies shape and colour have to be investigated both separately and in interaction. By systematically varying the orientation and border line thickness of icons, we aim to understand how these design parameters affect user preferences. A sample of participants was presented with a series of icons, each differing in orientation and border line thickness, and asked to rate their preferences. Obtained results revealed that both orientation and border line thickness noticeably influence user preference. Icons with certain orientations and moderate border line thickness were consistently rated higher in terms of visual appeal and usability. These findings have important implications for designers, suggesting that careful consideration of these variables can enhance user satisfaction and interface effectiveness.*

Keywords: symbol, shape, icon, orientation, thickness

1. INTRODUCTION

Pictorial information is known to be the quickest to notice and comprehend as a form of information presentation (Lidwell, Holden & Butler, 2003). In many research studies, graphical images were found to be superior to text in terms of recall and recognition accuracy (Shepard, 1967). Therefore, image-related icons are considered the most effective for fast and accurate recognition (Blankenberger & Hahn, 1991; Wiedenbeck, 1999). Icons are highly efficient at communicating ideas because they transcend language barriers and present meaning in a condensed form, unlike words (Yan, 2011). Communication with a digital interface is primarily done through a direct manipulation interaction style (Shneiderman, 1982, 1983), enabling users to interact directly with on-screen elements. In everyday point-and-click tasks, people interact with user interfaces and human-machine interfaces while searching for icons of interest (Galitz, 2007).

Visual search plays a key role in identifying icons. As icon complexity increases, so does search time, due to the additional processing needed to integrate all of the icon's features into a cohesive perception (McDougall, 2006). The impact of icon complexity on search time remains significant over the long term and does not diminish with experience (McDougall, 2006).

The perception of shapes is closely related to the perception of contours. Contours provide the primary source of shape information, with the greatest curvature along the contour typically carrying the most shape information (Singh, 2015). The human visual system represents contours and shapes in parts. The visual system breaks down contours and shapes into smaller, simpler parts and organizes the perception of shapes by considering the parts of shapes and their spatial relationships (Singh, 2015). Gestalt psychologists have shown that contours contain the most information related to the perception of objects, including shape, colour, and depth (Pinna & Deiana, 2015). Not all properties of an object are perceived with the same intensity, some properties are more prominent, some less so. When asked what an object represents, the spontaneous answer is usually a description of the object based on its shape (Pinna & Deiana, 2015). It is less common for a description of an object to begin with its colour, and even rarer for it to start with attributes like volume, material quality, or other characteristics. These research results suggest that not all visual attributes have the same level of visibility; rather, they are typically organized along a complex 'gradient of visibility' and follow a certain visual syntax (Pinna & Deiana, 2015).

Shape is one of the primary factors that attract early attention. A preattentive feature implies features that guide attention during visual search and cannot be broken down into simpler features (Wolfe & Utochkin, 2019). The mechanism of early attention, commonly known as 'popout,' is referred to in professional contexts as a 'preattentive feature.' Early researchers claimed that this phenomenon occurs before the

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conscious formation of attention; however, modern views suggest that the presence of attention is crucial for this effect (Ware, 2021).
Factors that are considered certain to cause early attention include:

1. colour;
2. movement;
3. orientation;
4. size.

Since the aesthetic appeal of an icon is an important factor in the likability of an interface and is crucial for ease of searching for icons, this preliminary study aims to investigate the most preferred icon design. This icon will be further examined in another experiment that utilizes colour harmonies.

2. METHODS

2.1 Participants

A total of 95 college students (a mix of men and women, ages ranging from 18 to 25 years) participated in this preliminary study. All participants had normal or corrected vision. Participants had not participated in similar studies before.

2.2 Apparatus

The preliminary study was conducted online. Stimuli were presented in a Google Forms questionnaire survey. Participants were instructed to fill out the questionnaire survey on a 24-inch monitor while seated in a chair. Responses were collected via Google Forms.

2.3 Stimulus design

The stimulus used for the questionnaire survey is an icon featuring a telephone symbol on a white square background with a border. The telephone symbol was varied in orientation, and the border was varied in thickness.

2.4 Preliminary study questionary survay design

The first question in the questionnaire survey was about the symbol orientation, as shown in Figure 1. Participants were presented with 11 different orientations of the telephone symbol, each rotated in steps of 15 degrees in both clockwise and counterclockwise directions. Tasked with choosing the most legible symbol, the majority of participants chose the orientations of 45 degrees and 60 degrees. Therefore, the orientation of 60 degrees was used for the questions about border line thickness.
In the second question, which focused on border line thickness, participants were asked to choose a border line that was acceptable—not too thick, as shown in Figure 2. In the third question, also about border line thickness, participants were asked to choose a border line that was acceptable—not too thin, as shown in Figure 2.

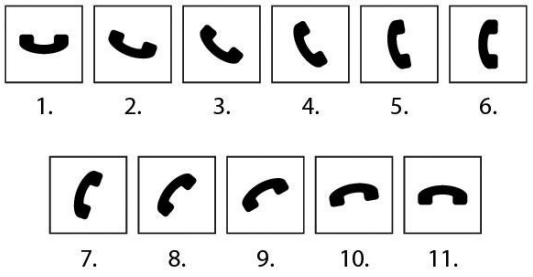


Figure 1: Stimuli for the first question in the questionnaire survey

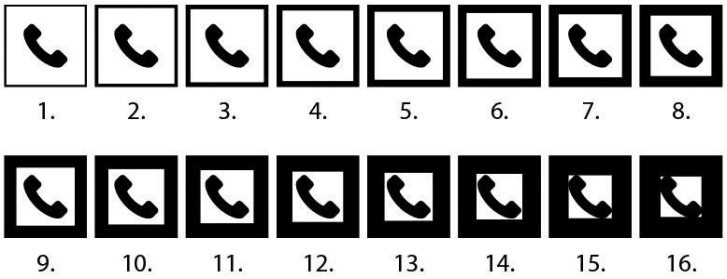


Figure 2: Stimuli for the second and third question in the questionnaire survey

3. RESULTS AND DISCUSSION

The results obtained from the questionnaire survey showed (Figure 3) that most participants chose two orientations that are the most representative of this symbol. The largest number of participants (37.9%) chose the telephone symbol with a 45-degree orientation, as shown in Figure 1, number 4. Additionally, a large number of participants (33.7%) chose the telephone symbol with a 60-degree orientation, as shown in Figure 1, number 3. This implies that these two orientations are the most commonly used orientations for this symbol.

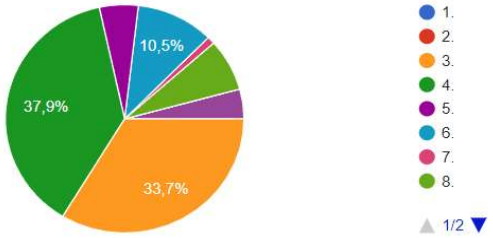


Figure 3: First question of the questionnaire survey and obtained results

In the second question, the obtained results showed (Figure 4) that most participants chose two thicknesses that are not too thin but acceptable. Most participants (29.5%) chose the border line thickness labelled as number 3, as shown in Figure 2, number 3. Additionally, a large number of participants (24.2%) chose the border line thickness labelled as number 4, as shown in Figure 2, number 4.

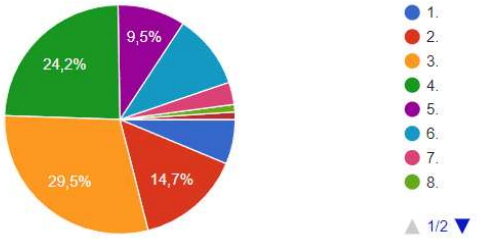


Figure 4: Second question of the questionnaire survey and obtained results

In the third question, the obtained results showed (Figure 5) that most participants chose two thicknesses that are not too thick but acceptable. The largest number of participants (22.1%) chose the border line thickness labelled as number 6. Additionally, a large number of participants (18.9%) chose the border line thickness labelled as number 7. There is also a significant number of participants who chose the border line thickness labelled as number 2 (14.7%) and number 5 (12.6%).

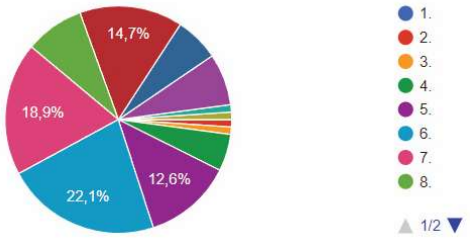


Figure 5: Third question of the questionnaire survey and obtained results

5. CONCLUSIONS

Preliminary research is conducted with the aim of assessing users' aesthetic appeal for icons concerning symbol orientation and border line thickness. The likability of the interface is an important factor, and it is crucial for the ease of searching for icons. This preliminary study aims to investigate the most preferred symbol orientation and border line thickness. This icon will be further examined in another experiment using colour harmonies. Results obtained from the questionnaire survey show the most preferred symbol orientation and the minimum and maximum border thicknesses. These findings have important implications for designers, suggesting that careful consideration of these variables can enhance user satisfaction and interface effectiveness.

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ECOLOGY

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CALCULATION OF THE CARBON FOOTPRINT OF BOOKS AND E-READERS THROUGH THE STAGES OF THE PRODUCT LIFE CYCLE

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Abstract: *In this research, the carbon footprint for the book and e-reader was calculated for all phases of the product's life cycle. The scientific paper also compares the amount of CO_2 equivalents by stages of the life cycle analysis of the listed products, identifies possible places in production or individual habits that can be responsible for reducing the carbon footprint, and suggests ways to reduce the carbon footprint. The CO_2 equivalent was used in the carbon footprint calculations because other greenhouse gases such as methane, N_2O and fluorinated gases are also emitted during the life cycle of books and e-readers. Calculating the carbon footprint is essential for understanding, monitoring and reducing greenhouse gas emissions. The calculation can contribute to raising people's awareness of issues important for reducing the negative impact on the environment, can be a driver of necessary changes in lifestyle with the aim of more sustainable business and lifestyle, and contributes to global efforts in the fight against climate change. The importance of the obtained indicative numbers lies in the fact that individuals and organizations can use the obtained values to make informed decisions that positively affect the environment, society and the economy.*

Key words: carbon footprint, product life cycle stages, book, e-reader

1. INTRODUCTION

When calculating the impact on the environment, the CO_2 equivalent is most often used, which is a measure used to convert the amounts of different greenhouse gases into an equivalent amount of carbon dioxide (CO_2) (Çelekli & Zariç, 2023; East, 2008). The calculation is based on their global warming potential (GWP), which shows how many times more (or less) heat a particular gas retains in the atmosphere compared to CO_2 over a certain period, usually 100 years (Pandey, Agrawal & Pandey, 2008). When studying the carbon footprint balance for books, other greenhouse gases should be taken into account in addition to carbon dioxide (CO_2). Different greenhouse gases have different global warming potentials (GWP), so it is important to consider all relevant gases to get a complete picture of the overall environmental impact (Courchene & Allan, 2008; Edgar & Peters, 2009). When the life cycle of a book is divided into the stages of paper production, printing, transport and disposal, it can be concluded that CO_2 is present as the main pollutant. In addition to the aforementioned gas, methane emissions (CH_4) are present at landfills where paper waste is decomposed anaerobically, and nitrogen oxide emissions (N_2O) from the production and use of fertilizers for growing trees that are used for paper and transport processes.

Electronic equipment has a significant impact on the environment throughout its life cycle, including production, use and disposal (Gard & Keoleian, 2008). Electronic devices require the extraction and processing of various metals and rare earth elements, which can cause environmental devastation, including habitat loss, water pollution and soil degradation (Oladipo et al., 2023). The product design phase should be based on the development of products with a smaller carbon footprint, increased energy efficiency and the use of sustainable materials. CO_2 emissions are related to energy consumption during the production, transportation and use of electronic devices. Fossil fuels emit significant amounts of CO_2 in the mentioned phases of the product's life cycle. In addition to CO_2, other greenhouse gases such as methane, N_2O, and fluorinated gases are also emitted. Electronic production can indirectly contribute to methane emissions, particularly through energy consumption from fossil fuels such as natural gas and coal. Industrial processes, including the manufacture of electronic components, can emit N_2O as a by-product (Lee, Ryu & Moon, 2012; U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2020). Fluorinated gases are used in manufacturing processes to clean semiconductor devices. They have a very high global warming potential (GWP) and are long-lived in the atmosphere. PFCs (perfluorocarbons) are used in the production of semiconductors (Tsai, 2002). SF_6 (sulfur hexafluoride) is used in electrical equipment as an insulating gas due to its excellent dielectric properties (Dervos & Vassilou, 2000; Badrul, 2021; Zhou, Teng & Tong, 2018). The last phase of the product's life

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cycle should be delayed as much as possible with responsible device maintenance, because e-waste often contains toxic materials (e.g. lead, mercury, cadmium) that can contaminate soil and water if not properly disposed of. Recycling electronic equipment can reduce the need to extract new raw materials but requires specialized processes to safely extract useful materials and dispose of hazardous components. Responsible practices include developing more efficient methods to extract and reuse valuable materials from e-waste. The aforementioned implements the circular economy model, which has become imperative in all production branches (Zhou, S., Teng, F. & Tong, 2018; Geissdoerfer et al., 2020).
Carbon footprint is an important factor in understanding environmental impact. Calculating the carbon footprint helps identify the largest sources of greenhouse gas emissions within an organization, process or product (Yang & Meng, 2020). The obtained data have a qualitative and quantitative dimension of reporting on emissions and thus can contribute to easier achievement of sustainability (Durojaye, Laseinde & Oluwafemi, 2019; Kumar, Sharm & Vashista, 2014). Organizations can use carbon footprint data to set emission reduction targets and track progress towards those targets. Often, the calculation of the carbon footprint can contribute to improving efficiency by identifying places to optimize resources, which can lead to reduced emissions and costs. In addition to reducing costs, carbon footprint monitoring can lead to new investments as investors increasingly seek information on sustainability and greenhouse gas emissions before deciding to invest. Organizations that monitor and reduce their carbon footprint may have easier access to funding. Consumers are becoming increasingly aware of the environmental impact of their purchasing decisions. Products with a smaller carbon footprint can have a market advantage. In addition to the aforementioned, many legislative bodies impose reporting requirements on greenhouse gas emissions (Hertwich & Peters, 2009; Hawkins, Ma, Schilizzi & Zhang et al., 2016). Calculating the carbon footprint helps organizations comply with regulations. Some companies have introduced transparent carbon footprint reporting to improve the organization's reputation and the desire to present themselves as companies that are committed to sustainable business and production. It can be noted that as regulations have been tightening for many years, organizations that already monitor their carbon footprint are better prepared to adapt to the new requirements. Requirements for reducing global greenhouse gas emissions are reflected in various national and international goals, such as the goals of the Paris Agreement and the Sustainable Development Goals (SDGs) set by the United Nations, which relate to climate action and sustainable production (Jones et al., 2017; Ordonez-Ponce, 2023; Rei, Goncalves & de Souza, 2017; Streck, Keenlyside & von Unger, 2016). Awareness of one's carbon footprint can motivate individuals and organizations to adopt more sustainable practices. In this paper, a carbon footprint for a book and an e-reader will be presented. The stages of life cycle analysis of the listed products will be compared and possible places in production or individual habits that can contribute to reducing the carbon footprint will be defined.

2. METHODS

To define the product life cycle, all phases of the product life cycle are identified: procurement of raw materials, production, distribution, use, and disposal or recycling. Research papers related to greenhouse gas emissions and carbon footprints of various materials and processes were searched in the scientific databases ScienceDirect, Google Scholar, and PubMed. In addition to the above, reports from industrial organizations were also used, such as those dealing with production, transport and recycling, which can provide data on energy needs and emissions. Literature published by environmental protection agencies and NGOs, manufacturers' specifications and declarations, and websites offering carbon footprint calculators (e.g. Carbon Footprint Calculator) for preliminary estimates were studied. The collection and analysis of data for the calculation of the product's carbon footprint required a systematic approach and the use of a large number of enumerated data sources.
Various greenhouse gases such as methane (CH_4), nitrogen oxide (N_2O), and fluorinated gases (HFCs, PFCs, SF_6), which significantly contribute to global warming, are integrated into the calculation. Each of these gases has a different GWP, the GWP of methane (CH_4) is 28-36 times greater than CO_2 over 100 years, while the GWP of nitrous oxide (N_2O) is about 298 times greater. CO_2 equivalent enables simpler communication and comparison of total emissions of different gases because it converts all emissions into one common measure. This makes it easier to calculate the overall impact of activities and products on climate change. The use of CO_2 equivalents standardizes the data, allowing for consistency and comparability between different studies.
To calculate the CO_2 equivalent, you need to multiply the amount of each gas by its GWP (Equation 1):

$$CO_2\text{-}eq=(M_{CO2}\times 1)+(M_{CH4}\times GWP_{CH4})+(M_{N2O}\times GWP_{N2O})+\ldots \quad (1)$$

Where is:

M_{CO2}: Mass of emitted CO_2
M_{CH4}: Mass of emitted CH_4
GWP_{CH4}: Global Warming Potential of Methane (CH_4)
M_{N2O}: Mass of emitted N_2O
GWP_{N2O}: Global warming potential of nitrogen oxide (N_2O)

By including all relevant greenhouse gases in the calculation of CO_2 equivalents, a more comprehensive assessment of the real impact of climate change is obtained.
To verify the accuracy of certain parts of the phases of the product life cycle, the results were validated by comparing the obtained results with other studies or reference values to ensure credibility. By combining quantitative and qualitative data from reliable sources, accurate and detailed insight into the total carbon footprint of the product throughout its entire life cycle can be achieved. This data can help identify key areas to reduce emissions and improve product sustainability.

3. CALCULATION OF CARBON FOOTPRINT

The carbon footprint of physical books and e-readers has been calculated, which includes an assessment of the CO_2 emissions associated with their life cycles to make a judgment about their environmental burden.

3.1 Calculation of carbon footprint for book

The life cycle of a physical book includes paper production (growing raw material or using recycled raw material, paper production), printing and binding, distribution (transport to bookstores and/or end users, use (generally no additional emissions) and disposal (recycling or disposal) (Figure 1) (Borggren, Moberg & Finnveden, 2011). Paper production includes processes such as the extraction of wood and other raw materials needed for paper production. CO_2-eq emissions include emissions from logging machines, transportation of raw materials to paper mills, etc. During the paper pulp production process, wood chips are cooked and washed, as white and dry paper pulp. These processes are energy-intensive and often use fossil fuels. If we assume that the average book has about 200 to 300 pages, it is evident that 1 kg of paper, emits 1,2-1,5 kg of CO_2-eq (Gower et al., 2006; Moberg & Borggren, 2010).
According to CEPI (Confederation of European Paper Industries), average CO_2-eq emissions for paper production in Europe are around 0.78-1.32 kg CO_2-eq per kilogram of paper, depending on the type of paper and the efficiency of the production process. The Environmental Paper Network (EPN) reports that CO_2-eq emissions for the production of recycled paper can be lower, around 0.7-1.0 kg CO_2-eq per kilogram, while emissions for raw fibre paper can be higher, around 1.3-1, 5 kg of CO_2-eq per kilogram. Ecoinvent Database like GaBi and SimaPro, contains data showing that CO_2-eq emissions for different types of paper can vary between 0.9 and 1.5 kg CO_2-eq per kilogram. Printing processes include the use of ink, printing machines and materials in finishing processes such as glue, and covers. All processes use energy for production. Emissions related to the printing and binding process emit approximately 1-2 kg of CO_2-eq. In total, to produce one book of 1 kg of paper, approximately 2,2-3,5 kg of CO_2-eq is emitted (Toffel, M. W. & Horvath, 2004; Wells et al., 2012).

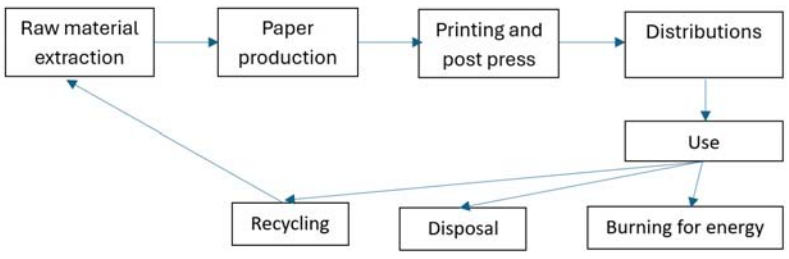


Figure 1: The life cycle of a book

The distribution estimate includes various stages of transportation, such as the transportation of books by trucks, ships, aeroplanes, and delivery vehicles. Different modes of transport (truck, ship, plane) have different emission profiles. Trucks and planes tend to have higher CO_2-eq emissions per kilogram of cargo than ships (Ferrer & Thomé, 2003; Yoon, Y., Yang, M. & Kim, 2008). The estimation of the amount of CO_2-eq emissions is influenced by the distance from the printing press to the warehouse and from the warehouse to bookstores or end users, as well as the size of the load. Larger loads distributed over longer distances result in higher emissions. When studying international transport according to data from Carbonfund.org, the CO_2-eq emissions for transporting one ton of cargo over 1,609 km by truck are about 63 kg of CO_2-eq. For a ship, the same distance amounts to about 6 kg of CO_2-eq. According to the European Environment Agency (EEA) average emissions for heavy truck transport (HGV) are around 62-105 g CO_2-eq per ton-kilometre (g CO_2e/Tkm). Data from the IPCC (Intergovernmental Panel on Climate Change) are similar, where emissions range from 60 to 150 g CO_2-eq per ton-kilometre, as well as from DEFRA (UK Department for Environment, Food & Rural Affairs), where approx. 80-120 g CO_2-eq per ton-kilometre. For transport within the country, the amounts are quite different, depending on the mode of transport and the size of the country, i.e. the length of the journey. Estimates of emissions for distribution vary around 0.1-0.5 kg CO_2-eq per book.

Transport from the printing house to the warehouse (by truck):
Distance: 1000 km
Emissions: about 0.063 kg CO_2-eq T/km
For 1 kg of books: (0.063 kg CO_2-eq / 1000 kg) * 1000 km = 0.063 kg CO_2-eq

Transport from warehouse to bookstore or user (local delivery by truck or van):
Distance: 100 km
Emissions: about 0.2 kg CO_2-eq T/km for local delivery
For 1 kg of books: (0.2 kg CO_2-eq / 1000 kg) * 100 km = 0.02 kg CO_2-eq

Delivery to the end user (delivery vehicle or car):
Distance: 10 km
Emissions: about 0.1 kg CO_2-eq T/km
For 1 kg of books: (0.1 kg CO_2-eq / 1000 kg) * 10 km = 0.001 kg CO_2-eq

The total emission in the transport phase is about 0.084 kg CO_2-eq due to large variations in the parameters for further calculation the amount of approximately 0.5-1 kg CO_2-eq per book will be used.
It was mentioned earlier that the phase of use does not affect CO_2 emissions. In the disposal phase, different methods can be used, such as recycling, incineration and landfilling (Shang et al., 2021; Laurijssen et al., 2010). The paper recycling process includes collection, transport to a recycling facility, and an energy-consuming recycling process. Recycling reduces the need for new raw materials but still consumes energy that generates CO_2-eq emissions. According to the Environmental Paper Network (EPN), paper recycling can reduce CO_2-eq emissions by about 1.4 kg CO_2-eq per kilogram of recycled paper compared to the production of paper from raw fibres. IPCC (Intergovernmental Panel on Climate Change) research estimates that CO2-eq emissions for paper recycling are around 0.3-0.6 kg CO_2-eq per kilogram of paper, including all collection, transport and processing processes Burning books can generate energy, but it also emits CO_2. Emissions depend on the efficiency of the incineration plant and the energy value of the burned material. Paper should not be disposed of in landfills, but some paper still ends up there (Guo et al., 2020). Paper in a landfill can be decomposed anaerobically, emitting methane (CH_4), a powerful greenhouse gas. Modern landfills often have methane capture systems, which can reduce emissions. A study on the life cycle of paper estimates that CO_2-eq emissions from recycling one kilogram of paper amount to about 0.0007-0.001 kg CO_2-eq. The amount indicates a very high efficiency of the recycling process. When studying landfilling, the EPA (United States Environmental Protection Agency) claims that CO_2-eq emissions are about 0.3 kg CO_2-eq per kilogram of paper, but this number can be higher due to methane (CH_4) emissions from landfills. The IPCC estimates that emissions from paper disposal can be between 0.5-1.0 kg CO_2-eq per kilogram of paper, taking methane emissions into account. Incineration with energy valorization has a smaller impact on the environment, so the European Environment Agency (EEA) estimates emissions of about 0.7-1.2 kg CO_2-eq per kilogram of paper, while the EPA at about 0.8 kg CO_2-eq per kilogram of paper. When paper is burned without energy valorization, the IPCC estimates the emission at around 1.0-1.5 kg CO_2-eq per kilogram of paper. The estimate that book disposal emits approximately 0.1-0.5 kg of CO_2-eq per book is based on analyses of different disposal methods and their emission profiles.

When the average impact for all phases of the book's life cycle is added up and when all contributions are considered, the total carbon footprint per book is about 3.6-7.5 kg CO_2-eq.

3.2 Calculation of carbon footprint for e-reader

The life cycle of an e-reader includes production (extraction of raw materials, production of components, assembly), transport (transport to the end use), use (energy consumption during use) and disposal (recycling or disposal) (Figure 2).

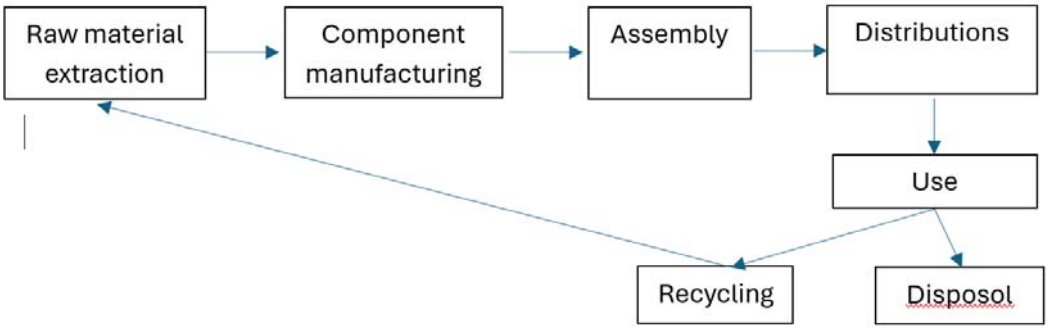


Figure 2: The life cycle of a e-reader

In the production phase of e-readers, CO_2 is emitted through the extraction, transportation and refining of raw materials, i.e. metals (e.g. lithium, cobalt) for batteries, rare earths for electronic components, and other raw materials such as plastic, which is energy intensive (Moberg, 2010). Emissions from metal extraction and refining: about 30 kg CO_2-eq. In e-readers, many metals are used to make housings and other structural parts, so for example copper is used in printed circuit boards (PCBs) for electrical connections and wiring due to its excellent conductivity (Chancerel, 2015). Gold and silver are used for plating contacts and connectors because of their exceptional resistance to corrosion and good conductivity (Vats & Singh, 2015). Along with plating, nickel is used in alloys to increase resistance to corrosion and wear. Lithium is used in batteries due to its high energy density and long service life, and cobalt is used in lithium-ion batteries as well as in cathode materials due to its electrochemical properties (Park & Fray, 2009). Tin is used for soldering components on printed boards, and palladium is used in capacitors and contacts for its exceptional conductive and chemical properties (Gorewoda et al., 2020). Steel is characterized by strength and resistance to mechanical stress, so it is used in screws and internal structures. The next step is to manufacture the components including the screen, battery, processor and other electronic components. Production of screens (e-ink or LCD) emits about 40 kg of CO2-eq, batteries about 20 kg of CO_2-eq, and other electronic components about 30 kg of CO_2-eq. Energy consumption and emissions in this phase depend on the production technology and the energy used in the factories (Kozak et al., 2021; Majeau-Bettez, Hawkins & Strømman, 2011; Williams, 2004). Assembling the components into the finished device includes the energy costs of the assembly lines and auxiliary processes, which amount to about 10 kg of CO_2-eq. Emissions in the transportation phase include the transportation of raw materials to factories and finished components to assembly plants, which amounts to about 38 kg of CO_2-eq. Emissions depend on the distance of transport and the means of transport used. The Life Cycle Assessment of Electronic Devices study provides estimates of CO_2-eq emissions for the life cycle of e-readers that vary between 150-200 kg CO_2-eq, depending on the model and technology. Some manufacturers publish environmental reports detailing the CO_2-eq emissions associated with their products, for example, Amazon publishes CO_2-eq emissions for different models of Kindle devices. The calculated value in this study coincides with the study and manufacturer's reports and is approximately 168 kg CO_2-eq per device.

The calculation of the carbon footprint for the transport phase is based on the same settings as for the calculation for the book, with the difference that here, for international transport, the data is given for transport by ship, because raw materials and parts of the reader can come from overseas countries, so such transport is more favourable by ship. CO_2-eq emissions for ship transport, according to the European Environment Agency (EEA) are about 3-15 g CO_2-eq per T/km, according to the IPCC they are about 5-15 g CO_2-eq per T/km and according to the IMO (International Maritime Organization are around 8-18 g CO_2-eq per T/km.

The emissions of transport by ship:

The emissions of transport by ship are about 6 g CO_2-eq per ton per kilometre, so for a distance of 10,000 km, it would amount to 0.012 kg CO_2-eq with a reader weight of 0.2 kg.
(6 g CO_2-eq / 1000 kg) * 10,000 km * 0.2 kg = 0.012 kg CO_2-eq

Transport from the port to the warehouse (by truck):

When the distance from the port to the warehouse, from the warehouse to the user, which we estimated at 1000 km, is combined with the transport by ship, the CO_2-eq emission is 0.0126 kg, i.e. a total of 0.0246 kg.

Emissions: about 63 g CO_2-eq T/km
For 0.2 kg e-reader: (63 g CO_2-eq / 1000 kg) * 1000 km * 0.2 kg = 0.0126 kg CO_2-eq
Combining the stages of transport (Ship transport + truck transport): 0.0246 kg CO_2-eq

More realistic scenarios often include air transport, which significantly increases emissions, and additional local transport is also required. Air transport by plane has an average emission of about 500 g CO_2-eq per ton per kilometre travelled. Emissions related to the aforementioned transport depend on many factors, so conservative emission calculations of around 500 g CO_2-eq per ton of product per kilometre are used here.

Air transport:

The calculation for a distance of 10,000 km would be:
For 0.2 kg e-reader: (500 g CO_2-eq / 1000 kg) * 10,000 km * 0.2 kg = 1 kg CO2-eq

Local transport:

With an additional local transport of 500 km with emissions of about 63 g CO2-eq per ton per kilometre for a 0.2 kg e-reader were 0.0063 kg, i.e. a total of 1.0063 kg.
63 g CO_2-eq / 1000 kg) * 500 km * 0.2 kg = 0.0063 kg CO_2-eq
Combining the stages of transport (Transport by plane + transport by truck): 1.0063 kg CO_2-eq

The average power consumption of a book reader (e-reader) may vary depending on several factors such as screen size, screen type (e.g. E Ink vs. LCD), screen brightness, frequency of use of wireless functions (Wi-Fi, 3G/4G) and page-turning frequency. But in general, e-readers with E Ink screens, which are the most common among devices specialized in reading books, are known for very low energy consumption. The reasons for the low energy consumption are, among others, the fact that E Ink screens consume energy only when refreshing the page, which means that a static display does not consume energy. This technology is very energy efficient, resulting in a long battery life. Some e-readers have a built-in front light that can increase power consumption if used at higher brightness. In addition to the aforementioned use of Wi-Fi or mobile data can significantly increase energy consumption. A larger battery capacity enables a longer duration between charges but does not directly affect energy consumption per hour of use.
Calculating the carbon footprint of e-book readers by product life stage involves estimating CO_2 emissions during the different stages of the device's life cycle. These phases include production, transport, use and disposal. The carbon footprint of e-reader manufacturing includes extraction of raw materials, manufacturing of components and assembly of the device. Emissions estimates can vary, but data from life cycle analysis (LCA) studies are often used (Hischier & Wäger, 2005; Gatti, Basseau & Bourely, 2011; Moberg et al, 2010; Teehan & Kandlikar, 2013). According to a study from 2012, it is estimated that the production of e-readers (e.g. Kindle) emits about 168 kg of CO_2-eq. Transport includes emissions associated with moving the device from the place of production to the end user. These emissions depend on the distance and mode of transport (aeroplane, ship, truck). Transport emissions can vary, but the average value is around 10 kg CO_2-eq. Usage includes emissions associated with electricity consumption over the lifetime of the device. Unfortunately, e-reader manufacturers rarely directly mention the exact amount of energy consumed in watts or watt-hours but often provide estimates of battery life under typical usage conditions. However, there is information that can be used to approximate energy consumption. For example, the Amazon Kindle Paperwhite can do up to 28 hours of continuous reading with Wi-Fi off and low brightness, which can be estimated at around 2-3 weeks of use per charge, with a typical usage of around 30 minutes per day. The Kindle Paperwhite has a battery with a capacity of about 1500 mAh at 3.7V, which gives a total of about 5.55 Wh (1500 mAh * 3.7V). In this case, a calculation was made to estimate the consumed energy as follows:

Battery life in hours of use: 6 weeks x 7 days/week x 0.5 hours/day = 21 hours of total use.
Energy consumption per hour: 5.55 Wh / 21 hours ≈ 0.26 Wh per hour of use.
For the calculation, let's assume 2 hours of daily use over 3 years (typical service life):
Total hours of use: 2 hours/day * 365 days/year * 3 years = 2190 hours
Total energy consumption: 2190 hours * 0.26 Wh/hour = 569.4 Wh = 0.5694 kWh
Carbon emissions for use: 0.5694 kWh * 0.475 kg CO2/kWh ≈ 0.27 kg CO_2-eq

Similar figures are for the Kindle, the Clara HD can also last several weeks on a single charge under similar conditions of use. E-readers consume very little power, often between 1-2 W, which allows long-term use without frequent charging. Kobo quotes similar figures to Amazon, up to 6 weeks with an average of 30 minutes of daily use, Wi-Fi off and low brightness. Clara HD has a battery with a capacity of 1500 mAh at 3.7V, which gives a total of about 5.55 Wh. It was already mentioned earlier that energy consumption depends on the specific model and method of use, but it is clear that e-readers are designed for maximum energy efficiency. To calculate for a certain device, reviews by technology portals like CNET, TechRadar, or The Verge can be used, which often include battery life tests: such tests can often provide additional information about the energy efficiency of the device and mention the conditions of use of the device and energy consumption (Wang et al., 2011; Keil & Jossen, 2016; Birkl et al., 2017; Peters et al., 2017; Xu et al., 2016).
Disposal includes emissions associated with recycling, incineration or end-of-life disposal of devices. Factors that affect CO_2-eq emissions in the recycling of e-readers are the collection and transport of the device to recycling facilities and the possibility of separating, processing and recycling different materials (plastics, metals, glass). It is necessary to emphasize that in the calculation it is necessary to consider the energy required for the breakdown of the device and the recovery of the material. According to life cycle studies, recycling of electronic devices can result in emissions of around 2-4 kg of CO_2-eq per device, depending on the type and size of the device and the efficiency of the recycling processes (Dias, Bernardes & Huda, 2018; Peiró, Méndez & Ayres, 2013; Chancerel & Rotter, 2009; Hischier, Wäger & Gauglhofer, 2005; Kissling et al., 2013). When incineration (with energy recovery) is planned at the end of the life cycle, it should be considered whether the mentioned item can generate energy by incineration and whether incineration will emit CO_2 and other greenhouse gases, as would be the case with e-readers. CO_2-eq emissions from incineration of electronic devices vary but can be between 1-3 kg CO_2-eq per device, considering the energy generated during incineration (Oguchi, Sakanakura & Terazono, 2013; Ciacci et al., 2010; Niu & Li, 2007; Li et al., 2007; Jiang, Chen & Liu, 2012). The amount of energy generated will not be crucial, how important is the raw material that can be reused by recycling. E-readers in landfills can emit greenhouse gases during decomposition. CO_2-eq emissions from the disposal of electronic devices in landfills can amount to about 1-2 kg of CO_2-eq per device, depending on the conditions of the landfill and the presence of a gas collection system (Gamberini et al., 2011; Kiddee, Naidu & Wong, 2013; Nixon et al., 2013; Chung & Zhang, 2011; Song, Li & Zeng, 2015). As with the incineration process, it should be noted that the disposal of e-readers in landfills is not sustainable management because the raw material can be reused in the cyclical economy process. Disposal emissions can vary, but the average value is around 3 kg CO_2-eq.
By adding up all the contributions in the individual phases of the life cycle of the e-reader, the total carbon footprint of the e-reader is approximately 183.27 kg CO_2-eq.
Total carbon footprint: 168 + 10 + 0.27 + 3 ≈ 181.27 kg CO_2-eq.
It should be emphasized that carbon emissions depend on the energy source. Each country has a different mix of energy sources, which affects carbon emissions per kWh. According to data from the International Energy Agency (IEA), the global average of CO_2 emissions from electricity production is around 0.475 kg CO_2/kWh.

4. DISCUSSION

When studying the products book and e-reader both involve production processes that require extraction of raw materials, production, assembly and distribution. Although both products have a carbon footprint related to transport to the end user, the specific emissions of transport are different due to the weight of the product, the supply of raw materials over different distances and the transport of finished products over different distances. The raw material for the book can be produced at a shorter distance due to the greater availability of the raw material, i.e. cellulose, than the metals that are needed to make e-readers. Chip production is also tied to fewer locations in the world, so there are often higher emissions when

transporting parts or semi-finished products. Both options have emissions associated with disposal, although the methods and amounts of emissions vary (recycling paper vs. electronic components). The book has no additional shows during reading. The e-reader consumes energy during use. Average consumption is low, but long-term use generates additional emissions due to electricity consumption.
If the e-reader is used to read a large number of books, the emissions per book decrease with the increase in the number of books read.

100 books read on an e-reader: 183.27 kg CO_2-eq / 100 books = 1.83 kg CO_2-eq per book

200 books read on an e-reader: 183.27 kg CO_2-eq / 200 books = 0.92 kg CO_2-eq per book

The carbon footprint of a physical book is approximately 3.6-7.5 kg CO_2-eq per book, while that of an e-reader is initially high (183.27 kg CO_2-eq) but decreases as the number of books read increases. This analysis shows that e-readers become more environmentally friendly as the number of books read increases, while physical books have a constant carbon footprint per book.
Reducing the carbon footprint can be further influenced by lifestyle. Using an e-reader for a longer period reduces the overall carbon footprint because emissions from production are distributed over a larger number of books read. The life of an e-reader can be extended by regular maintenance and repairs of the device instead of replacing it with a new device. Creating good habits when optimizing the combination of reading books and e-readers can further contribute to reducing the carbon footprint. E-readers can be used by those who read often, while physical books are better to use if you rarely read them. Borrowing books from libraries or from acquaintances reduces the need to produce new books and e-readers.
The e-reader should be charged as much as possible using renewable energy sources (solar energy, green energy from the grid) to reduce the emissions associated with electricity consumption. If you reduce the time of using the device when it is not necessary (using sleep mode), a lot of energy will be saved. In addition to the aforementioned, it is important to dispose of the e-reader by recycling to reduce emissions from disposal in landfills. If available, it is recommended to use the device recovery program offered by the manufacturers.

5. CONCLUSIONS

The carbon footprint of books and e-readers varies significantly due to differences in production, use and disposal. E-readers have a larger initial carbon footprint due to complex manufacturing processes but may be more sustainable in the long run if used to read many books. By changing lifestyles, such as extending the life of devices, using renewable energy sources, optimizing reading and responsible disposal, their overall carbon footprint can be significantly reduced.
When reading habits are studied, one can greatly influence the reduction of the carbon footprint. People who read a lot of books may have a larger carbon footprint if they only use printed books. Their carbon footprint could be reduced if people used public libraries or e-readers. The environmental impact of an e-reader is greatly reduced as the number of books read increases, so it is a good option for avid readers. In addition to the active recycling of paper and electronic devices and the use of renewable energy sources for charging e-readers and supporting servers should be encouraged. Buying and selling used books extends their lifespan and reduces the need to produce new books.
At the beginning of product design, the use of recycled or biodegradable materials for e-reader components should be maximized. Recycled plastics can be used to make the case, while recycled metals can be used for internal components. In addition to this, attention should be paid to the easy disassembly of the device for more successful recycling, which supports the zero-waste policy. To reduce the CO_2-eq of transport, logistics should be simplified to reduce the distance and frequency of sending shipments. Such solutions should be combined with the use of low-emission transport such as electric trucks for local deliveries and maritime transport instead of air transport for international transport. E-readers should be designed to be more durable and resistant to damage, which extends their lifespan, and should allow for regular software updates to keep older devices functional and secure, reducing the need for frequent replacements. Optimizing device hardware and software to consume less energy, such as installing energy-efficient displays and processors, can contribute to reducing eCO_2. Customer service can ask users how to use their e-readers more efficiently, such as adjusting screen brightness and using power-saving modes. Return programs for the collection of old devices and proper recycling of e-readers and cooperation with certified e-waste recycling services will contribute to the increase in the recycling of e-reader components. Increasing the availability and variety of digital books will make e-readers a more

attractive option for consumers and reduce their carbon footprint per book copy. Addressing areas of product lifecycle stages that have proven problematic can significantly improve the productivity of e-readers while reducing their carbon footprint.

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THE PARTICULATE MATTER IN THE WORKING ENVIRONMENT OF THE DIGITAL PRINTING MACHINE DETECTED BY STATIONARY AND PERSONAL METHODS

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Abstract: *Particulate matter (PM) emitted during the digital printing process is potentially dangerous in the sense that it penetrates deep into the operator's lungs. The mass concentration levels of PM_1, $PM_{2.5}$, and PM_{10} particles emitted in the working environment of digital machines were measured after applying two sampling methods, spatial and individual. A sensor sampler with an optical particle counter was used for the spatial method, while a personal sampler of particulate materials was applied for the individual process. The paper's primary goal is to assess the comparability of the concentration of PM particles obtained by different sampling methods.*

Key words: particulate matter, digital printing, sensor, optical and gravimetric analysis

1. INTRODUCTION

The indoor air quality can be affected by various harmful contaminants such as carbon monoxide, carbon and nitrogen dioxide, hydrogen sulfide, sulfur dioxide, ammonia, formaldehyde, volatile organic compounds (including benzene, toluene, xylene, etc.), ozone, and PM (Adamović et al., 2022). PM is the most significant pollutant produced by industrial activities (Simões Amaral et al., 2015). To accurately assess the impact of these particles in the working environment, it's essential to determine their concentration and geometric characteristics (Ilić et al., 2014, Ilic Micunovic et al., 2024).

The analysis of PM is a complex process that requires the proposal of different analytical methods depending on the specific requirements and objectives of the research. PM measurement methods are divided into concentration methods such as gravimetric, optical, and microbalance and size distribution methods (microscopical, impaction, diffusion, charging, and complete systems). The gravimetric analysis provides basic quantitative information, while spectroscopy, electron microscopy, and microbalance analysis offer deeper insights into particles' chemical and physical composition. Combining these methods can enable a comprehensive view of the distribution, sources and potential impacts of PM on health and the environment (Simões Amaral et al., 2015).

Gravimetric analysis is a traditional method used to measure the total mass of particulate matter (PM) collected on a filter. This method involves passing air through a filter to trap particles, and then measuring the mass of the particles before and after sampling. Gravimetric analysis is widely used due to its simplicity and accuracy, but it does not provide information on the chemical composition or particle size. For more detailed information regarding these aspects, electron microscopy is recommended (Simões Amaral et al., 2015).

During optical analysis, PM particles are illuminated with a beam of light, during which light is reflected (scattered) from them in all directions while part of the light is absorbed. Optical instruments used to measure the concentration of particles can be based on the principles of light scattering, absorption and extinction (Simões Amaral et al., 2015).

The paper presents the quantitative mass concentration levels of PM_1, $PM_{2.5}$, and PM_{10} particles emitted in the working environment of ink jet digital printing machines. In the spatial method, the particles' mass concentration was detected by optical analysis with a sensor sampler. In contrast, in the individual process, the particles' mass concentration was quantified by gravimetric analysis with the personal sampler. The paper further examines the similarities and differences between the concentrations of PM detected with spatial and personal sampling.

ORCID numbers are provided at the end of the paper.

2. METHODS

2.1. Digital printing environment

The research took place at the printing laboratory of the Department of Graphic Engineering and Design at the Faculty of Technical Sciences in Novi Sad, Serbia. PM mass concentration levels were measured near the ink jet digital printing machine, model LEC-540 (Roland, Japan).

2.2. Analysis of particulate matter

The spatial method, an essential technique in air quality assessment, involves sampling particulate materials in the air using a static sensor sampler. Its strategic positioning at fixed locations is beneficial. In contrast, the individual sampling method, crucial in assessing workers' exposure, is equally important. Placing a personal sampler near the operator's breathing zone ensures occupational health and safety (Ilić Mićunović, 2018).

2.2.1. Sensor sampler

PM particle mass concentration levels were continuously monitored using an optical particle counter OPC-N2 (Alphasense, United Kingdom) sensor sampler. The sensor device is a portable and precise PM monitor known for measuring PM mass concentrations (μg/m³) with high accuracy and real-time data collection. The sensor was strategically placed where significant operator exposure was expected (Adamović et al., 2023).

2.2.2. Personal sampler

The EGO PLUS TT (Zambelli, Italy) personal sampler was used to collect PM particles with a diameter of less than 10 μm. The device consists of a display setting, a conical nozzle equipped with a filter, and a silicone hose. The membrane filters used were ME 27 (KEFO, Slovenia), made from a mixture of cellulose esters with a pore size of 0.8 μm and a diameter of 25 mm. The filter's effective diameter for collecting particles was 22 mm, and it had an effective surface of 380 mm^2. When using a conical attachment for measuring inhalable fractions of PM particles, the manufacturer recommended an airflow rate of 3.5 l/min (Zambelli, Italy). The sampling time was 30 minutes, and measurements were taken within the printing technician's breathing zone, placed on the upper part of the chest (Ilić et al., 2014, Ilic Micunovic et al., 2024).
The mass concentrations of particles with diameters less than 10 μm in the indoor air of digital printing machines were determined using the standard gravimetric measurement method (SRPS EN 12341:2023). To sample PM, a personal sampler collected PM using filter paper placed on the duraluminum filter holder of the sampler. The masses of the filter papers before and after one hour of sampling were measured on an analytical balance, model ABJ-120 (Kern, Germany) with an accuracy of $\pm 10^{-4}$ g. It's worth noting that the filter papers were only touched with a material called pancetta (Adamović et al., 2022).
The mass concentration levels (quantity) of PM particles with a diameter of less than 10 μm in the indoor air near the digital printing machine were determined according to the Equation (1) (SRPS EN 12341:2023, Adamović S. et al., 2022):

$$Q_{PM} = \frac{m_2 - m_1}{V} \cdot 10^6 \quad (1)$$

where:

- Q_{PM} is the quantity of particles less than 10 μm (μg/m^3),
- m_1 and m_2 are the masses of the filter paper before and after sampling (g), respectively, and
- V is the volume of air being passed through the device for 30 min (101,6 m^3).

3. RESULTS AND DISCUSSION

The mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} particles were measured with the sensor sampler before machine operation. The readings showed that there were 2.4 µg/m^3 of PM_1, 3.2 µg/m^3 of $PM_{2.5}$, and 3.7 µg/m^3 of PM_{10} particles in the air before the machine operation. These values indicate that some particle concentration remained in the air after ventilation and that particles from outside migrated into the indoor air of the printing laboratory, which is not isolated from the outside environment. To obtain accurate mass concentrations for the tested machine, the detected mass concentrations of PM particles were adjusted by the detected zero value. Figure 1 illustrates the concentration levels of PM_1, $PM_{2.5}$, and PM_{10} particles during 30 minutes of monitoring using a spatial sampling method with the sensor sampler, showing 8 values with a reading frequency of 4 minutes (Adamovic et al., 2022).

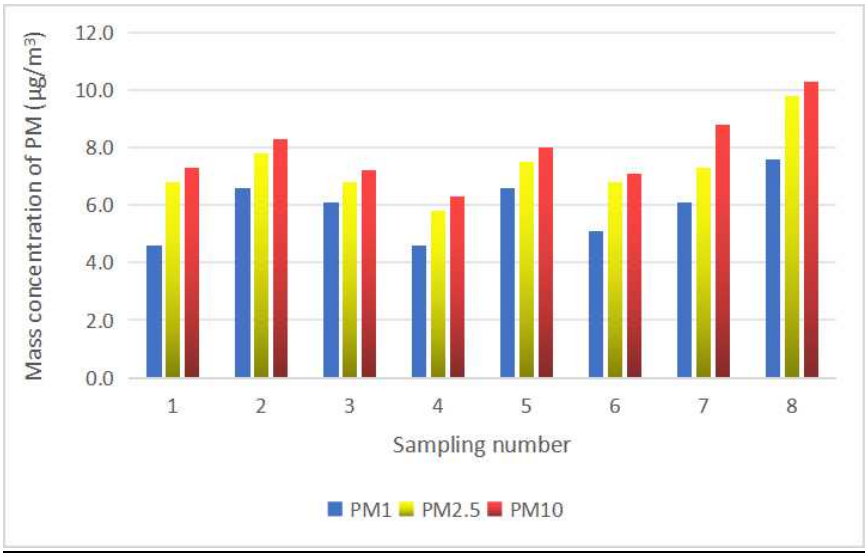


Figure 1: Concentration levels of PM_1, $PM_{2.5}$, and PM_{10} particles detected by spatial sampling with sensor sampler

The spatial sampling method detected concentrations of PM_1 particles in the range of 4.6 to 7.6 µg/m^3 for 30 minutes. The concentrations did not grow exponentially, but a 39.5% increase was observed from the 1st to the 8th sampling.

Over a 30-minute monitoring period using a sensor sampler, $PM_{2.5}$ particle concentrations ranged from 5.8 to 9.8 µg/m^3. There was a 40.8% increase in concentrations from the lowest (detected in the 4th sampling) to the highest value (detected in the 8th sampling).

The mass concentrations of PM_{10} particles during the same 30-minute monitoring period ranged from 6.3 to 10.3 µg/m^3. An increase of 38.8% was observed from the lowest concentration (detected in the 4th sampling) to the highest (detected in the 8th sampling).

After using the personal sampling method, the mass of the filter paper before and after 30 minutes of sampling was 0.0254 and 0.0374 g, respectively. Based on the measured masses and the volume of air passing through the device in 30 min (formula 1), the quantity of PM particles with a diameter smaller than 10 µm was 118.11 µg/m^3.

The results indicate that the mass concentration obtained by personal sampling is 5.6 times higher (an 82% increase) than the cumulative value (21.1 µg/m^3) of M_1, $PM_{2.5}$, and PM_{10} detectable particles with a sensor sampler.

It's important to note that spatial and personal sampling methods may not always produce comparable results. The measurements using personal samplers tend to demonstrate a higher concentration than spatial ones. This has practical implications for air quality monitoring, as it suggests that personal samplers may be more effective in detecting pollutants in certain situations (Ilić Mićunović, 2018). Due to their light weight, size, and the fact that they do not require calibration, passive samplers are preferred over active air pump sensor samplers (Simons et al., 2017).

4. CONCLUSIONS

The results based on spatial sampling indicate that the detected mass concentrations decrease in the following order: $PM_{10} > PM_{2.5} > PM_1$. The concentrations of PM_{10} particles are higher than those of PM_1 particles by 15.3% to 37.0% and more than 4.2% to 17% higher than $PM_{2.5}$ particles. Additionally, concentrations of $PM_{2.5}$ particles are higher than those of PM_1 particles by 10.3% to 32.4%. Also, the cumulative value of PM_1, $PM_{2.5}$, and PM_{10} detectable particles with a sensor sampler was 82% lower than the value detected by the gravimetric analysis after the personal sampler.
In future research, the focus will be on improving methodology and incorporating new methods. For example, using scanning electron microscopy, particles can be characterized by their morphological and size distributions. Drying the filters to a constant mass will eliminate the influence of moisture, leading to more accurate results through gravimetric analysis. Analyzing and optimizing the printing process can enhance the result correlations. Identifying the best position for the devices is crucial for minimizing discrepancies between results obtained from different methods.

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ADSORPTION PROCESS OF CYAN PRINTING DYE ONTO ACTIVATED CARBON: OPTIMIZATION AND KINETIC STUDIES

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Abstract: *The potential use of commercial activated carbon for the removal of water-based phthalocyanine printing dye (Cyan) form aqueous solution was investigated. Screening and optimization of four variables (initial dye concentrations, adsorbent mass, pH of the aqueous solution and reaction time) influencing the adsorption process are performed using a new design of experiments methodology, the definitive screening design (DSD). Maximum removal efficiency of 88.5% for Cyan dye was achieved under following conditions: 32.8 mgL^{-1} of the initial dye concentration, 0.09 g of the adsorbent mass, pH 6 and 20 minutes of the reaction time. The kinetic adsorption modelling followed the Elovich model, indicating monolayer chemisorption process on a heterogeneous adsorbent surface, with possible van der Waals interactions, hydrogen and halogen bonding, as an integral part of adsorption mechanisms of printing dye on activated carbon.*

Key words: Cyan dye, activated carbon, adsorption, optimization, kinetic models, mechanism

1. INTRODUCTION

Synthetic organic dyes are becoming increasingly important in most industries, including paper, plastics, pharmaceuticals, cosmetics and textiles, due to their ease of synthesis and speed of production, their stability and variety of colours (Boulika et al., 2023; Nabih et al., 2023; Rožić et al., 2023; Adamović et al., 2022). Organic dyes owe their colour to the content of certain chromophores, which are mainly acidic and basic functional groups. These dyes are carcinogenic, mutagenic and highly toxic to humans and aquatic organisms. They can also reduce light transmission and interfere with photosynthesis, which can disrupt the ecological balance, and they can break down into toxic, mutagenic or carcinogenic compounds that damage the aquatic body (Raji et al., 2023; Reddy et al., 2023). Due to their high stability and low biodegradability, wastewater containing such dyes can cause various problems leading to visual and chemical pollution. Therefore, it is important to remove these dyes from wastewater or treat it in a way that minimizes its impact on the environment (Boulika et al., 2023).

To resolve these problems, different conventional techniques for water treatment have been proposed, including coagulation-flocculation (Ihaddaden et al., 2022), electrochemical degradation (Abo-Ayad et al., 2024), photocatalysis (Zhao et al., 2024), biodegradation (Das et al., 2021), membrane filtration (Hou et al., 2023) and chemical oxidation (Neto et al., 2024). Some of these techniques, although effective, are restricted by secondary waste, expense, or complexity (Suhaimi et al., 2022). Among them, adsorption technology is widely recognized as an important way to remove pollutants due to several technical merits: ease of implementation, high efficiency, low material and operating costs, high performance and the ability to treat different dye concentrations (Raji et al., 2023; Suhaimi et al., 2022). On the other hand, the adsorption technique depends on the performance of a particular adsorbent for different types of dyes (Reddy et al., 2023).

Currently, different type of adsorbents like: composites (Cui et al., 2024), nanoparticles (Ali et al., 2024), polymers and resins (Elabboudi et al., 2023), clays and minerals (Cigeroglu et al., 2024), biochar (Mancuso et al., 2024), and biosorbents (Elboughdiri et al., 2024) are used for removal of dyes. Among the various adsorbents, activated carbon is emerged as the most commonly and widely utilized adsorbent due to its outstanding properties like adsorption capacity, microporous, high surface area, abundant functional groups, thermal and radiation stability (Reddy et al., 2023). In view of that, activated carbon can be used as a commercial product, or can be prepared from ubiquitous, inexpensive, and renewable precursors, such as rice husk (Zhang et al., 2023), moringa oleifera seed husk (Escobar et al., 2021), date palm waste (Arangadi et al., 2022), grass (Tu et al., 2021), pineapple leaves (Arumugasamy et al., 2022), pomegranate peel (Saadi et al., 2022), banana peel (Tripathy et al., 2021), and coconut shells (Widanarto et al., 2022).

The objective of this study is to investigate the effectiveness of commercial activated carbon for the removal of Cyan printing dye, by screening and optimizing the factors influencing the adsorption process, in order to obtain a maximum removal rate. Furthermore, the adsorption kinetics and mechanism are examined by using the pseudo-first and pseudo-second order models, as well as the Elovich model.

ORCID numbers are provided at the end of the paper.

2. MATERIALS AND METHODS

2.1 Materials and chemicals

The used chemicals and reagents were: synthetic solution of Cyan flexographic dye (Flint group), activated carbon (AC, Norit Row 0.8 Supra), sodium hydroxide (>98.8% POCH, Poland), hydrochloric acid (>96%, J.T. Baker - Fischer Scientific, USA), deionized water. Figure 1 shows the molecular structure of Cyan dye (Phthalocyanine type, C.I. PB15:3, CAS number: 147-14-8, λ_{max} = 636 nm) and Table 1 presents certain physico-chemical properties of activated carbon.

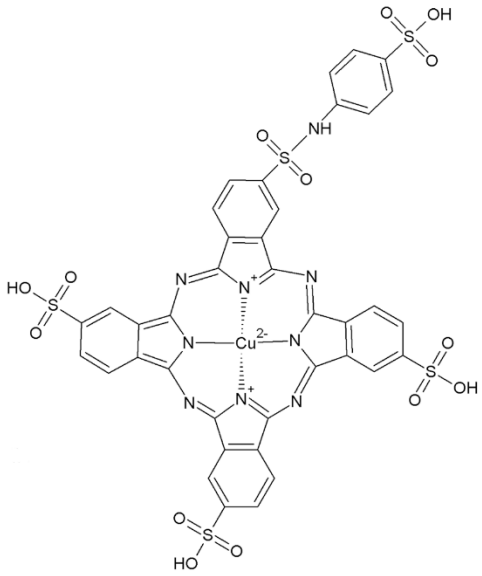


Figure 1: Chemical structure of Cyan dye

Table 1: Physico-chemical properties of activated carbon

Characteristic	Value
Iodine number (mgg^{-1})	1050
Specific surface area (m^2g^{-1})	1150
Ash content (%)	7
Moisture content (%)	2
pH_{PZC}	4.6
Density (kgm^{-3})	390

2.2 Experimental design

In order to optimize the experiment and to identify significant variables and eliminate irrelevant variables, a new generation statistical method, Definitive Screening Design (DSD), was used (Mohamed et al., 2017). DSD provides a compelling balance between the number of variables to be modelled and the number of experiments to be performed, with an ability to detect main, interaction, and quadratic effects without the need for effect aliasing (Boulika et al., 2023). The influence of four process parameters was studied: initial dye concentration (20, 100 and 180 mgL^{-1}), adsorbent mass (0.01, 0.055 and 0.1 g), pH (2, 6 and 10) and reaction time (1, 30.5 and 60 min). The selected software JMP 13 (SAS Institute, USA) was used for the experimental design and the complete statistical processing of the obtained results. The optimization of the adsorption treatment using the statistical DSD method with the selection of process parameters combination enables the achievement of the highest efficiency of adsorption process.

2.3 Adsorption experiments

Synthetic solution of Cyan dye was obtained from one flexographic printing facility in Novi Sad. A certain mass of activated carbon (0.01 - 0.1 g) was added to a 50 mL of sample volume of synthetic dye solution (concentration of 20 - 180 mgL^{-1}) and the pH value of the reaction medium was adjusted (2 - 10) with the addition of HCl (0.1 M) or NaOH (0.1 M) solution. The experiments were carried batchwise at room temperature (23° C), at a stirring speed of 240 rpm (IKA® Orbital shaker KS 130 Digital) with the estimated time (1 - 60 min), to ensure good dispersion of the solid particles of the activated carbon. After mixing, the samples were filtered through a cellulose acetate membrane filter with a porosity of 0.45 mm, and the absorbance of the solution was determined using a UV/VIS spectrophotometer (Genesys 10S, Thermo Fisher) (Tubić et al., 2023). The residual dye concentration was established immediately by measuring the absorbance of the aqueous solutions at 636 nm and the efficiency of adsorption treatment was calculated according to Equation (1):

$$E(\%) = A_0 - A/A_0 * 100 \quad (1)$$

where: A_0 is the initial absorbance of the aqueous solution sample before adsorption treatment and A is the absorbance of the aqueous solution sample after adsorption treatment.

2.4 Kinetic experiments

The adsorption kinetics and the mechanism of adsorption of Cyan dye on activated carbon were studied in a batch mode at room temperature (25°C) in laboratory conditions. In these experiments, the volume of the synthetic aqueous matrix was 50 mL, and the initial dye concentration was 100 mgL^{-1}. A dye concentration of 100 mgL^{-1} was selected for the adsorption kinetic experiments due to the Cyan dye concentration detected in printing wastewater samples, which was 94.16 mgL^{-1} (Tubić et al., 2023). A mass of 0.1 g of activated carbon was chosen based on the literature data (Raji et al., 2023). Complete suspension mixing was achieved using a digital mixer IKA® Orbital shaker KS 130 Digital) at 150 rpm at room temperature (25°C). The change in the concentration of the printing dyes after defined contact periods with the activated carbon (10 min, 30 min, 1, 2, 3, 5, 24 h) and filtration through a 0.45 µm cellulose acetate membrane filter was monitored using a UV/VIS spectrophotometer (Genesys 10S, Thermo Fisher).
The adsorption kinetic model could determine the relationship between adsorption time and adsorption capacity and could be used to analyze the adsorption mechanism of printing dye on activated carbon. The pseudo-first-order kinetics (Equation 2) and pseudo-second-order kinetics (Equation 3) and the Elovich model (Equation 4) were used in this study (Boulika et al., 2023; Li et al., 2021).

$$log(q_e - q_t) = logq_e - \frac{K_1}{2.303}t \quad (2)$$

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e} \quad (3)$$

$$q_t = \frac{1}{\beta} ln(\alpha\beta) + \frac{1}{\beta} ln\,(t) \quad (4)$$

where: q_e is the unit adsorption capacity of printing dye at adsorption equilibrium ($\mu g g^{-1}$), q_t is the unit adsorption capacity of printing dye at any time ($\mu g g^{-1}$), K_1 is the pseudo-first-order kinetics rate constant (1/h), K_2 is the pseudo-second-order kinetics rate constant (g/(µg·h)), α is the initial adsorption rate (mg/g·min), β is the desorption constant (g/mg), and t is the reaction time (min).

3. RESULTS AND DISCUSSIONS

3.1 Optimization of the adsorption process

Table 2 shows the 4-variable DSD matrix and obtained adsorption process efficiencies (%) for 15 experimental runs. The efficiency ranges from 11.53 to 83.78%, whereby it was found that the maximum and minimum decolorization efficiency during the adsorption treatment is achieved under different process conditions, which confirms the assumption that the dye removal process mainly depends on the applied experimental conditions.

Table 2: Experimental design layout and obtained adsorption efficiency

Experimental run	Dye concentration (mgL^{-1})	Adsorbent mass (g)	pH	Reaction time (min)	Adsorption efficiency (%)
1	100	0.1	10	60	11.53
2	100	0.01	2	1	51.40
3	180	0.055	2	60	35.18
4	20	0.055	10	1	81.08
5	180	0.01	6	1	47.04
6	20	0.1	6	60	79.73
7	180	0.1	2	30.5	79.05
8	20	0.01	10	30.5	39.19
9	180	0.1	10	1	71.74
10	20	0.01	2	60	59.46
11	180	0.01	10	60	59.68
12	20	0.1	2	1	83.78
13	100	0.055	6	30.5	63.86
14	100	0.055	6	30.5	66.36
15	100	0.055	6	30.5	67.60

Prediction profiler with optimal settings is shown in Figure 2. The optimization plot graphically illustrates how the adsorption process efficiency changes as a function of one of the variables, while all other variables remain constant. According to optimization results, maximum adsorption process efficiency of 88.5% is obtained for the following process conditions: 32.8 mgL^{-1} of Cyan dye concentration, 0.09 g of adsorbent mass, pH 6 and reaction time of 20 minutes.

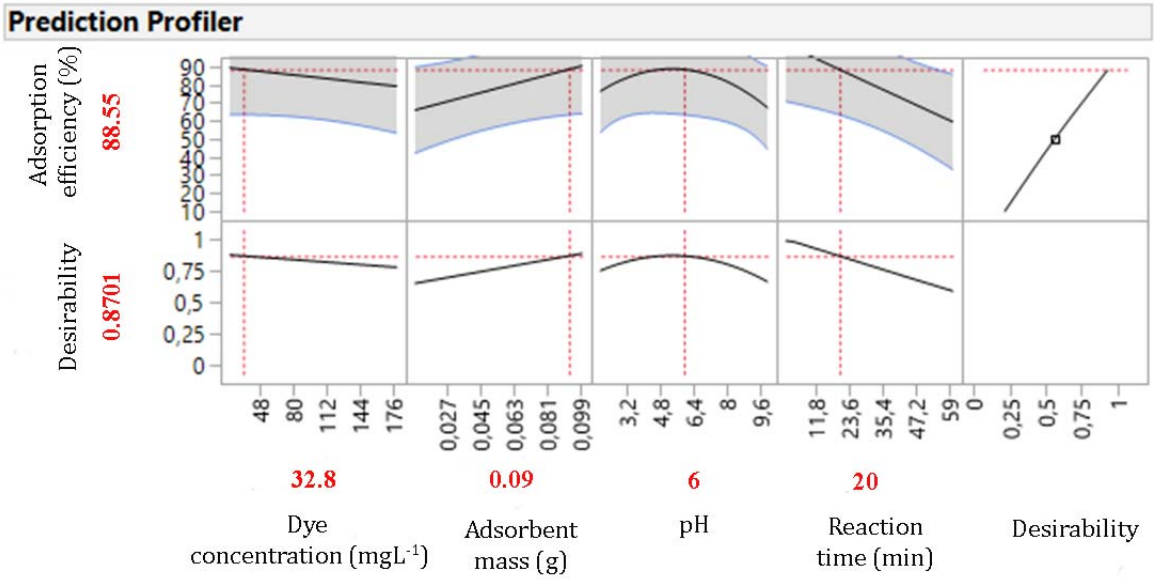


Figure 2: Optimization diagram

The optimization diagram clearly shows the strong influence of adsorbent mass, pH value and reaction time on the performance of the adsorption process. The results obtained confirm that the adsorption efficiency increases with increasing adsorbent mass and decreasing reaction time, due to the initially high number of free active sites, and finally to the coverage of the active sites by adsorbed dye molecules (Tubić et al., 2023).

3.2 Kinetics of adsorption

In order to analyze the Cyan adsorption behaviour on activated carbon, three kinetic models were used: pseudo-first order, pseudo-second order and Elovich model. The modelling curves are presentend in Figure 3. Based on the linear equations, the values of the pseudo-first-order (K_1) and pseudo-second-order (K_2) kinetics rate constants, the adsorption capacity at equilibrium (q_e), the initial reaction rate (h) for the adsorption of prinitng dye on activated carbon, the initial adsorption rate (α) and the desorption constant (β) were determined (Table 3).

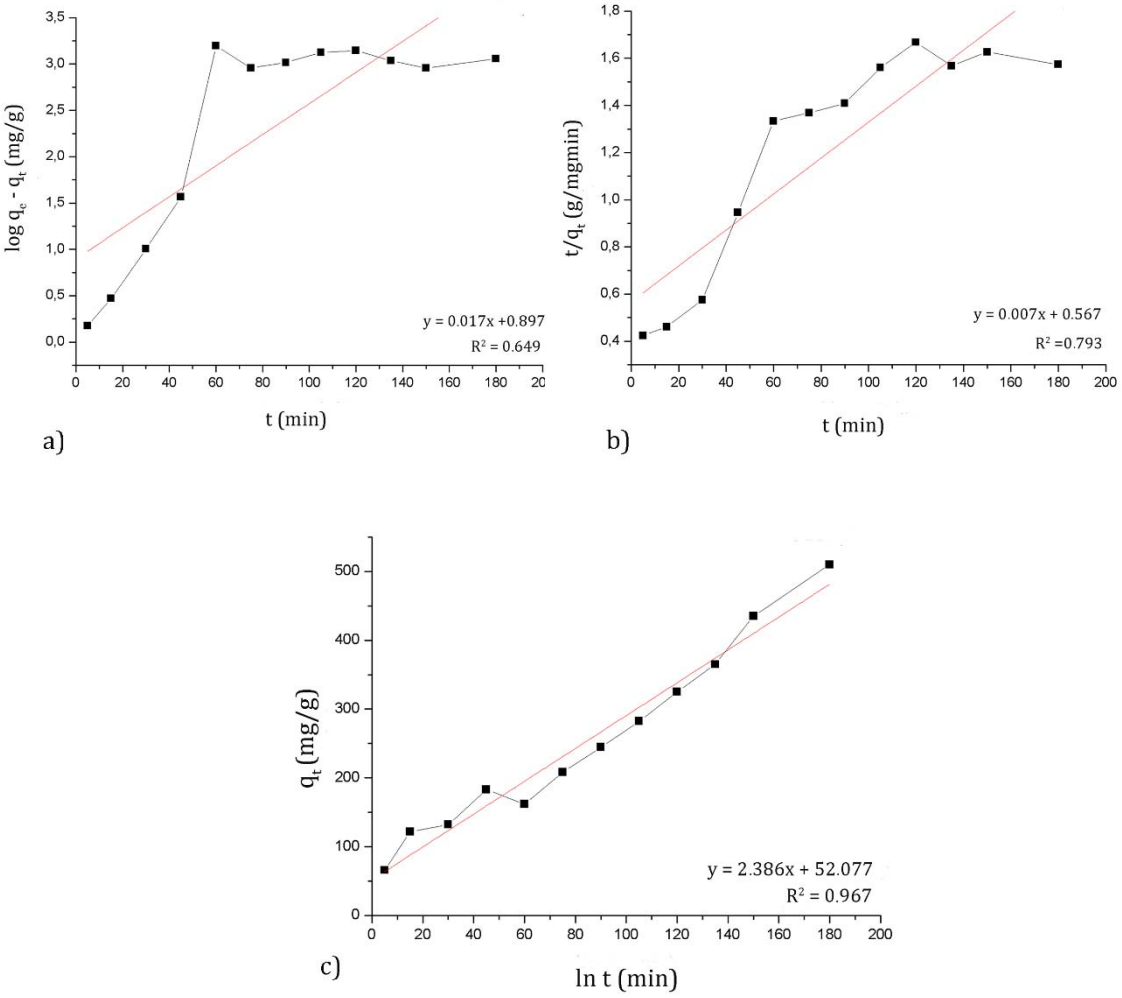


Figure 3: The plots of modelling experimental data: a) pseudo-first order, b) pseudo-second order, c) Elovich model

Table 3: Parameters of kinetic models for the adsorption of Cyan dye on activated carbon

Pseudo-first order			Pseudo-second order			Elovich		
K_1 (h^{-1})	q_e (µg/g)	R^2	K_2 (g/µg h)	h (µg/g h)	R^2	α (µg/gh)	β (µg/g)	R^2
1.33	409.7	0.649	0.0036	689.69	0.793	$2.28E^{+04}$	0.024	0.967

The obtained values of the coefficients of determination (R^2) leads to the conclusion that Elovich model (R^2 = 0.967) is best suited to describe the adsorption kinetics. The Elovich model is based on the assumption that the surface of the adsorbent is energetically heterogeneous an that chemical interactions occur in the activated carbon/prinitng dye system, which is primarily a consequence of the presence of numerous functional groups on the surface of the activated carbon that have a high affinity to the dye (Tang et al., 2021; You et al., 2021; Atugoda et al., 2020). The adsorption mechanism of Cyan dye onto the activated

carbon surface is probably accomplished by a variety of mechanisms including van der Waals interactions, hydrogen bonding and halogen bonding interactions (Tubić et al., 2013). Furthermore, Elovich model is related to the kinetic principle which assumes that adsorption decreases with time, due to the coverage of the active sites by adsorbed dye molecules (Ayawe et al., 2017), which is in accordance with the optimization diagram (Figure 2).

4. CONCLUSIONS

Commercial activated carbon was applied as adsorbent to remove water-based phthalocyanine printing dye (Cyan) form aqueous solution. In order to quantify and elucidate the effects of the influencing factors (initial dye concentrations, adsorbent mass, pH and reaction time on the removal rate of Cyan dye) definitive screening design was used to estimate the linearity of the effects. 32.8 mgL^{-1} of the initial dye concentration, 0.09 g of the adsorbent mass, pH 6 and 20 minutes of the reaction time led to the best Cyan dye removal (88.55 %), according to the desirability function. Cyan adsorption kinetics and equilibrium adsorption data show that the process is chemisorption onto a heterogeneous surface. Three kinetic models (the pseudo-first-order, the pseudo-second-order and Elovich) were evaluated in order to validate experimental facts about sorption mechanisms and identify potential reaction processes that control the adsorption mechanism. The adsorption mechanism implies chemical binding with several binding forces, such as hydrogen bonding, halogen bonding and van der Waals interactions, that may be involved in the adsorption of printing dye on activated carbon.

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GREEN RECYCLING OF TONER PRINTED PAPERS BY ENZYME DEINKING

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Abstract: *The basic printing material of the printing industry is paper. The paper industry uses trees as a source of raw materials. Due to the increasing need and the environmental effects of tree cutting, recycling of used papers, deinking and making papers reusable are among the popular study subjects. The chemicals used in traditional deinking processes are highly toxic. For this reason, environmental protection, which is one of the main reasons for recycling, cannot be adequately achieved with this method. In studies carried out for this purpose, environmentally friendly enzymatic ink removal methods can be used. The enzymatic deinking process is preferred because it has advantages such as high efficiency, low environmental impact, less harmful chemicals needed to achieve equal gloss, better strength, as well as a lower carbon footprint. One of the printing areas where paper is used most in daily life is the products printed with personal printing machines. In this study, it is aimed to print it with a desktop digital printing machine and deink it with amylase enzyme. In this sense, prints were made on 80g/m2 UPM office papers with black toner. Unprinted papers and printed papers were first chemically deinked according to the Ingede 11 method. Then, treatment with enzyme was added to the system as a secondary cleaning method. The amount of amylase enzyme used is 150 FPU/100 g paper. After the deinking process, filter papers were produced. The surface properties, colour, brightness, amount of contamination and amount of recycled ink of the produced papers were determined. Papers with only chemical deinking and those with additional enzymatic treatment were compared. As a result, it was concluded that cleaner papers were obtained with additional treatment with enzyme.*

Key words: Deinking, Amylase, Green Recycling, Paper

1. INTRODUCTION

With the rapid consumption of natural resources, the problem of eliminating waste has also emerged. In order to solve this problem, new methods have been tried to be found for reducing or evaluating waste. (Lüy, Varınca & Kemirtlek, 2007). In proportion to the increasing population in our world, wood fibre resources are decreasing and paper recycling is gaining great importance. Waste paper constitutes the largest portion of solid waste. Paper, which was previously destroyed by burning, has caused great harm to the world economy. Paper recycling has been widely used since the 1970s with the discovery of deinking. (Faul, 2010). Thanks to paper recycling, wastewater and carbon dioxide emissions are reduced, and energy savings reach up to 70%. (Yılmaz, 2024). It is important to use quality fibres in paper recycling. This is possible by completely separating the ink from the fibres. The ink that is to be removed from the fibres is separated with different processes. (Sežun, Karlovits & Kavčič, 2023). In the washing method, unwanted non-fibre materials are also removed along with ink removal. While the paper pulp is being purified from ink, they are examined under two main headings as disperse or non-disperse according to their status in the solution. In disperse materials, unwanted non-fibre materials and ink are removed from the pulp in the form of small particles by washing. Non-disperse ink can be seen in the recycled and prepared paper as small particles. In order to prevent this, a multi-stage washing process should be carried out. Flotation, washing and bleaching are methods of removing ink from paper. The basic principle of the flotation method is to give air to the prepared paper pulp and thus to obtain clean fibre particles by allowing the ink particles attached to the air bubbles to rise to the surface. The most common method, the flotation method; It is used in the production of papers used in health and personal care, office paper, magazine and newspaper paper. (Sahin, 2016). Chemicals such as NaOH, Na_2SiO_3, NaOH and surfactants are substances used in traditional deinking processes. Chemicals are pollutants in deinking and also reduce the strength of the paper fibre and cause waste. (Malhotra & Chapadgaonkar, 2023). With the increase in office paper usage, these separation processes using toxic chemicals are harming the environment. With the increase in environmental awareness, the need to use environmentally friendly materials instead of chemical toxic substances used to remove ink from paper in recycling technologies has also increased. For this reason, it is necessary to protect the environment by using different surface active substances that do not harm the

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environment. (Pimenta, 2023). Another method is to remove unwanted substances that could not be removed by washing and flotation by bleaching. Some of these bleaching chemicals are hydrogen peroxide and sodium hypochlorite. In recent years, instead of traditional deinking with chemicals, enzymatic deinking has begun to be used. It has been observed that deinking with enzymes further improves physical and optical properties such as tensile strength, whiteness, brightness, opacity, drainage speed and reduces the amount of ink residues. Among the enzymes that replace harmful chemicals, xylanase, lipase, cellulase and laccase are the most commonly used ones (Cicekler & Tutus, 2020). The aim is to separate all unwanted materials except fibre from the pulp. There are standards developed by the International Association of the Inking Industry (IGNEDE) to determine the deinkability. The IGNEDE 11 laboratory test is used to measure the deink removal efficiency of the flotation cell in the paper-ink combination at defined dimensions. However, the deink removal efficiency can be evaluated with this test using alkaline pulp without the need for bleaching and washing under deink conditions (Cicekler & Tutus, 2020). In this study, office papers were printed with black toner and the ink was chemically removed from the pulp using the IGNEDE 11 method. Then, enzyme purification was performed and filter papers were produced. The physical and optical parameters of the produced filter papers were measured. Papers obtained with different processes were compared.

2. MATERİAL AND METHODS

2.1 Materials

Office paper (80 g/m^2) was purcased from Sodium dodecyle sulphate,amylase (≥500 units/mg protein) and other chemicals obtained from sigma aldrich.

2.2 Methods

Firstly In the this study test prints were made on uncoated 80 g/m^2 office paper with Canon F166400 black toner-based laser digital printer (Figure 1).



Figure 1: Black toner printed papers

After printing, the papers were kept for 2 years. Then, the printed papers were torn into small pieces of 20 mm x 20 mm and kept in airtight plastic bags for 1 day. Then, the papers were pulped using sodium hydroxide 0.6%; hydrogen peroxide 0.7%; sodium silicate 1.8% and oleic acid 0.8% according to the standard İNDEGE method 11 p (Figure 2). method. Sodium hydroxide was used to swell the ink on office papers and separate them from the fibres, hydrogen peroxide was used to whiten the papers without yellowing, sodium silicate was used to loosen the ink particles on the fibres and prevent them from accumulating on the fibres again, and oleic acid was used to capture the ink particles removed from the fibres and carry them to the surface.

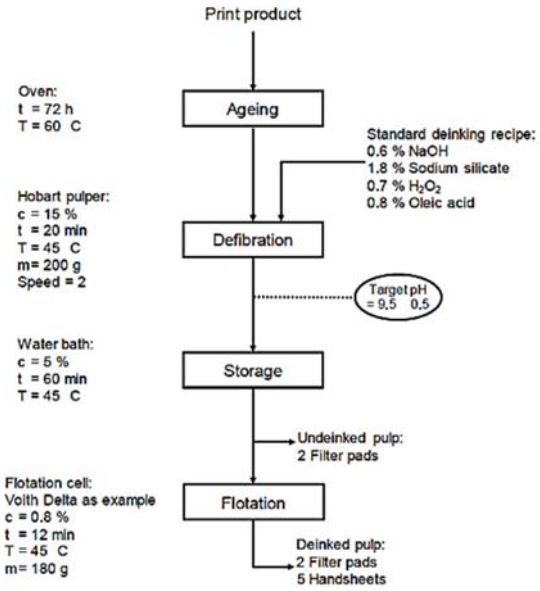


Figure 2: Flow chart of INGEDE method 11p

The pulping process was carried out in two stages. 103.11 g (completely dry) pulp was used in each stage. The pulping process was carried out at 250 rpm speed, for 20 minutes and at 15% concentration at 45 °C. Half of the pulp was separated and 0.2% amylase enzyme was added to the pulp and it was shaken at 45-500°C for 2 hours at pH 7. Then, 0.15% sodium dodecyl sulphate was added to make the ink released into the medium easier to separate (Figure 3). After the shaking continued for another 15 minutes, the flotation process was started.

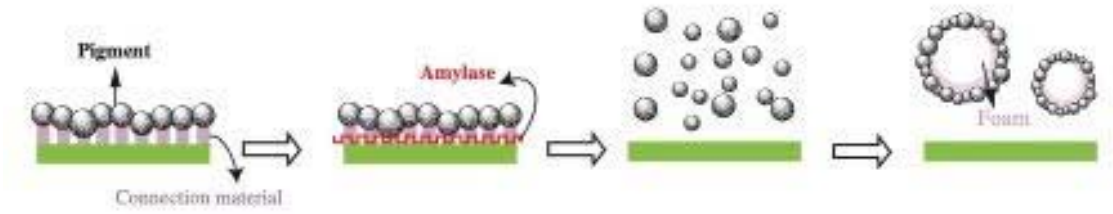


Figure 3: Deinking mechanism diagram of amylase and SDS

In the flotation process, the system with 1% concentration was operated at 45°C., 1450 rpm and 10 minutes. The air pressure was set as 0.566 m^3/min. While the flotation cell was operating, the dirty foamy part formed on the surface was scraped off at certain intervals with the apparatus on the system. After the flotation process, the deinked pulp with 1% concentration was filled into the inner chamber of the device at certain intervals and the waste water was left to flow out of the sieve on its own (Figure 4).



Figure 4: Flotation cell image

Then, the pulp remaining in the inner chamber was squeezed to ensure that the concentration reached around 30-32%. The high concentration pulps were placed in polyethylene bags and stored in a refrigerator at ¬16°C for further processing. The standard raw material preparation method was applied to obtain the pulps as an aqueous suspension. Then, standard laboratory test papers were made from pulp suspensions of known concentration. In the production of hand papers, the Tappi T 205 sp-06 standard was used in the Standard British Handsheet Former device. In the production of handsheets on the Standard British Handsheet Former, at least 6 test papers were made for each trial of each pulp, and the water was removed between the drying discs and absorbent blotter papers in the laboratory press at 80 PSI pressure for 40 seconds and then completely dried in the drying cylinder. The papers obtained were conditioned in a controlled room at 23±1°C and 50±2% relative humidity in accordance with the Tappi T 402 om-88 standard for at least one day. The optical properties of the obtained base paper (BP), base paper subjected to deinking (DBP), defibrillated non-flotation printed paper (UPP), enzyme-treated deinking printed paper (EDPP) and only deinking printed paper (DPP) samples were determined. Colour, whiteness values were measured using the X-Rite eXact spectrophotometer according to the colour ISO 12647-2:2013. The measurement conditions were carried out according to the relevant appropriate standards. The difference between the colours of the different prints were calculated according to the CIE ΔE 2000 colour difference Equation (1) ISO 11664-6:2014. Calculations were made by taking the average of five measurements. ΔL*, Δa*, Δb*: Difference in L*, a*, and b* values between specimen colour and target colour. Lightness is represented by the L* axis which ranges from white to black. The red area is connected to the green by the a* axis, while the b* axis runs from yellow to blue.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'\ \Delta H'}{k_C S_C k_H S_H}} \quad (1)$$

where ΔL*, ΔC*, and ΔH* are the CIEL*a*b* metric light- ness, chroma, and hue differences, respectively, calculat- ed between the standard and sample in a pair, ΔR is an interactive term between chroma and hue differences. The SL, SC, and SH are the weighting functions for the lightness, chroma, and hue components, respectively. The values calculated for these functions vary according to the positions of the sample pair being considered in CIEL*a*b* colour space. The kL, kC, and kH values are the parametric factors to be adjusted according to different viewing parameters such as textures, backgrounds, sep- arations, etc., for the lightness, chroma, and hue compo- nents, respectively. All paper's glosses were measured with BYK Gardner GmbH BYK Gardner GmbH micro Tri-gloss 60° geometry in accor- dance with ISO 2813:2014. The surface properties of the produced papers were determined by scanning electron microscope (SEM) (Phillips XL 30 ESEM-FEG). Bio based papers were cryo-fractured with liquid nitrogen. Fractured films surfaces coated with gold before SEM imaging. In addition, the surface structure and cleanliness of the papers were examined by LEİCa optical microscope at 2.5 magnification. The obtained papers were printed using Micheal Huber München magenta oil based ink with the help of IGT C1 under a printing pressure of 300 newtons and the obtained prints were subjected to the above examinations.

3. RESULTS AND DISCUSSION

Generally, traditional chemical deinking uses alkaline pulping. Although composite surfactant can effectively disperse ink particles in the fibre, deinking uses NaOH, Na_2SiO_3, EDTA, H_2O_2 and other chemicals, which not only increases the cost of deinking, but also leads to serious chemical pollution in wastewater and increases the cost of wastewater treatment. In addition, the presence of these chemicals can damage the fibres, reduce the quality of the fibres, and reduce the number of fibres recycled. In addition, the use of surfactant can help remove ink. the surfactant itself can adsorb on the surface of the ink to reduce the surface tension of the ink and promote the emulsification and dispersion, which is favourable for the removal of ink and prevents the redeposition of ink via dispersion. In this study, SDS, one of the most widely used surfactants, was used and it was determined that it provided effective separation. As seen in Figure 3, the deinking process performed with amylase leaves fewer toner particles than other processes, which is an indication of this. In this study, laser printed papers were evaluated on account of deinkability by using enzyme and chemical process. In order to evaluate the enzyme influence, chemically deinked samples were used as control samples. Papers were produced again from the obtained fibres. The image of the produced papers is given in Figure 5.



Figure 5: Papers produced using chemical process and enzymatic process (Enzyme treated deinking printed paper (EDPP), chemical deinking printed paper (DPP), Defibrillated undeinking printed paper (UPP), deinking base paper (DBP) respectively)

When Figure 5 is examined, it is seen that the paper that was subjected to only deinking processes without any printing on the base paper is visually and tactilely more stable than all other papers, as expected. When the other papers are examined, it is determined that the paper subjected to enzymatic deinking gives the closest visual effect to the paper produced in the recycled form of the base paper, but has a smoother surface in terms of touch. It is concluded that the printed paper that was not subjected to deinking looks the dirtiest and the ink particles are not separated. When they are ranked among themselves, it is determined by eye that there is ink separation as paper produced with enzymatic deinking, paper produced only with chemical deinking and paper that has not been deinked at all. In addition, the deinking rates of the produced papers are calculated according to Equation (2).

$$Deinking\ ability = \frac{Brightness\ of\ the\ treated\ sample - Brightness\ of\ the\ untreated\ sample}{Brightness\ of\ the\ untreated\ sample}\ x\ 100 \quad (2)$$

When calculating deinking abilities, the brightness of newly produced papers was used as treated sample and base paper without any treatment was used as untreated sample. Accordingly, for enzyme applied deinking applied printed paper (EDPP), chemically deinking applied printed paper (DPP), defibrillated undeinking printed paper (UPP), deinking applied base paper (DBP) it was found as 6.8; 4.6; 2.14; 0.34 respectively (Figure 6). This result also gives us the conclusion that enzyme treated paper has a better deinking ability than papers with only chemical deinking and without deinking, parallel to the result with visual effect.

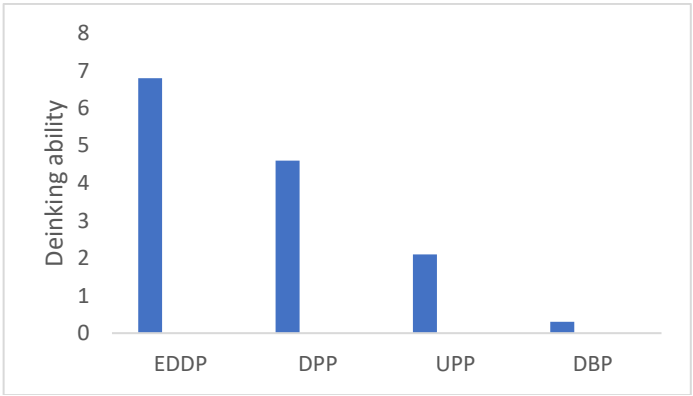


Figure 6: Deinking ability of produced papers

The colour, gloss and printability properties of the produced papers were examined and are given in Table 1. When the gloss values were examined, the gloss was the lowest in the enzyme added recycling. This was due to the principle of amylase deinking, where the enzyme hydrolyzes the resin binder in the ink and separates the ink from the fibres. In the chemical method, some decrease in gloss is due to the protonation of the resin particles. The gloss changed less in the other two recycled papers. When the colour values are examined, the base paper that has not been recycled in unprinted papers is used as a reference. When the unprinted papers are examined among themselves, it is seen that the difference is due to the L and b values. The decrease in the L value is due to the toner particles found as residue in the processed paper. When the

enzyme and unprinted recycled papers are examined, it is determined that the L value is closest to the reference. This shows that the best deinking is performed with enzymes. There is a blue shift in the b values of all papers subjected to the deinking process. The reason for this is that the resin used as a binder in the paper is removed with the processes performed, and accordingly, the colour changes occur. The most change is seen in the enzyme-treated papers as expected from gloss, while the least change occurs in unprinted papers. When the colour differences are examined, it is clearly seen that the lowest difference is in the unprinted processed paper. It has been determined that the main reasons for the colour differences are the blue shifts originating from the resin removal and the filler material removed from the environment. The CIE whiteness is a measurement of the light reflected by the paper across the visible (daylight) spectrum. The CIE have set a standard of D65 illumination which is a standard representation of outdoor daylight under which the amount of light reflected is measured. For a perfect reflecting, non-fluorescent white material, the CIE whiteness would be 100, however most 'white' paper will increase CIE whiteness measures up to 100-140 due to the addition of Optical Brightening Agents (OBAs) which are designed to reflect light from the non-visible range (mainly ultra-violet) back in the visible spectrum. When the whiteness values are examined, it can be concluded that the whiteness value of the untreated paper is over 100 and therefore contains optical brighteners. It has been observed that the whiteness value increases the most in papers that have been subjected to enzyme and chemical deinking processes. This can be concluded that the filler in the paper is removed from the paper environment by the processes, but the optical brightener cannot be removed, thus increasing the CIE whiteness of the paper. It has been determined that the least change in whiteness is in unprinted paper.

Table 1: Colour, gloss and printability properties of the produced papers

	L	a	b	Gloss	Whiteness (CIE)	Opacity	Delta E (ΔE)
Base paper	94,00	1,38	-5,88	95,76	109,89	0,92	REF
Unprinted EDPP	93,07	2,67	-11,67	89,53	129,77	0,91	6,00
Unprinted DPP	90,87	2,26	-10,31	91,26	114,14	0,91	5,50
Unprinted UPP	90,90	2,37	-10,10	94,38	110,11	0,91	5,33
Unprinted DBP	93,89	1,64	-9,40	94,34	109,92	0.92	3,53
Printed EDPP	54,66	57,55	0,72		Not measured	Not measured	0,95
Printed DPP	54,10	56,18	1,21		Not measured	Not measured	1,75
Printed UPP	52,91	56,72	2,37		Not measured	Not measured	2,11
Printed DBP	53,76	57,84	0,79		Not measured	Not measured	REF

All papers produced were successfully printed and the results obtained were parallel to unprinted papers. However, colour differences were significantly reduced. This shows us that the ink tolerates colour differences.

When the opacity results in Table 1 were examined, it was determined that there was no noticeable difference between the opacity values. The results are consistent with the literature. (Lasheva et al, 2016) Tensile strength depends on the amount and strength of the binding forces between the fibres in the finished paper sheet. When Figure 7 is examined, it is determined that the chemicals and enzymes used in the produced paper reduce the binding and therefore the tensile strength decreases, but this decrease is quite small.

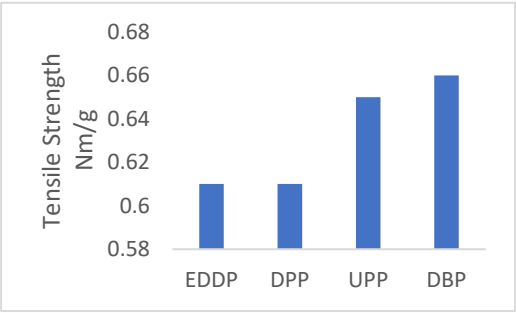


Figure 7: Tensile strength of produced paper

The bursting resistance of the produced papers is shown in Figure 8. The bursting resistance depends primarily on the structure of the paper samples obtained. In the examinations, it was concluded that the processes performed did not change the bursting resistance of the paper noticeably.

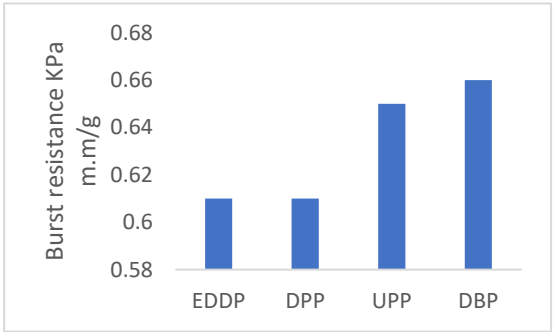


Figure 8: Burst resistance of produced paper

Tear resistance depends primarily on the strength of the nature of the fibres that make up the paper obtained. As shown in Figure 9, it was determined that flotation did not cause much change in the fibre length and nature of the fibres and had the highest tear resistance. Since the fibres were slightly shortened by chemical or enzymatic treatments, a small decrease in tear resistance occurred. The produced papers were examined with SEM and optical microscope. SEM images are given in Figure 10.

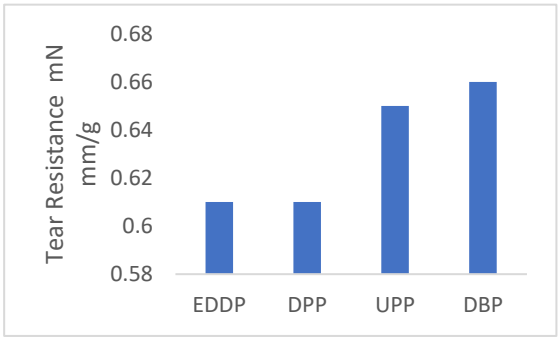


Figure 9: Tear resistance of the obtained paper

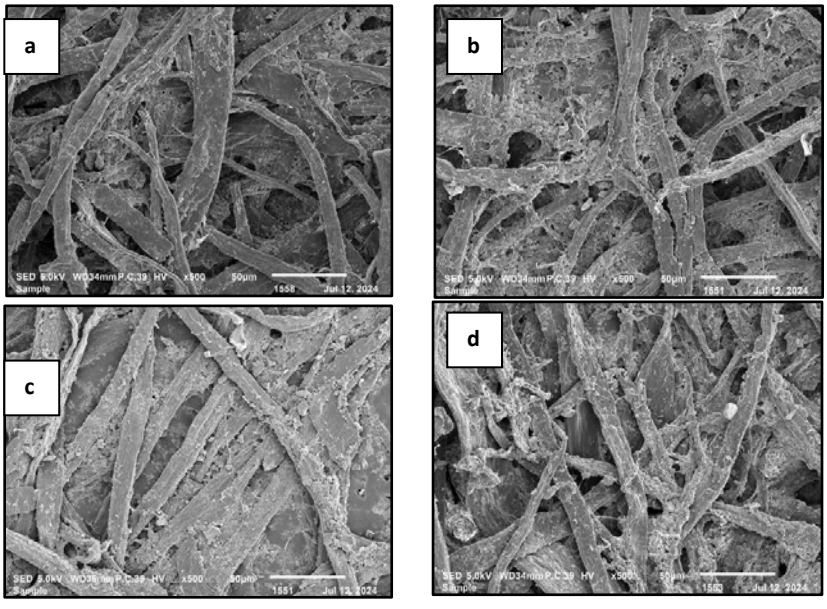


Figure 10: SEM images of produced papers.(a:EDDP, b:DPP, c:UPP, d:DBP)

When the SEM results were examined, it was determined that the papers deinked with enzymes had less toner residue and filler, similar to the visual examination, but there were deformations in the fibres. In the recycled form of the unprinted base paper, the fibres were subjected to the least deformation, but there were filler residues. It was seen that the paper that was not subjected to the deinking process could not be cleaned of both toner and filler. There were toner residues and filler in the papers subjected to chemical deinking. However, the amount of toner is less than the paper that was not deinked, the results are consistent with the visual data.
At the same time, the produced papers were also examined with an optical microscope. When the optical microscope results (Figure 11) were examined, toner residues could be seen in the undeinked paper and the chemically deinked paper. It could be clearly seen that the fibres of the enzyme deinked paper had undergone some deformation. The results are consistent with the SEM results and visual results.

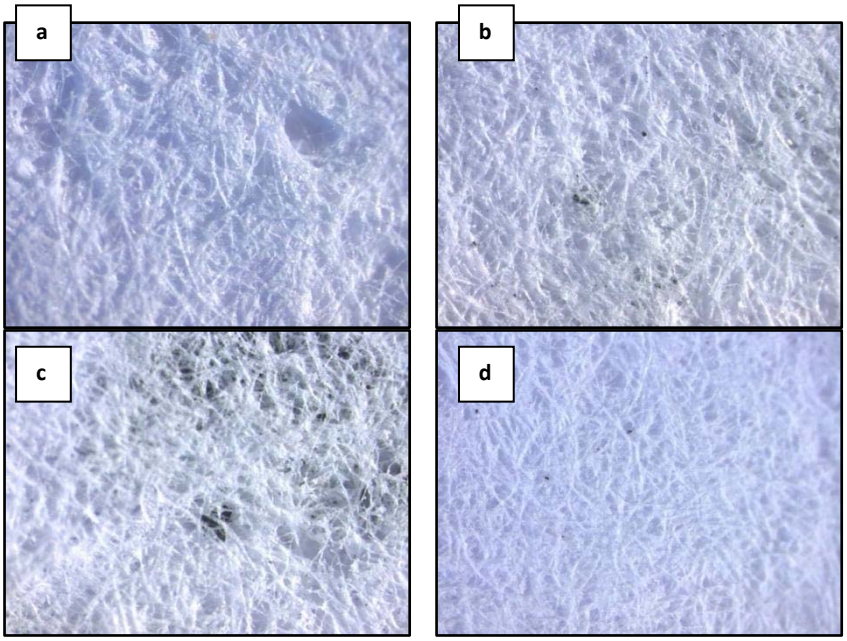


Figure 11: Optic microscope images of produced paper (a:EDDP, b:DPP, c:UPP, d:DBP)

4. CONCLUSIONS

As a result, using enzymes improves the properties of paper such as colour and ink separation processes. However, using only enzymes was not examined in this study. It was concluded that it exhibited a synergetic effect with chemical deinking. While deinking, amylase enzyme also removes the resin and filler of the ink, therefore, it creates changes in colour, gloss and whiteness. The best cleaning is done with enzymes. It was determined that not all toner could be removed in chemical deinking. It was concluded that chemical and enzyme+chemical processes caused deformation in paper fibres. It was concluded that enzyme use can be used as an effective, environmentally friendly method in office paper deinking.

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RECOVERY OF SILVER FROM PRINTED ELECTRONIC WASTE

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Abstract: *Printed electronics are preferred over traditional circuit systems in various fields such as energy, healthcare, packaging, and automotive due to reasons like lower silver ink usage, thinner product production, and suitability for mass production. The most commonly used type of ink in printed electronics is silver-based ink. Due to silver's high conductivity and the conductivity of its oxide, it is the most widely used material in printed electronic inks compared to other organic materials and metals. The growing needs of developing technology and the use of silver in other industries continually drive up its price. Considering environmental issues, the recovery of silver from printed electronics has become quite significant. This study aims to determine the effectiveness of two different methods in the recovery of silver ink printed on textile material. In the study, commercial silver paste inks were printed on textile material using screen printing. After drying, the printed samples were aged for two years, and then the silver recovery process was applied. Two methods were employed for silver recovery. In the first method, the silver-printed sample was burned at high temperature, and the silver in the resulting ash was dissolved in nitric acid. In the second method, the silver-printed sample was cut into small pieces and treated with nitric acid without burning to dissolve the silver. The amount of silver dissolved in the solution in both methods was determined using atomic absorption spectrophotometry. Additionally, the effects of nitric acid concentration on recovery were investigated. As a result, it was determined that the amount of silver recovered by the incineration method was higher, but the energy cost was also higher compared to the other method.*

Key words: silver recovery, printed electronics, sustainability, screen printing

1. INTRODUCTION

For many years, electronic circuits have been used in all devices across various aspects of our lives. In recent years, with the rapid development of smart hardware and big data, the use of printed electronics has come to the forefront, replacing traditional circuit systems. Printed electronics are rapidly growing with great potential in fields such as healthcare, energy, packaging, education, social networks, and the military. Materials such as paper, polymeric films, and textile materials are mostly used for printed electronics. The wide design options, the ability to produce thinner products, different material options, production techniques, and extensive applications have fostered increasing research interest in printed electronics. Currently, the production of conductive components generally relies on organometallic compounds, graphene, carbon nanotubes, conductive polymers, and metal nanoparticles (Islam et al., 2024). Due to their high conductivity, metal nanoparticles have become one of the most effective components (Boumeganane et al., 2022). Metals such as gold (Au), silver (Ag), and copper (Cu) are commonly used as potential conductive materials in printed electronics. Silver (Ag) is preferred for formulating conductive inks because it has the highest electrical conductivity (6.3×10^7 $S.m^{-1}$) among metals. In addition to high conductivity, it also offers advantages such as high resistance to oxidation and an applicable processing method. Therefore, silver stands out as the preferred material for printed electronics (Xia et al., 2006; Ibrahim et al., 2022).

Using textile materials as the base material in printed electronics, especially because they are soft and flexible enough to wear, combining smart electronics that interact with the environment with daily textiles has great potential, especially in improving human health, disease prevention, and healthcare services (Chen et al., 2022; Yuan et al., 2022).

The development of printed electronics essentially requires producing a conductor on a material. The process ensures that the conductor completely accumulates on the base material to be used. The processes in conventional printed circuit production can cause the use and disposal of large amounts of conductive material that is often toxic, environmentally harmful, and non-biodegradable. However, printing, that is, locally depositing the active material in ink/paste form onto textiles, can provide a sustainable solution both environmentally and economically compared to the conventional printed circuit production process. Additionally, the printing technique stands out with simple, low-cost, time-saving, versatile, and environmentally friendly production technologies on textile surfaces. Therefore, the next trend in wearable

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e-textile production is rapidly moving towards printing all electronic parts onto textiles (Kastner et al., 2017).

The printing process involves the controlled deposition of material onto a substrate to produce a predefined pattern for decorative or functional purposes. Despite the presence of other deposition processes such as painting or spraying, printing becomes even more significant as it can quickly reproduce the same layers as the original. Screen printing, gravure printing, flexographic printing, continuous inkjet printing, and on-demand inkjet printing are the printing technologies used for e-textile production Hu et al., 2018). The types of printing may have advantages over each other depending on the physical and chemical properties of the material and ink to be used. However, one of the biggest advantages of screen printing is that it allows the use of a wide range of substrates, such as paper, cardboard, polymer materials, textiles, wood, metal, ceramic, glass, and leather. Screen printing is by far the most widely used method in wearable e-textile applications (Izdebska & Thomas, 2016). To date, researchers have applied screen printing for the manufacturing of textile-based strain, pressure, temperature, and humidity sensors (Filipowska et al., 2018). Various textile-based biosensors, such as electrocardiogram (ECG), electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG), have also been reported to be made using the screen printing method (Gerlach et al., 2015; Jost et al., 2013). In addition, several screen-printed textile-based supercapacitors and heating elements have been demonstrated (Wu et al., 2019).

Materials that are not recycled at the end of their life cycle bring significant environmental and economic burdens due to pollution formation and the loss of valuable resources. The extensive usage of conventional or printed electronics makes the waste management of these materials after they become waste a crucial issue. Considering the rapid and increasing turnover rate of electronic products, electronic waste (e-waste) containing toxic substances and valuable metals like gold and silver is an urgent environmental, safety, and economic concern. However, recycling procedures for the recyclability of electronics can lead to secondary pollution and insufficient recovery of valuable components (Mondal et al., 2023). Regarding electronic waste, a study conducted in 2018 showed that 533 tons of silver were used in the electronics industries worldwide (Alexander et al., 2019). According to e-waste production studies, the amount of e-waste produced worldwide in 2018 was around 53.6 million tons (Forti et al., 2020). According to Statista, the amount of e-waste production in 2022 was 62 million tons. Furthermore, this trend is projected to persist, with annual e-waste production anticipated to reach 82 million metric tons by 2030 (Baldé et al., 2024). However, the total amount of e-waste collected for recycling was only about 11% (Mondal et al., 2023). These data suggest that electronic waste recycling is not adequately provided, which means both increasing negative environmental impacts and continuing negative economic effects due to the lack of recovery of valuable metals. From this perspective, the importance of studies on the recovery of electronic waste is clearly understood. As a solution to adverse environmental impacts, materials called transient electronics are produced. These are intended not to cause environmental pollution when various layers degrade after their operational lifetime. For this, embedding enzyme nanoclusters into plastics can program the degradation of polyesters under industrial composting conditions (Kwon et al., 2022). Integrating these new developments into composite materials is thought to serve sustainable printed electronics and the reduction of e-waste.

Methods such as exposure to high temperatures (Jaziri et al., 2024), ultrasound-assisted chemical flotation (Chen et al., 2023), pyrometallurgical, chemical leaching, and bioleaching (Schwartz et al., 2024) are applied for the recovery of metals from printed electronics or, in general, electronic waste.

In this study, it was aimed to determine the effectiveness of two different methods for the recovery of silver from textile material printed with silver ink. In the study, commercial silver paste inks were printed on textile material using screen printing. After drying and fixing, the printed samples were conditioned in oven at 100^{o}C for an hour and kept in desiccator then, the silver recovery process was applied. Two methods were employed for silver recovery. In the first method, the silver-printed sample underwent combustion at high temperature, and the silver in the resulting ash was dissolved in nitric acid. In the second method, the silver-printed sample was cut into small pieces and treated with nitric acid without combustion to dissolve the silver. The amount of silver dissolved in the solution in both methods was determined using atomic absorption spectrophotometry. Additionally, the effects of nitric acid concentration and time on recovery were investigated.

2. METHODS

2.1 Materials

Silver paste ink for screen printing on the fabric was obtained from Nanovatif Material Technologies Türkiye. Dyed and finished 100% cotton fabric was used for preparing e-textile material. ATAÇ GK40 RKL was used for fixing the printed textile material. Nitric acid (HNO_3) was procured from Carlo Erba. Distilled water was sourced from ISOLAB LWD-3008, and Precisa XB220 model balance was employed for mass measurements. The separation of solids from solutions after combustion was carried out using the ISOLAB 0.45 μm filter. Yellow line OS 10 basic shaker was employed for shaking. Silver analyses were performed using Analytik Jena ZEENit 700 Flame Atomic Absorption Spectrometer (FAAS). Thermal studies were performed using a Binder oven and Lenton CAL 8000 furnace.

2.2 Fabric printing

Screen printing, a method introduced in the late 9th century, is a traditional printing technique applied to a wide variety of materials, including textiles, ceramics, glass, plastics like polyethylene and polypropylene, paper, metal, and wood. It is often favoured over alternatives such as hand block printing, engraved roller printing, heat transfer, and inkjet printing due to its simplicity and low cost. In this process, a design is transferred onto a fine mesh screen, with non-printing areas blocked by an impermeable substance. Ink is then pressed through the mesh using a squeegee to print the design (Kazani et al., 2012; Ragab et al., 2022). In this study, a monofilament polyester 230 mesh with a thickness of 110 µm and a sieve opening of 45% was used. The printing design consisted of a rectangle measuring 8 x 4 cm. The printing of silver ink onto the fabric involved four print passes, meaning the squeegee was passed over the stencil four times. Then, the printed fabric was fixed at 120°C for 15 minutes. The textile material, before and after printing, was shown in Figure 1.

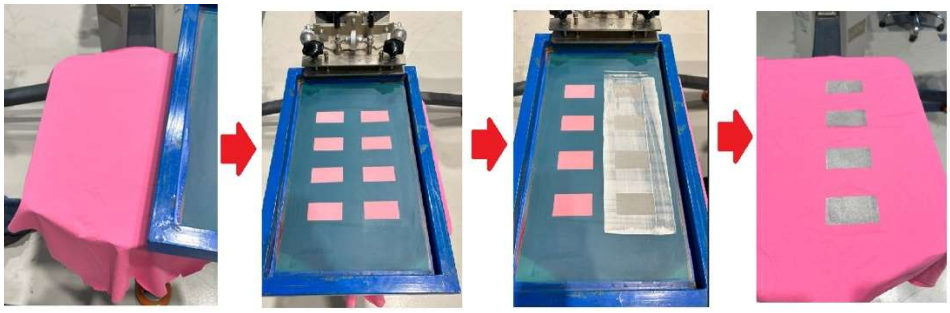


Figure 1: Screen printing on the cotton fabric

Conductivity of printed fabric was tested by a simple electric circuit using led diodes. While electrical conductivity was not observed in the fabric where silver ink printing was not applied, it was observed that the printed parts had very good electrical conductivity (Figure 2). The manufacturer informed us that the resistance of the silver ink used is 10 milliohms. Since the aim of this study is to investigate the recovery of silver from silver-printed textile materials, no studies were conducted on print quality or more detailed measurements of the electrical conductivity of the print. These topics are beyond the scope of our study.

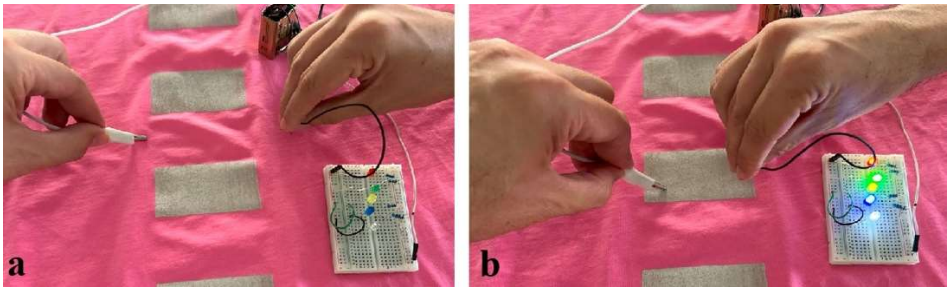


Figure 2: Conductivity of (a) unprinted cotton fabric and (b) silver printed cotton fabric

2.2 Silver recovery studies

Two different methods have been employed for recovery of silver from the printed fabric. First, silver recovery from the printed fabric was carried out using the traditional method of incineration followed by acid leaching, which is also used to analyze the metal content in fabrics (Analytical methods for a Textile Laboratory, 1984). For this, a certain amount of the printed fabric sample was burned at 550°C for different durations (Figure 3), and the remaining ash was treated with nitric acid. After the cloudy mixture was filtered through a 0.45 µm filter and filled up to a specific volume, the silver content was determined using flame atomic absorption spectrophotometry.

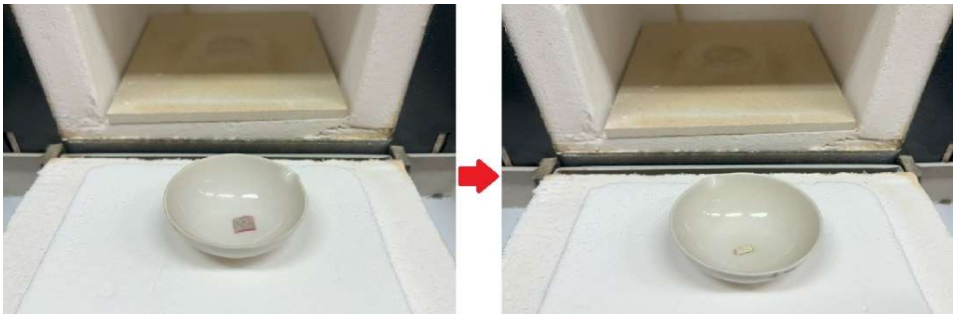


Figure 3: Incineration of printed cotton fabric

As a second method, direct leaching from the printed fabric using an oxidizing acid was attempted. For this purpose, 1 cm x 1 cm pieces of printed fabric were shaken in 20 mL of HNO_3 solutions at concentrations of 0.5, 1.0, 2.5, 5.0, and 10.0 M for different durations (Figure 4), and the amount of silver transferred into the solution was determined using flame atomic absorption spectrophotometry.

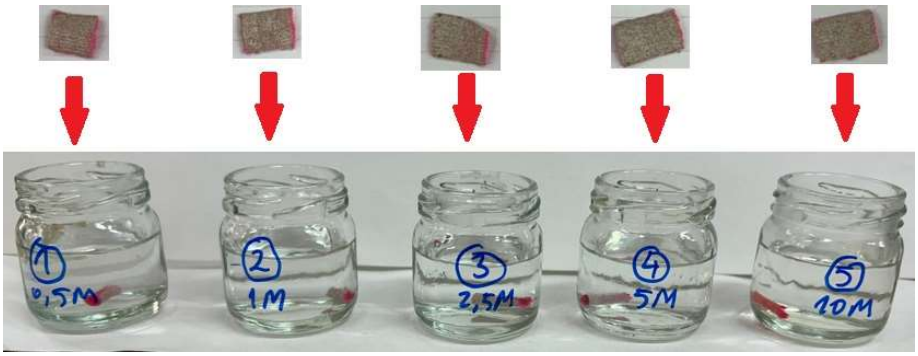


Figure 4: Direct leaching of printed cotton fabric

3. RESULTS

In this study, the efficiency comparison between the traditional incineration and acid leaching method and the direct oxidizing acid leaching method for silver recovery from silver-printed e-textiles was carried out. In the traditional incineration and acid leaching method, only the effect of incineration time on recovery was examined. In the direct oxidizing acid leaching method, the effects of acid concentration and exposure time to the acid on recovery were investigated.

3.1 Incineration time

To determine the metal content of a fabric, the 'analytical methods for a textile laboratory' published by the American Association of Textile Chemists and Colorists are mostly applied. In this method, the fabric is first incinerated at 550°C until it turns into white ash. Then, this white ash is treated with different acids depending on the type of metal to be analyzed, allowing the metal ions to be extracted from the fabric into the solution. In this study, 2, 5, 10, 15 minutes of incineration time were carried out for recovery of silver from the printed fabric. The results showed that ten minutes of incineration is sufficient for recovering all the silver from the printed fabric (Figure 5).

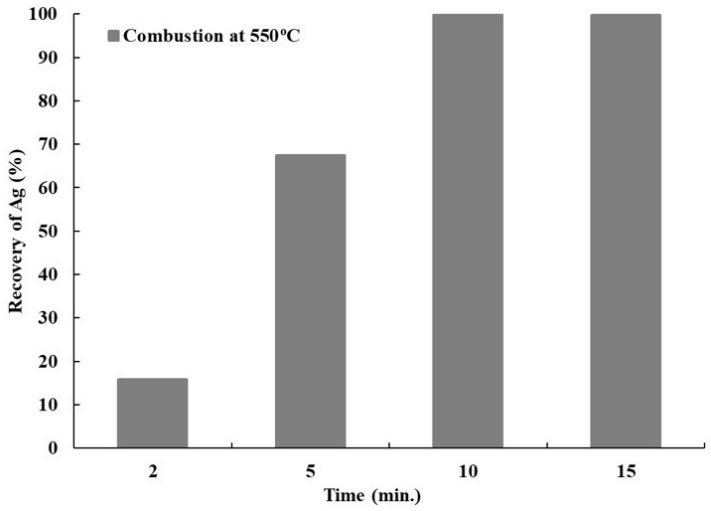


Figure 5: Effect of incineration time on recovery of silver

3.2 Concentration of HNO_3

To investigate the effect of HNO_3 concentration on the recovery of silver from the printed fabric, the fabric was treated with five different concentrations of HNO_3 solution, ranging from 0.5 M to 10.0 M. According to the obtained data, recovery of silver increases as the HNO_3 concentration increases (Figure 6).

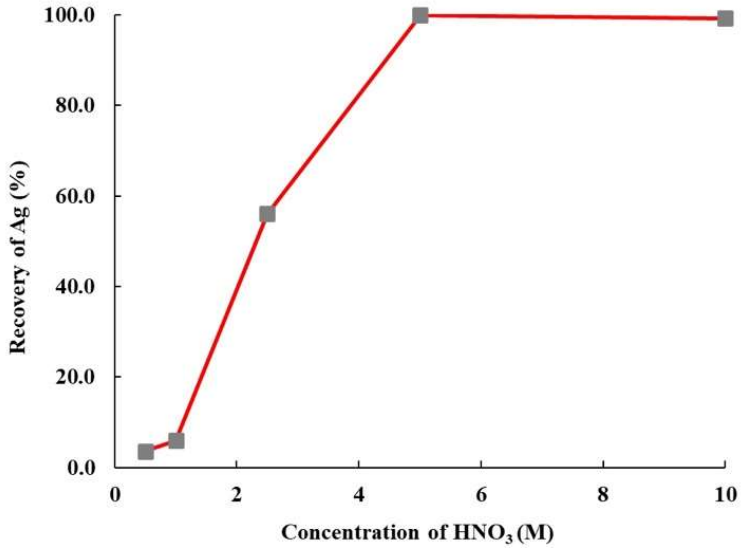


Figure 6: Effect of HNO_3 concentration on recovery of silver

3.3 Treatment time with HNO_3 solution

One of the important parameters for the recovery of silver from the printed fabric is the treatment time of the fabric with HNO_3 solution. To determine the optimum treatment time, the printed fabric was treated with different concentrations of HNO_3 solutions for varying times, ranging from 2 minutes to 4 hours. According to the obtained results, it was observed that the treatment time required to achieve maximum recovery decreased significantly as the HNO_3 concentration increased. Particularly at concentrations of 5.0 M and 10.0 M, maximum recovery values were reached within a few minutes. To better understand the obtained results, the data are presented in three different ways in Figure 7.

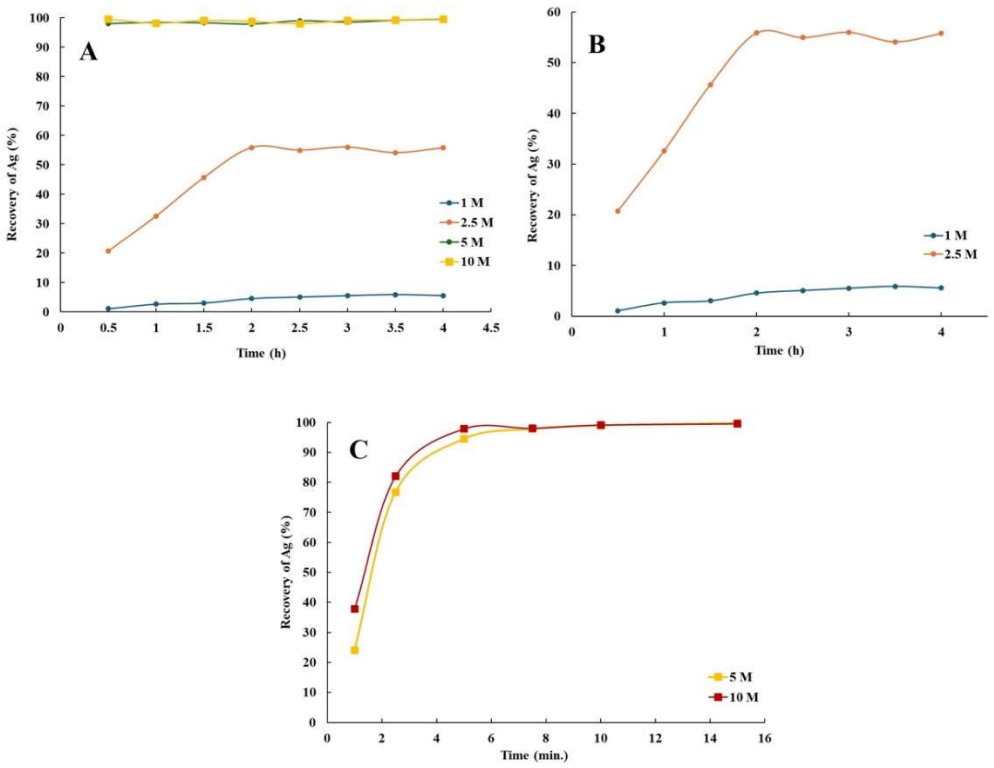


Figure 7: Effect of treatment time with (A) all HNO_3 concentrations (B) with 1.0 M and 2.5M HNO_3 and (C) with 5.0 and 10.0 M HNO_3 on recovery of silver

4. DISCUSSION

Metals in their elemental form react with acids to be oxidized into water-soluble cations. However, noble metals only react with oxidizing acids or acid mixtures. Silver metal, reacts with oxidizing acids to form the water-soluble Ag^+ ion. Therefore, nitric acid is suitable for dissolving elemental silver metal into a water-soluble form. Additionally, the nitrate anion present in nitric acid can also remain in a water-soluble form with silver ions. The chemical reaction between silver and non-concentrated nitric acid at room temperature was given in Equation (1). For this reason, nitric acid was chosen in this study to easily recover metallic silver from printed fabric.

$$3\,Ag_{(s)} + 4\,HNO_{3\,(aq)} \rightarrow 3AgNO_{3\,(aq)} + NO_{(g)} + 2H_2O_{(l)} \quad (1)$$

Additionally, silver recovery from the same printed fabrics was also attempted using the incineration and acid leaching method. As shown in Figure 5, it was observed that all the silver in the printed fabric could be recovered within a short period of 10 minutes using this method. However, this method requires a significant amount of electrical energy. Instead, the recoverability of silver metal was investigated using nitric acid, an oxidizing acid, without incineration, thereby avoiding the high energy requirement. According to the obtained results, recovery increased with the concentration of nitric acid, as seen in Figure 6. It is understood that all the silver metal in the fabric is recovered at concentrations of 5.0 M and higher. Another important parameter is the contact time with the acid solution. The dissolution of the polymeric resin, which serves as a binder in addition to the silver metal in the printing ink, is essential for the acid to eventually come into contact with the silver metal. It is thought that at concentrations of 5.0 M and higher, this resin is completely degraded, and the silver metal reacts completely with the acid to dissolve. Additionally, as the acid concentration increases, the amount of acid available to react stoichiometrically with the silver also increases, which may explain the increased recovery. The low recovery at lower concentrations might be due to the insufficient amount of H^+ ions from the acid to dissolve all the silver metal. This needs to be clarified through further studies and is also a topic for future research. In this study, it was found that 20 mL of 5.0 M HNO_3 solution was sufficient to recover all the silver from a fabric piece containing approximately 15 mg of silver, and it was observed that all the silver metal could be dissolved into the solution within a few minutes.

5. CONCLUSIONS

In this study recovery of silver from the printed cotton fabric carried out by chemical leaching using nitric acid solution and incineration and acid leaching methods. Screen printing was applied to 100% cotton fabric using an ink containing approximately 70% silver and a polyurethane resin binder. The optimum nitric acid concentration and treatment time required to recover silver from the printed fabric were determined. According to the obtained data, it was found that when a printed fabric piece containing approximately 15 mg of silver was shaken with 5.0 M HNO_3 for 5 minutes, all the silver in the fabric could be recovered.
Additionally, with the incineration and acid leaching method, it was observed that all the silver in the printed fabric could be recovered by holding the fabric at 550°C for 10 minutes, followed by treatment with 10.0 M nitric acid.
As a result, it was concluded that silver can be successfully recovered from the printed fabric using both methods. However, due to the high electrical energy consumption of the incineration method, it was concluded that the direct treatment method with nitric acid solution, applied in this study, would be more suitable due to its lower energy cost and ease of application.

6. ACKNOWLEDGMENTS

The author sincerely thanks Nanovatif Material Technologies Inc. for supplying the silver paste ink, Prof. Dr. Burcu Yılmaz and Res. Assist. Onur Atak for supplying the cotton fabric and their help in performing the screen printing, and Assoc. Prof. Dr. Emine Arman Kandırmaz for her support in the completion of this study.

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https://doi.org/10.24867/GRID-2024-p75 Original scientific paper

REMOVAL OF INK DYE FROM WASTEWATER USING ADSORPTION BY NANOCELLULOSE BASED HYDROGELS

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Abstract: *Adsorption's high efficiency, low operating cost, and versatility have made it a popular and successful approach for removing contaminants from wastewater. Various synthetic and natural adsorbents have been created for this purpose and used to remove a variety of contaminants, including printing inks. Growing environmental concerns have spurred interest in creating more environmentally friendly and biodegradable materials. Hydrogels are produced using a variety of recently developed or identified monomers and cross-links, as well as pre-made biocompatible polymers and cutting-edge synthesis techniques. Hydrogels can be made more intelligent by altering their morphology, crosslinking, chemical structure, or manufacturing methods. Hydrogels must be collected, regenerated, and reused in order to be deemed life cycle sustainable. This is an economic system in which natural ecological feedback or technological means transform waste into resources.*
In this work, dye adsorption experiments were carried out using wastewater from printing. Hydrogels based on nanocellulose were employed as adsorbents. Firstly, nanocellulose was produced. Nanocellulose was used to create hydrogels, while $ZnCl_2$ was used as a cross-linker. The batch technique was used for the adsorption trials. ATR-FTIR, or attenuated total reflection/Fourier transform infrared spectroscopy, was used to examine the chemical structures of the hydrogels. The different parameters were found, including pH, contact time, and removal quantity. Thus, with the aid of produced hydrogel, red coloured dye used commercially in flexography inks effectively cleansed the wastewater.

Key words: nanocellulose, hydrogel, dye adsorption

1. INTRODUCTION

The food, cosmetic, textile, pharmaceutical, and materials industries all employ pigments extensively. Synthetic pigments have been widely employed to address the industrial need for pigments because of their flexibility in changing chemical characteristics or colour, high manufacturing yield, and low cost of production (Bernard et al., 2024). The wastewater that results from using these pigments in printing ink is strongly coloured, signifying pollution. Such printing facilities are not allowed to directly release wastewater because of the harmful effects it has on both the environment and human health.
Various methods, including chemical, physical, and biological ones, are used to remove colorants, dyes, and pigments from wastewater. Coagulation-flocculation, filtration, adsorption, oxidation, ozonation, electrolysis, and bioremediation are some of these techniques. Every approach has a unique mix of benefits and drawbacks that change based on the particular sector in which it is used (Piaskowski et al., 2018, Liu et al., 2019; Nishat et al., 2023; Shaikh et al., 2021; Rashid et al., 2021; Khan et al., 2023; Ercan et al., 2015; Pavithra et al., 2019).
The use of adsorption as a popular and effective method of removing impurities from wastewater has grown significantly. Numerous benefits come with this approach, including great efficacy, minimal operating costs, and flexibility. As a result, scientists have created and employed a variety of synthetic and natural adsorbents to efficiently extract different contaminants, such as pigments, from wastewater. Environmentally friendly adsorbent production and application have grown in importance in recent years. Of these, the hydrogel derived from nanocellulose is a notable adsorbent since it is non-toxic, simple to manufacture, and reasonably priced (Kumar et al., 2021; Patra et al., 2024; Jagadeesh et al., 2023; Agarwala et al., 2023; Dutta et al., 2021; Osman et al., 2023).
In this study, a straightforward technique was used to create nanocellulose hydrogel in a way that was both economical and environmentally benign. The application of the nanocellulose hydrogel to eliminate coloured dye was the main focus of the investigation. The produced hydrogel was extensively analyzed by the use of methods like TGA and FTIR spectroscopy. In order to understand how several parameters, including pH, contact time, and pigment content, affected the adsorption process, the removal efficiency was calculated.

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2. METHODS

2.1 Synthesis of cellulose

Alkaline and bleaching methods were used to separate hemicelluloses and lignin from the raw material in order to extract cellulose from wood sawdust. In summary, hemicellulosic components were removed from wood sawdust by boiling it in water for 20 minutes at 100°C. After that, an alkaline treatment using 1.0 M NaOH solution was applied to 50 g/L of leftover sawdust, and it was left for two hours at 80°C while being mechanically stirred. The remaining alkaline sample was rinsed with hot water and then bleached for one hour at 100°C and pH 4.5 using 2.5% w/v sodium chlorite at a material-to-liquid ratio of 1:20. In the end, the bleached cellulose was washed three times in boiling water to remove any leftover or unreacted chemicals, and it was then dried in an oven (Sriruangrungkamol et al., 2021).

2.2 Synthesis of cellulose nanocrystals (CNC)

The as-purified cellulose was treated with sulfuric acid for acid hydrolysis while an ultrasonic method was implemented. 60% (w/w) sulfuric acid was added to 10 g of pure cellulose to hydrolyze it and produce a suspension (10 mL/g cellulose). This suspension was sonicated for 60 minutes at 60°C to facilitate hydrolysis. Once hydrolysis was completed, the suspension was rapidly diluted five times with cold distilled water to stop the process. The suspension was then transferred into centrifuge bottles, spun at 12,000 rpm for 10 minutes, and the crystals were separated by decanting. The solid aggregates in the suspension became disordered due to sonication (Sriruangrungkamol et al., 2021).

2.3 Preparation of nanocellulose hydrogel

The following ingredients were added in droplets to create nanocellulose hydrogels. The surface of the CNC water dispersions along the walls of the cylindrical Teflon mould is treated with a 20% w/w $ZnCl_2$ water solution. In the subsequent procedures, 1% mass concentration CNC water dispersions were employed. The ultimate zinc ion concentration in each mixture used in this investigation was kept at 0.1 mol/L. After that, the mixture was allowed for a full day without being stirred to enable the creation of nanocellulose hydrogels. In order to eliminate unattached Zn2+, the resultant hydrogel was lastly washed with distilled water (Lu et al., 2020; Ai et al., 2023).

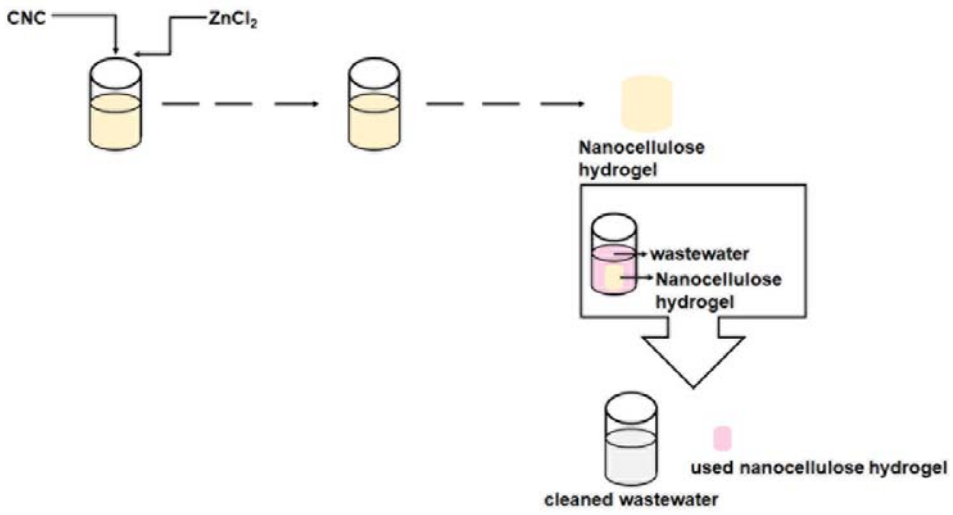


Figure 1: Preparation route of the hydrogel

2.4 Adsorption Studies

Using the produced nanocellulose hydrogel, adsorption experiments of the dye were conducted in batch mode with a shaker. The studies used precise amounts of adsorbent and 25 mL of pigment solution at different concentrations, all conducted at room temperature. The adsorption process was tuned for a number of factors, including pH, pigment content, and contact time. Solutions of diluted HCl and NaOH were used to alter pH. Whatman No. 44 filter paper was used to filter the adsorbent and solution, and a UV-Vis spectrophotometer operating at 511 nm was used to measure the filtrate's absorbance.

3. RESULTS AND DISCUSSIONS

3.1 Characterization of the prepared hydrogel

ATR-FTIR analysis was used to characterize the structural properties of the prepared hydrogel. Figure 2 displays the produced hydrogel's FTIR spectrum. The produced hydrogel's FTIR spectrum showed several noteworthy characteristics. The -OH band is represented by the large peak seen at about 3344 cm^{-1}. Furthermore, the stretching vibrations at 2908-2896 cm^{-1} are peaks that correspond to the -CH_2- groups. The carboxylic acid groups' carbonyl groups are vibrating, which is the cause of the strong peak at 1700 cm^{-1}. O-H bending is responsible for the vibration peak at 1428 cm^{-1}. The produced hydrogel's ATR-FT-IR spectra showed absorption bands corresponding to O-H bending, C-O stretching, CO-O-CO stretching, and C-H bending were detected at 1315 cm^{-1}, 1161 cm^{-1}, 1030 cm^{-1}, and 985 cm^{-1} wave numbers, respectively (Figure 2). The spectral data of the prepared hydrogel were in agreement with the spectral data in the literature (Lu et al., 2020; Ai et al., 2023).

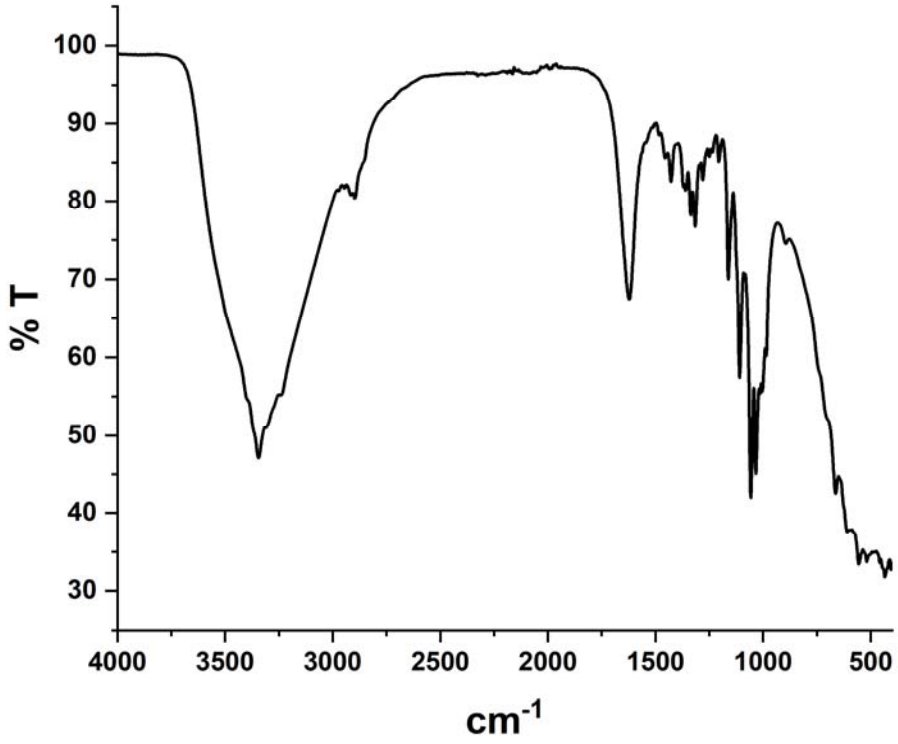


Figure 2: FTIR spectrum of the prepared hydrogel

Using TGA in a nitrogen environment, the produced hydrogel's thermal degradation behaviour was examined. In Figure 3, the TGA curve is displayed. The produced hydrogel's maximal heat degradation happened in two stages between 95 and 593°C, and the breakdown of the hydrogel's absorbed water was responsible for 85% of its weight loss. The produced hydrogel's TGA spectrum revealed mass loss between 30 and 150°C. Mass losses of water absorbed on the material happen in this temperature range (Sriruangrungkamol et al., 2021). The literature and these findings are in agreement. The temperature at which a 5% mass loss happens during decomposition is 80°C, and a 10% mass loss occurs at 105°C.

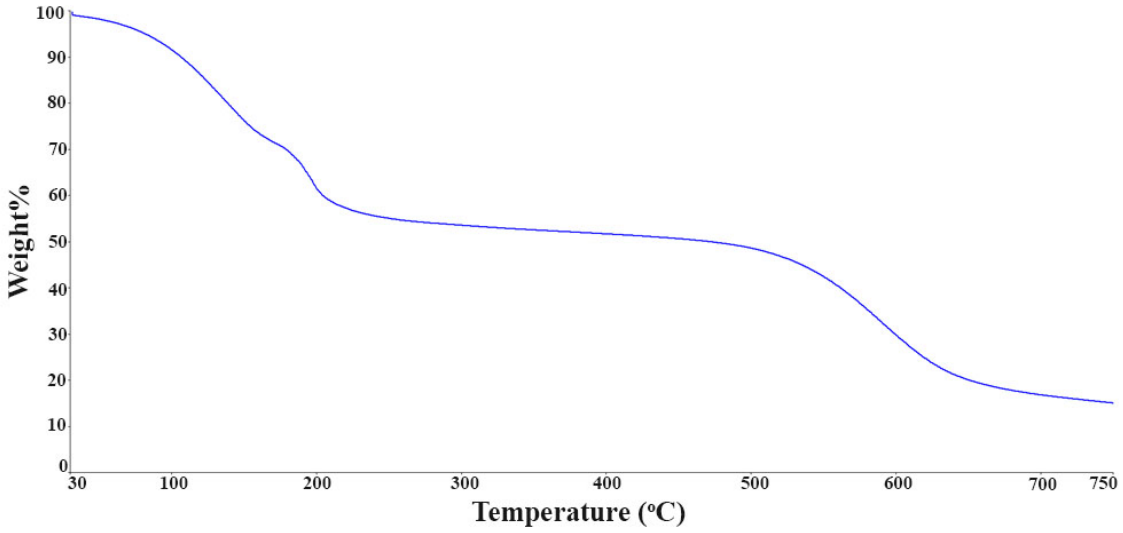


Figure 3: TGA curve of the prepared hydrogel

3.2 Effect of pH

The adsorption capacity of the hydrogel can be influenced by the pH of the solution. The impact of pH on the adsorption behaviour was examined within the range of pH 2-10. The results indicated that the maximum adsorption occurred at pH 2 (as shown in Figure 4), thus pH 2 was determined as the optimal condition. Figure 5 displays the colours of the dye solutions at different pH levels before and after adsorption, respectively.

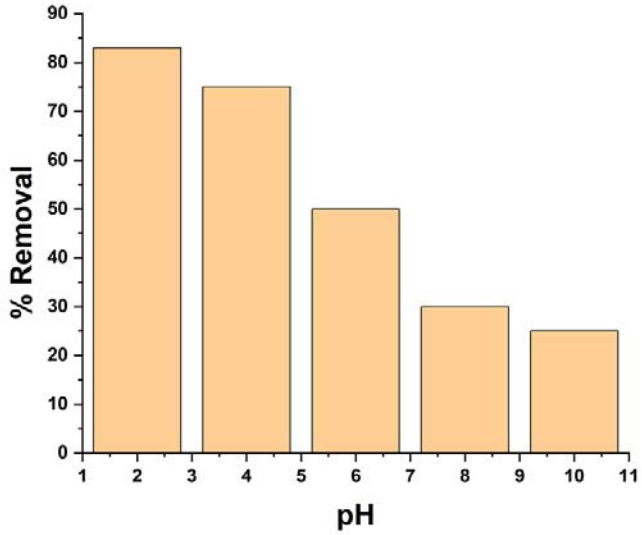


Figure 4: The influence pH on removal efficiency

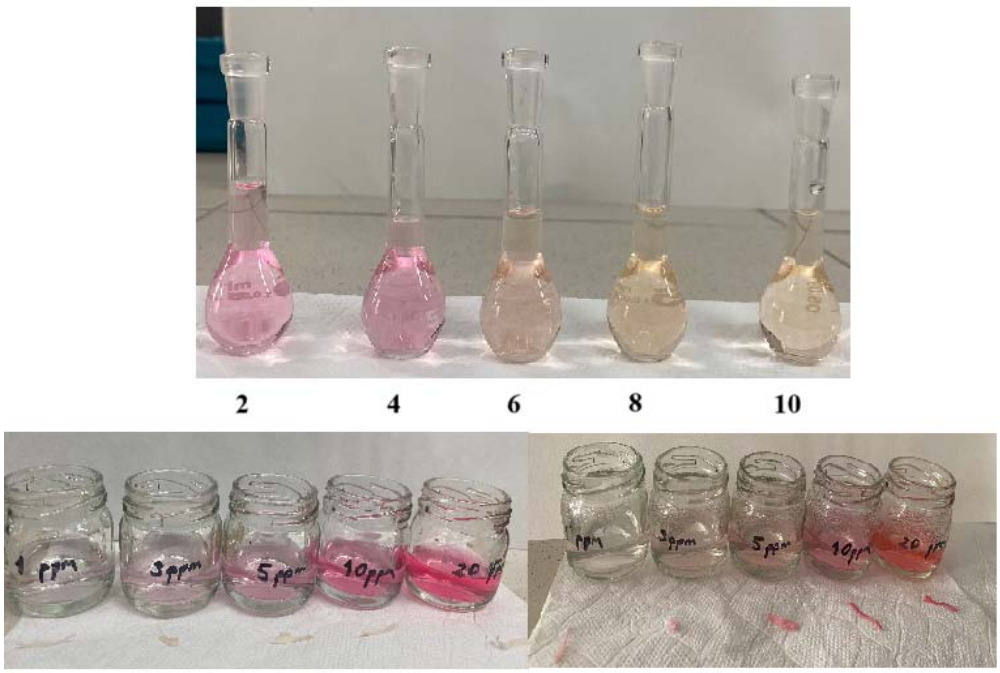


Figure 5: Colour Chancing of solutions before and after adsorption

3.3 Effect of contact time

During the adsorption process, it is essential to stir or shake the adsorbent and adsorbate for a specific duration until the adsorption equilibrium is reached. As the adsorption progress, the adsorbate molecules adhere to the active surface of the adsorbent, eventually reaching a point where further adsorption ceases to occur. The prepared adsorbent and dye solutions were agitated for varying durations, ranging from 1 to 75 minutes, at pH 2. The results are presented in Figure 6. It was observed that maximum colour removal was achieved within a very short time, and the optimum contact time was determined as 30 minutes.

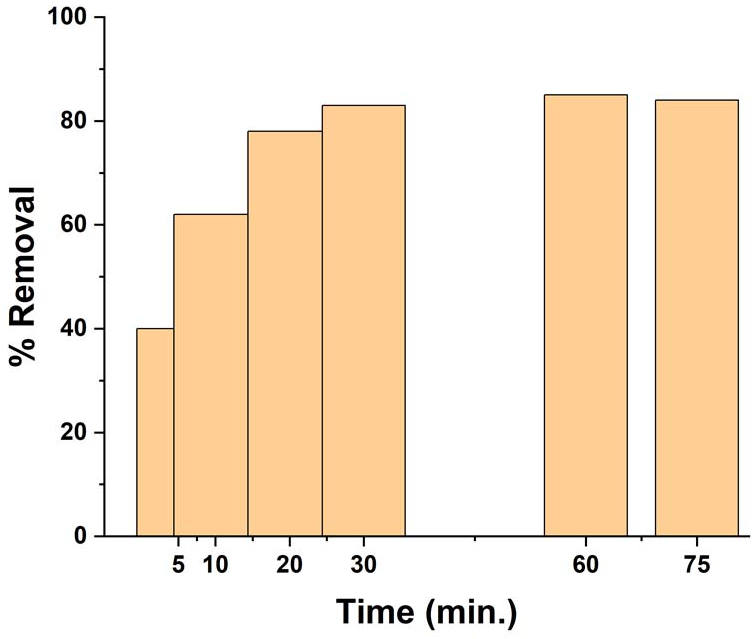


Figure 6: The effect of contact time

3.4 Effect of initial pigment concentration on adsorption

In order to evaluate the removal efficiency of the hydrogel for coloured dye, a series of adsorption experiments were conducted using coloured dye solutions with concentrations ranging from 5 to 20 mg/L. The experiments were performed at pH 2 and for a duration of 30 minutes and the removal efficiency of various concentrations of coloured dye was depicted in Figure 7.

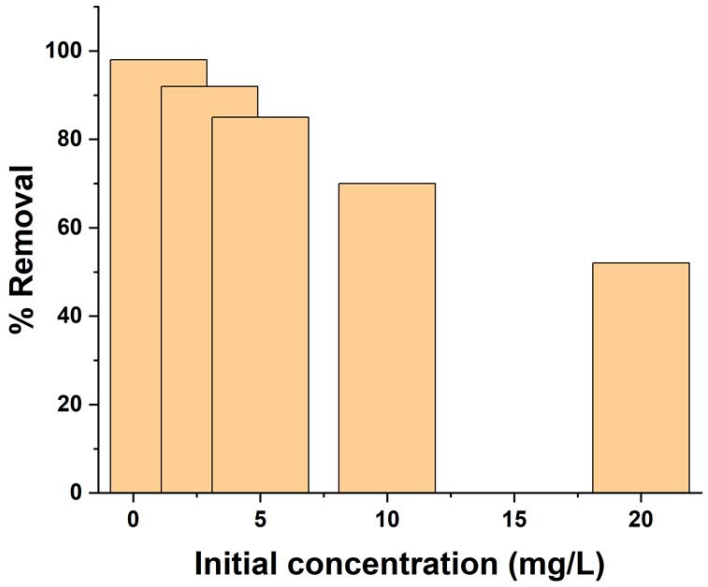


Figure 7: The effect of dye concentration on the removal efficiency

4. CONCLUSIONS

This study focused on the preparation of an environmentally friendly bio-based hydrogel used for the removal of coloured dye pigment from aqueous media. Adsorption experiments were carried out in a batch process. The adsorbent was characterized using attenuated total reflectance/Fourier transform infrared spectroscopy (ATR-FTIR) and thermogravimetric analysis (TGA). Various parameters including pH, contact time, and dye concentration were evaluated. The optimum contact time was determined to be 30 minutes, while the optimum pH was found to be 2. The results showed that the prepared adsorbent effectively removed red-coloured dye, which is commonly used in offset inks, from wastewater.

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PAPER AS A SUBSTRATE



SUSTAINABLE FOOD PACKAGING MATERIALS BASED ON HEMICELLULOSE COATED PAPERS

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Abstract: *This paper presents investigations on the utilization of xylan hemicellulose and its derivatives (hydrophobized and acetylated xylan) combined with chitosan biopolymer to improve the barrier and strength properties of paper. In this context, coatings based on hardwood xylan hemicellulose in different combinations, were used for surface treatment of paper. The results demonstrated improved barrier properties to water, gases, oil, and grease, as well as enhanced resistance to microbial attacks and increased mechanical strength of the coated papers. Based on these results, it can be concluded that xylan hemicellulose is a promising biopolymer to substitute synthetic polymers in the treatment of papers for food packaging applications.*

Key words: xylan hemicellulose, coatings, packaging papers, barrier properties

1. INTRODUCTION

The demand for sustainable alternatives is growing, and developing eco-friendly packaging from renewable resources, like lignocellulosic biomass or agricultural residues, could help mitigate environmental harm without competing with food production. These bio-based materials can provide a more sustainable solution by reducing reliance on fossil fuels and promoting biodegradability, thus aligning with circular economy goals (Zhao et al., 2021).
Cellulose-based materials, such as paper and board, are widely regarded as cost-effective and highly promising options due to their numerous inherent advantages. They are less expensive than many alternative materials, highly recyclable, and biodegradable. Additionally, they are easy to convert into containers with specific strength and stiffness properties, offer greater resilience than glass or plastic across a broader temperature range, are lighter in weight, and provide superior printability compared to other materials.
However, when used as food packaging, paper and board face inherent challenges due to their poor barrier properties. The porous structure and hydrophilic nature of cellulose fibers, which form their basic structure, make them ineffective at blocking water vapor, oxygen, flavors, or microbial contamination. Current methods to enhance the barrier properties of paper for agro-food packaging involve coating it with synthetic polymers or laminating it with plastic or aluminum foils. Unfortunately, these modifications negatively impact the sustainability of the packaging by relying on non-renewable resources, reducing recyclability, and hindering biodegradability (Johansson et al., 2012; Liu et al., 2016).
For these reasons, there are both opportunities and challenges in developing cellulose-based packaging materials that meet market performance expectations. The goal is to design suitable barrier and active antimicrobial properties while maintaining their recyclability and biodegradability. Achieving this balance is essential to ensure that these materials offer effective protection for food products without compromising their environmental sustainability.
The utilization of biopolymers to obtain the food packaging papers with appropriate barrier properties, represent a potential alternative to meet the technical, economical and environmental requirements of food packaging industry.
Over the past two decades, research has shown that hemicelluloses, particularly xylan polysaccharides (XyHCs), have significant potential for industrial applications. However, this potential has yet to be realized on a commercial scale. Xylan, the primary hemicellulose in hardwood, is found abundantly in the secondary cell walls of agricultural residues and as a byproduct of the wood and pulp industries. Despite its availability,

ORCID numbers are provided at the end of the paper.

the industrial use of XyHCs remains limited due to their hydrophilic properties, which pose challenges for broader application (Ren & Sun, 2010, Wissam, 2018).
The esterification of xylan hemicelluloses (XyHCs) is often reported as a method to produce functionalized xylan films with enhanced properties. This chemical modification improves the water and grease barrier capabilities of the films, while also reducing their oxygen permeability, making them more suitable for industrial applications that require these characteristics.
In this paper are presented the results on the utilization of xylan hemicellulose in native and chemically modified state and chitosan biopolymer in coatings for food packaging papers. Two xylan derivatives (hydrophobized xylan and acetylated xylan) and native chitosan were used in homogenous formula for surface treatment of packaging paper in single and double layer with 4,5 – 5 g/m^2 weight on both sides of paper. The functional properties as barrier to water, oils, greases, mechanical and antimicrobial, specific for food packaging applications were evaluated.

2. METHODS

Two different esterification methods for chemical modification of xylan hemicellulose were employed:

- *acetylation of xylan using acetic anhydride,* at 50°C for 1h and molar ratio of acetic anhydride to functional hydroxyl groups in the structural unit of xylan about 8:1. Resulted acetylated xylan has a degree of substitution (DS) of 0.48 (Roman et al, 2023), and
- *the reaction of xylan with alkyl ketene dimer (AKD),* which reacts with the hydroxyl groups of xylan to form β-keto ester compounds. The reaction was developed at 20°C for 24h using a magnetic stirrer at 1500 rpm (Nechita et al, 2022).

The functionalized xylan was characterized using FT-IR analysis and applied as coating on packaging paper surface.
Colloidal dispersions of xylan or its derivatives and chitosan were prepared by gradually adding the xylan/xylan derivative solution dropwise into the chitosan dispersion at a rate of about 60 mL/h, while stirring continuously with a magnetic stirrer. Once the chitosan addition was complete, the mixture of dispersions was stirred magnetically for 24 h.
A TQC SHEEN automatic film applicator (TQC B.V., Netherlands) was employed to coat paper samples. In this setup, an aqueous coating dispersion was applied in front of a 6 mm diameter rod. The rod automatically rotated over the paper substrate in a longitudinal direction at 100 mbar pressure and a speed of 125 mm/s, ensuring a precise application of the coating dispersion. The coating layer's thickness was controlled by the rod's diameter. A total of 20 coated paper samples, each measuring 20 × 25 cm, were produced and tested for their functional properties. Uncoated paper (base paper) was used as a reference. (Table 1).
The performances of xylan hemicellulose coated papers were assessed by evaluating the barrier properties to water, oil, grease, gases and against the microbial attack and mechanical strength using standardized methods.
The surface morphology of the coated papers was analyzed using a scanning electron microscope (SEM) FEI QUANTA 200 operating at an acceleration voltage of 20 kV.
Barrier to air and water vapours of coated papers were evaluated by measuring the resistance to air passing (Gurley porosity according to ISO 5636-5:2013 and water vapours transmission rate (WVTR) according to the ISO 2528:2018 standard which used the gravimetric (dish) method to measure the rate at which water vapours passe through the paper.
The wettability of coated surface was evaluated by analyzing of water contact angle and water absorption capacity of coated papers.
Oil and Grease Resistance was tested by measuring the oil absorption capacity as Unger-Cobb600 index (TTAPPI T 441 om-09) and as KIT rating of paper samples according to the TAPPI T 559 cm-12, respectively.
The antimicrobial activity of the coated papers was tested against Gram positive bacteria, *Bacillus sp* using a modified and adapted method of the ISO 846 (2000) standard.

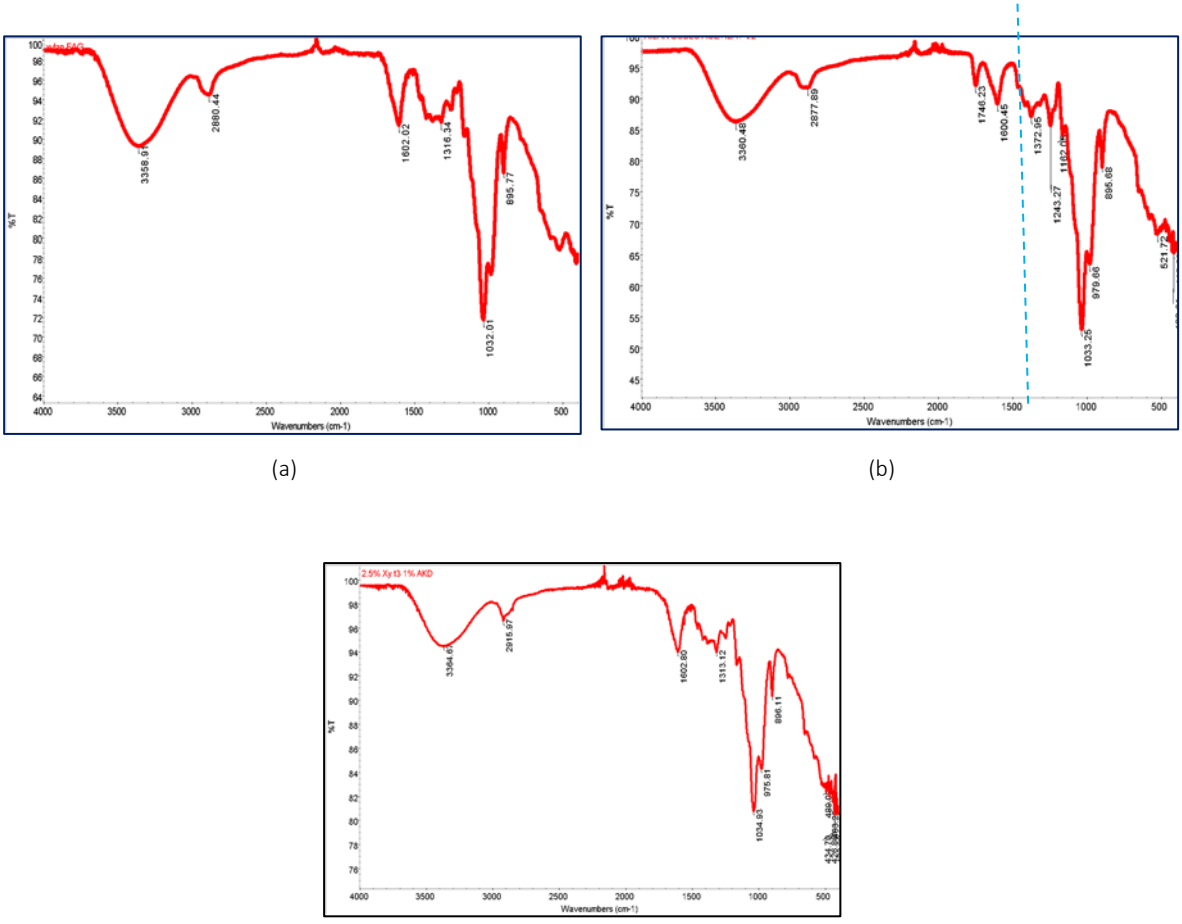
Table 1: The codification and composition of xylan hemicellulose coated papers

Sample codification	Composition					
	Single layer			Double layer		
	Native xylan (Xy)	Acetylated Xylan (XyAc)	Hydrophobised Xylan (XyAKD)	L1: Xy L2: Chi	L1: XyAc L2: Chi	L1: XyAKD L2: Chi
P1	100	-	-	-	-	-
P2	-	100	-	-	-	-
P3	-	-	100	-	-	-
P4	-	-	-	L1:100/ L2:100	-	-
P5	-	-	-	-	L1:100/ L2:100	-
P6	-	-	-	-	-	L1:100/ L2:100

3. RESULTS AND DISCUSSIONS

3.1 Structural characteristics of xylan derivatives

The structural analyses by FT-IR indicated the presence of absorption peaks at 1746 cm^{-1} which are associated to C=O vibration stretching from acetyl and -COOH groups (Figure 1b) and the vibration stretching characteristic absorption peaks of β-ketone ester bond formed between xylan hemicelluloses and AKD at 1602 cm^{-1} and 1733 cm^{-1} (Figure 1c). These confirm the chemical modification of xylan hemicellulose by introducing the new functional groups in the chemical structure (Figure 1a).



(a) (b)

(c)

Figure 1: FT-IR spectra of: (a) Native xylan; (b) Acetilated xylan XyAc; (c) Hydrophobised xylan XyAKD

3.2 The surface morphology of coated papers

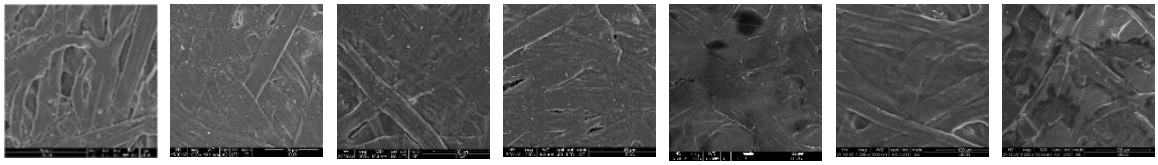
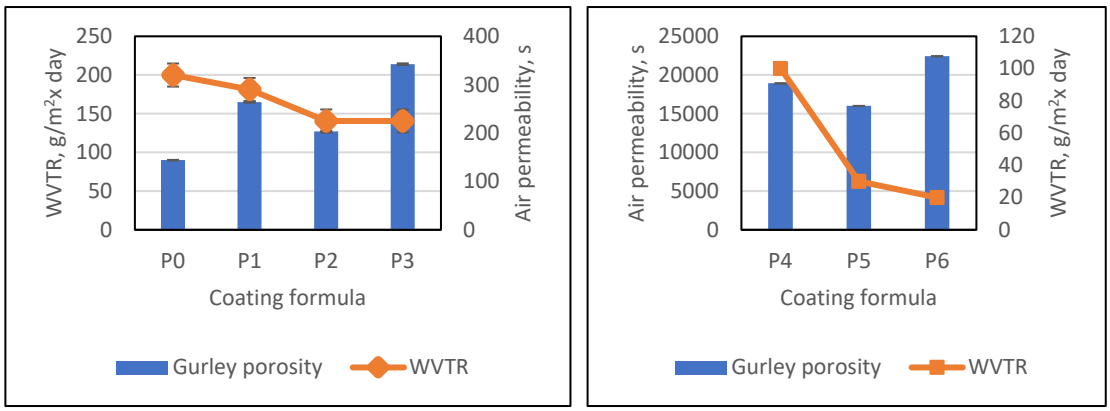


Figure 2: Surface morphology of the polysaccharides coated papers

The surface morphology of hemicellulose-coated papers, as shown in Figure 2 varies depending on the coating combination applied. The uncoated paper (P0) exhibits a porous structure with numerous cavities. Applying a coating layer improves surface uniformity and smoothness. When two successive layers are applied, with chitosan as the top layer, a distinct surface topography is observed. The excellent film-forming ability of chitosan results in a uniform, crack-free surface, in contrast to the samples coated with xylan or its derivatives.

3.3 Barrier to air and water vapors

In general, the air and water vapor barrier properties of paper coated with xylan or xylan derivatives are improved compared to uncoated papers. When two successive layers are applied (P4-P6 samples), a dense structure is formed, significantly reducing air permeability and water vapor transmission rate (WVTR) (Figure 3). Coating with polymer dispersions typically leads to partial or complete filling of the cellulose fibers, resulting in the densification of the paper sheet. This reduces interfiber interactions and limits water vapor diffusion into the substrate.

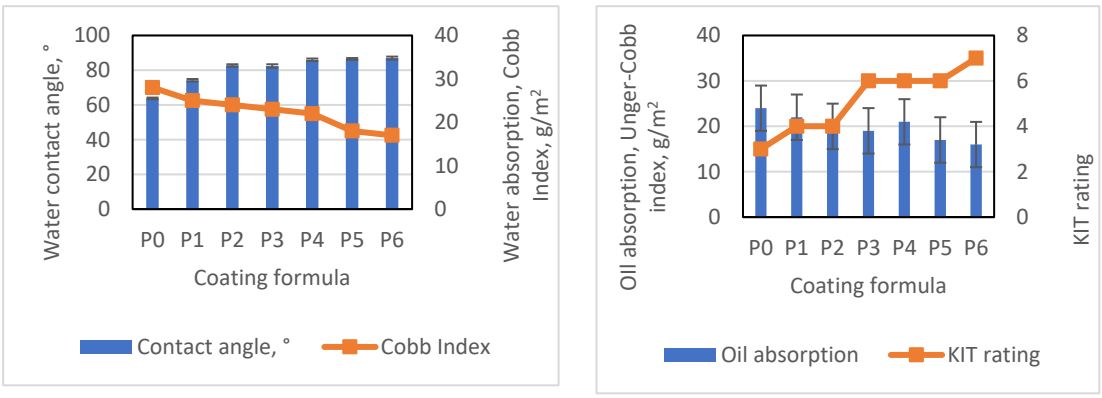


(a) (b)

Figure 3: Gases barrier properties of xylan coated papers (a) single layer; (b) double layer

3.4 Barrier to water, oils, and greases of coated papers

In general, the paper samples coated with successive layers of xylan derivatives and chitosan showed improved water absorption and contact angle values compared to papers coated with single layer of native xylan and its derivatives. For samples P5 and P6, water absorption was the lowest, and the contact angle measured 86-87° (Figure 4a). Analyzing the results shown in Figure 4b, it can be observed that the oil and grease resistance of the samples coated with two successive layers of xylan derivatives and chitosan improved, reaching 16 g/m² for oil absorption (Unger Cobb test) and 7 in the KIT test (samples P5 and P6). These values are comparable to those of current food packaging papers coated with synthetic polymers or fluorochemical compounds.



(a) (b)

Figure 4: Barrier properties of hemicellulose coated papers to:(a) water; (b) oils and greases

3.5 Antibacterial capacity of coated papers

In general, papers coated with xylan derivatives showed a slight inhibitory effect, indicating that a small inhibition zone can be observed on the surface and around it, as shown in Figure 5. However, papers coated with acetylated xylan exhibit a stronger inhibition effect. These results are consistent with the lower WVTR values observed for these paper samples. The samples coated with xylan derivatives and chitosan in two layers exhibited better inhibition effects, with sample P6 having a total inhibition of *Bacillus sp.*

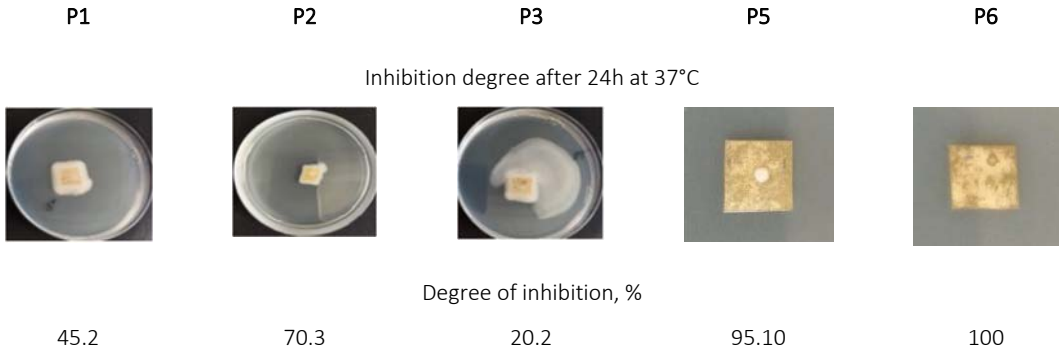


Figure 5: The antibacterial activity of hemicellulose coated papers

3.6 Strength properties

In addition to functional properties, mechanical strength is crucial for paper packaging to ensure adequate protection of the packaged material during transport and handling. Compared to uncoated paper, all coated samples exhibited improved bursting strength, a key characteristic for packaging paper (Figure 6). This can be attributed to the fact that, at low coating weights, the additional moisture in the paper substrate due to the hygroscopic nature of xylan coatings is minimal and does not negatively affect the bursting strength of the coated paper (Zachary, 2018).

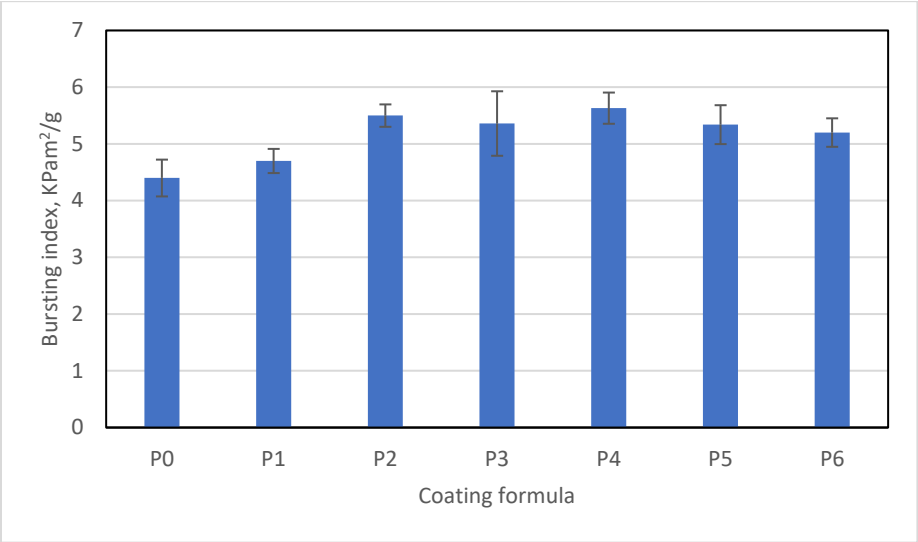


Figure 6: The strength properties of hemicellulose coated papers

4. CONCLUSIONS

Based on the obtained results, it can be concluded that coating paper with xylan hemicellulose leads to improved water, oil, greases and gas barrier properties. Additionally, the xylan coating has a positive effect on the bursting strength of the coated papers, which is one of the most important strength properties for packaging paper.

Coating paper with successive layers, with chitosan as the top layer, resulted in improved inhibition of *Bacillus sp.* after 24 hours. Generally, the antimicrobial properties of coated papers are closely linked to their water barrier properties; samples with reduced water and water vapor permeability tend to inhibit bacterial growth more effectively.

5. ACKNOWLEDGMENTS

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THE IMPACT OF PAPER MADE FROM RECYCLED AND NON-WOODY PLANTS ON THE EFFECT OF FLUORESCENT PRINTS

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Abstract: *Fluorescent printing inks are often used for design elements in printing, signage, highlighted segments on packaging, and similar applications. In this research, commercially available papers made from recycled and non-woody fibers, such as hemp and cotton, will be used as substrates for printing with fluorescent inks. Paper printing substrate made entirely from virgin fibers will serve as a reference paper. The aim of this study is to determine the influence of paper made from recycled and non-woody plants on the effect of printed fluorescent inks. These paper printing substrates will be examined for their structural, surface, and optical properties, as well as screen-printed with fluorescent inks. The characteristic fluorescent effect of the printed ink will be evaluated using spectrophotometric method on all printing substrates. The difference between papers made from non-woody plants and recycled fibers compared to the reference paper made from virgin fibers will be determined, as well as their impact on the optical effect of fluorescent inks, printed elements, and line width. Additionally, a survey will be conducted to identify the most acceptable paper substrate for designs printed with fluorescent inks.*

Key words: recycled paper, non-woody plant paper, fluorescent printing inks, spectroscopy

1. INTRODUCTION

In the field of graphic technology and design, there is potential for replacing papers made from primary fibers with those made from recycled and non-woody materials. These materials, including papers produced from agricultural residues, align with the principles of a circular economy and support all three pillars of sustainability. Their selection can reduce environmental impact by lowering reliance on wood fibers and addressing the raw material crisis in the paper industry (Teacă, 2023; Cassel et al., 2023). Non-wood materials, such as agro-waste, have been found to exhibit comparable properties to traditional wood fibers, making them suitable for paper production (Kumar, 2022; Jaishwal et al., 2024; Clift et al., 2022). Using alternative materials can improve the physical properties of paper products, providing a sustainable and cost-effective solution to reducing wood pulp consumption and mitigating deforestation and CO_2 emissions (Cassel et al., 2023; Kurek et al., 2022). Additionally, papers made from recycled fibers and non-woody plants show potential for various printing techniques, including digital UV inkjet and flexography (Cassel et al., 2023; Rudolf et al., 2024) The print quality on these papers is comparable to that of papers made exclusively from recycled wood fibers (Rudolf et al., 2024). However, challenges such as increased ink penetration into the substrate need to be considered (Tamboli et al., 2022).

Fluorescent printing inks interact well with various substrates, offering excellent fluorescent effects and anti-fake properties. This broadens their application range, ensuring durable prints with enhanced visual appeal. (Dongjun, 2016). Fluorescent printing inks are classified as special effect inks, possess the ability to absorb UV radiation and re-emit photons at different wavelengths, a phenomenon known as luminescence (Jameson, 2014; Becidyan, 1995). This unique property enables them to be utilized across various applications, including decorative and packaging industries, for markings, signaling, orientation purposes, and document security (Bodenstein et al., 2019; Yook & Lee, 2013). In printing processes, fluorescent printing inks can be applied as varnishes in flexography, offset, and relief printing (Bozhkova et al., 2017; Talebnia et al., 2014), and in screen printing, they are often used by mixing the pigments with a transparent base (Becidyan, 1995).

Given the growing trend towards using alternative source printing substrates, their application in industries such as packaging is highly promising for the future. Additionally, these substrates are likely to be combined with various printing inks, including those with special effects such as fluorescent inks. This study aims to assess how paper substrates made from recycled and non-woody plants influence the performance of printed fluorescent inks. The investigation will focus on the structural, surface, and optical properties of these paper types, which will be screen-printed with fluorescent inks. To evaluate the distinctive fluorescent effects of the inks, spectrophotometric analysis will be employed across all paper substrates.

ORCID numbers are provided at the end of the paper.

The study will compare the performance of non-woody and recycled fiber papers against a reference paper made from virgin fibers, analyzing their effects on the optical properties of fluorescent inks, printed elements, and line widths. Additionally, a survey will be conducted to identify the most favorable paper substrate for designs utilizing fluorescent inks.

2. METHODS

2.1 Materials

In this research, five types of uncoated papers are used, including high-quality uncoated offset paper based on virgin fibers serving as a reference, marked as MN. Paper printing substrates RW and NC are specified as uncoated recycled papers suitable for all common printers and printing processes. While both are made from recycled fibers, NC is produced entirely from post-consumer waste (PCW). PC and MH are specified as uncoated papers with rough surface, suitable for offset, UV offset, letterpress, and screen printing. PC is produced entirely from cotton fibers and has an uncoated surface. MR is produced from 30% hemp, 30% PCW, and 40% virgin fibers. Here, hemp is used as a fast-growing plant for raw material in paper production, with a significant share of virgin fibers, to gain a high whiteness grade.

Table 1: Paper-printing substrates used in the research

Paper-printing substrate	Grammage (g/m^2)	Paper composition - fibres
MN	120	Virgin
RW	80	Recycled
NC	80	Recycled
PC	120	100% cotton
MR	118	30% hemp, 30% PCW, 40% virgin

Daylight – visible fluorescent printing ink (Sebastar neon pink 103.466, Sebek Inks, Belgium) was used for printing full tone, letters and line elements on all printing substrates. The ink was screen printed on all selected paper substrates in 43 l/cm mesh for a full tone print, and 100 l/cm mesh for motif used in the research survey. The prints were made in a controlled laboratory conditions, and air-dried 72h before further tests.

2.2 Methods

Images of the paper surfaces and print lines on selected substrates were taken using an Olympus BX51 microscope (Olympus Corporation, Tokyo, Japan) at a magnification of 100× and 50×. The thickness (caliper) of the papers was measured with the DGTB001 thickness gauge (Enrico Toniolo, Milan, Italy), according to ISO 534:2011 (ISO: Geneva, Switzerland, 2011). Smoothness of the paper printing substrates was measured using PTI line Bekk Tester (PTI Austria GmbH, Laakirchen, Austria) on 10 samples for each substrate (5 on the felt side and 5 on the wire side of the paper), according to ISO 5627:1995 (ISO: Geneva, Switzerland, 1995).
The Cobb test is performed to determine the water absorptiveness of the selected paper printing substrates, according to ISO 535:2023 (ISO: Geneva, Switzerland, 2023). This method is suitable for sized paper and board, under standard conditions (ISO 187:2022) (ISO: Geneva, Switzerland, 2022). The Cobb test is directly related to the sizing of the paper, as the sizing process plays an important role in achieving a certain degree of resistance to the absorption or penetration of liquids, especially water (Deshpande, 2011). The ISO 535:2023 [42] test procedure includes placing a dry sample under the metal ring, pouring 100 mL of distilled water and leaving it to stand for 60 s. At 10 ± 2 s before the expiration of the test period, the water is poured out of the ring, and the sample is then placed between standardized blotting papers and the excess water is removed with a roller. The sample is weighed before and after exposure to water, resulting in the paper absorptiveness value (g/m^2). The test, in this research, is performed on the smoother side of the paper, selected for printing.

Optical properties of the paper substrates were measured with X-Rite (Grand Rapids, MI, USA), D50/2°, M1. Whiteness was measured over the entire visible range of the spectrum, while brightness was measured at 457 nm.
Spectral reflectance of the fluorescent prints on all papers was measured using 50 mm wide integrating sphere (ISP-50-8-R-GT) on the fibre-based USB 2000+ spectrometer (Ocean Optics, USA), set to CIE illuminant D50/2°, with UV lamp used as a light source, so that the fluorescence effect could be measured. The purpose of these measurements was to determine the influence of different paper printing substrates on spectral reflectance of fluorescent prints.
The final step in this research was a survey conducted on 76 respondents, in order to identify the most acceptable paper substrate for designs printed with fluorescent inks and to evaluate the correlation between visual perception and measured results of fluorescent prints on different substrates.

3. RESULTS AND DISCUSSION

3.1 Properties of Paper Substrates

The results of the caliper (thickness), bulk (specific volume) and density of the papers are presented in Table 2. Before the measurements, the preparation of the samples was conducted in accordance with the ISO 187:2022 standard for conditioning paper samples at 23 ± 1◦C and 50 ± 2% relative humidity (ISO: Geneva, Switzerland, 2022). The grammage (Table 1) and caliper values of each individual sample were used to calculate the density of the paper using the Equation (1) (ISO: Geneva, Switzerland, 2011):

$$Y = x/d \times 1000\ (g/cm^3) \quad (1)$$

Where: x is the basis weight (g/m^2); d is the caliper (mm).

The density of the paper sheet represents the mass of one cubic centimeter of the tested sample. It is influenced by various additives used in paper production, such as fillers, sizing agents, and dyes, and the fiber type, separation, and mechanical treatments like refining, drying, and calendering. This parameter significantly affects the paper's optical and mechanical properties, including its structure, porosity, and compactness. In addition, the paper density is an indicator of the relative air content in the paper (Holik, 2013). The results presented in Table 2 show the highest density of 0.83 g/cm^3 for reference sample MN, followed by RW (0.81 g/cm^3), NC (0.80 g/cm^3), MR (0.69 g/cm^3), and PC (0.61 g/cm^3). This property of paper varies inversely with bulk (specific volume), which is calculated using the Equation (2) (ISO: Geneva, Switzerland, 2011):

$$1/Y = d/x \times 1000\ (cm^3/g) \quad (2)$$

The specific volume of paper (bulk) is the volume per mass unit of paper (cm^3/g). A lower specific volume typically indicates denser paper. This property is important in the printing industry as it affects ink absorption, air permeability, and the final appearance of the printed material. The paper's specific volume is closely related to ink absorbency in printing processes. The ink absorption capacity of paper can be influenced by parameters such as the type of pulp used, basis weight, sizing agent, and beating degree (Ataeefard, 2015). The results indicate that PC has the highest bulk of 1.64 cm^3/g, followed by MR of 1.45 cm^3/g; NC of 1.25 cm^3/g; RW of 1.24 cm^3/g; and reference paper MN, having the lowest bulk of 1.21 cm^3/g (Table 2). This means that the reference paper MN has the highest density, lowest relative air content, and is more compact than the rest of the samples, which are more porose. Previous studies have shown that low density values were found to be more common in the recycled paper and paper made from non-woody plants than in paper made from virgin fibers, which is due to the larger voids and gaps between the fibers in the recycled paper and non-woody papers (Tampichai et al., 2019; González et al., 2014).

Table 2: The results of measured basic and structural properties of selected papers

Paper-printing substrate	Caliper (µm)	Density (g/cm³)	Bulk (cm³/g)
MN	0.145	0.83	1.21
RW	0.099	0.81	1.24
NC	0.1	0.80	1.25
PC	0.197	0.61	1.64
MR	0.171	0.69	1.45

The results of the paper smoothness using the Bekk method are shown in Figure 1 and represent the mean values of five (5) measurements for each individual type of paper tested on wire and felt side (marked as A and B). The surface properties of the paper have a significant effect on the print reproduction and quality. Uncoated papers exhibit a different surface smoothness on the wire and felt side, which is a result of the paper manufacturing process. Since high-quality printing and reproduction requires a high degree of smoothness, it is recommended to print on the smoother side of uncoated paper whenever possible. The results in Figure 1 show the highest degree of smoothness was measured for the RW B sample, with a value of 30.98 s. The smoothness of NC A is 30.54 s, followed by MN A (17.58 s), MR B (7.76 s), and PC B (1.98 s). The smoother side of each paper was selected for printing (marked pink in Figure 1) and analyzed in further tests.

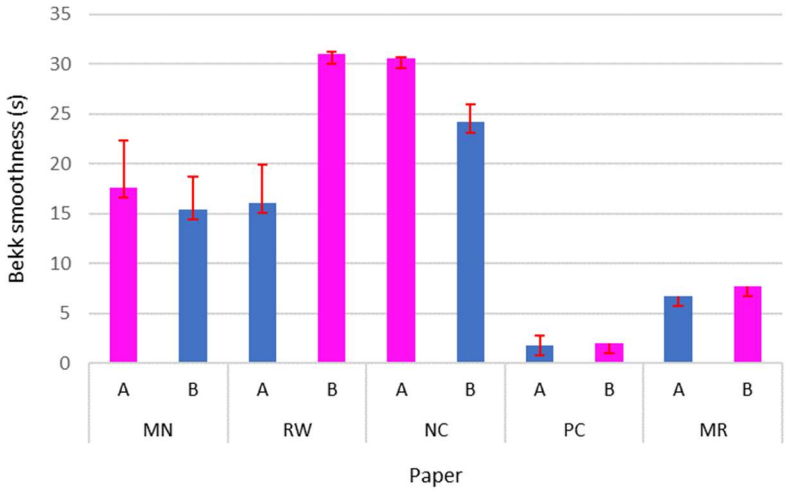


Figure 1: The results of Bekk smoothness of the papers

Figure 2 shows the results of water absorptiveness of the paper used in this research, according to the Cobb method. The results show the highest water absorptiveness, of 100 g/m^2, was found for MR. For hard-sized papers intended, for example, for offset printing, the Cobb value usually does not exceed 100 g/m^2 (TAPPI: Atlanta, GA, USA, 2013). Paper MR could be categorized between the class of hard-sized (Cobb value < 100 g/m^2) and soft-sized papers (Cobb value > 100 g/m^2). Soft-sized (or weak-sized) papers tend to absorb more water and have a more open structure (such as newsprint paper). They are suitable for printing techniques that require greater ink absorption. The water absorptiveness of papers made from recycled fibers, RW (78.8 g/m^2) and NC (36.4 g/m^2), showed different absorptiveness values compared to the reference sample MN (66 g/m^2), which are most likely due to different additives in paper production, such as fillers and sizing agents, which reduce the water absorption capacity. The water absorptiveness of PC is the lowest of all samples, resulting in 25.9 g/m^2. These results are also influenced by the paper composition, fiber type, and surface roughness.

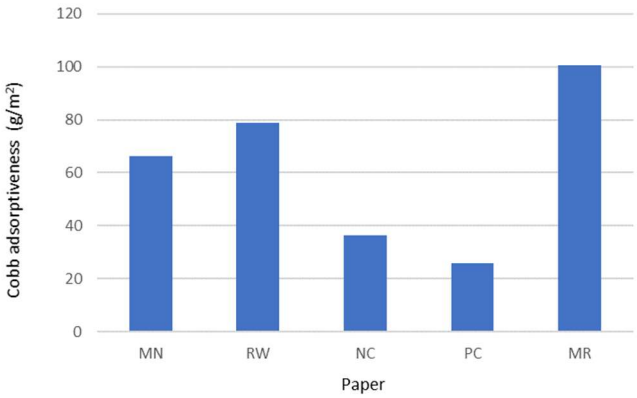


Figure 2: The results of Cobb absorptiveness (t = 60 s) of the papers

Optical properties of measured printing substates show the highest whiteness grade for the reference MN (141.2%) and PC (139.6%), followed by MR (121.4%), and recycled papers NC (101.9%) and RW (51.3%) (Figure 3a). Brightness measurements resulted in the highest degree for PC (106.5%) and PC (106.5%), which is almost equaled with the reference MN (101.0%) (Figure 3b). Recycled paper substrates NC and RW have the lowest brightness degree of 86.3% and 66.6%, consistent with the paper composition which implies the residual printing ink particles and secondary fibers. Additionally, such paper composition can result in higher degree of yellowness, especially if no OBA (Optical Brightening Agents) or dyes are used. This is most likely for the paper RW, since measured yellowness has a positive value of 7.9% (Figure 3c). Base-paper composition and additives have a crucial role in optical properties of the paper, which greatly affect the characteristics of the print. The result of optical measurements for reference paper MN shows the presence of OBAs, since whiteness exceeds 100%, with the lowest yellowness rate of -17.5%. The results of optical measurements confirm high properties of papers made of non-woody plants (PC and MR), consistent with visual impression.

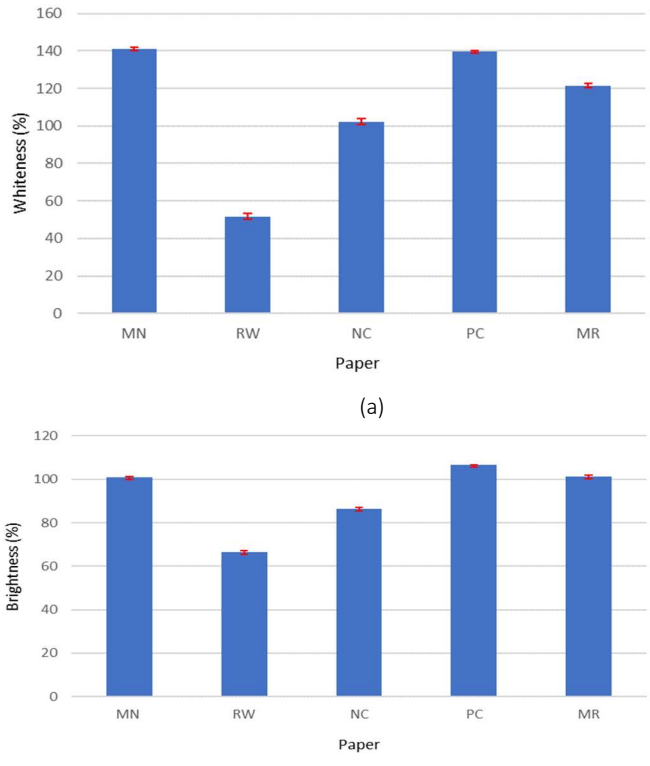
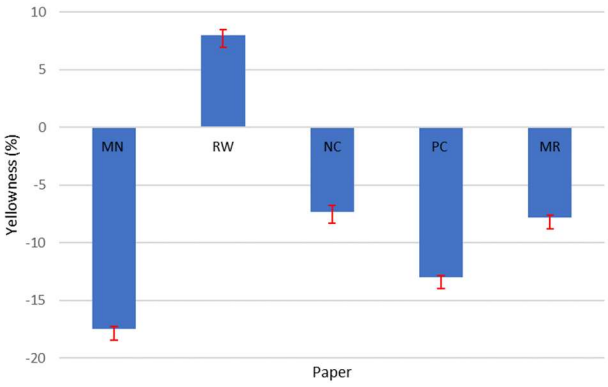


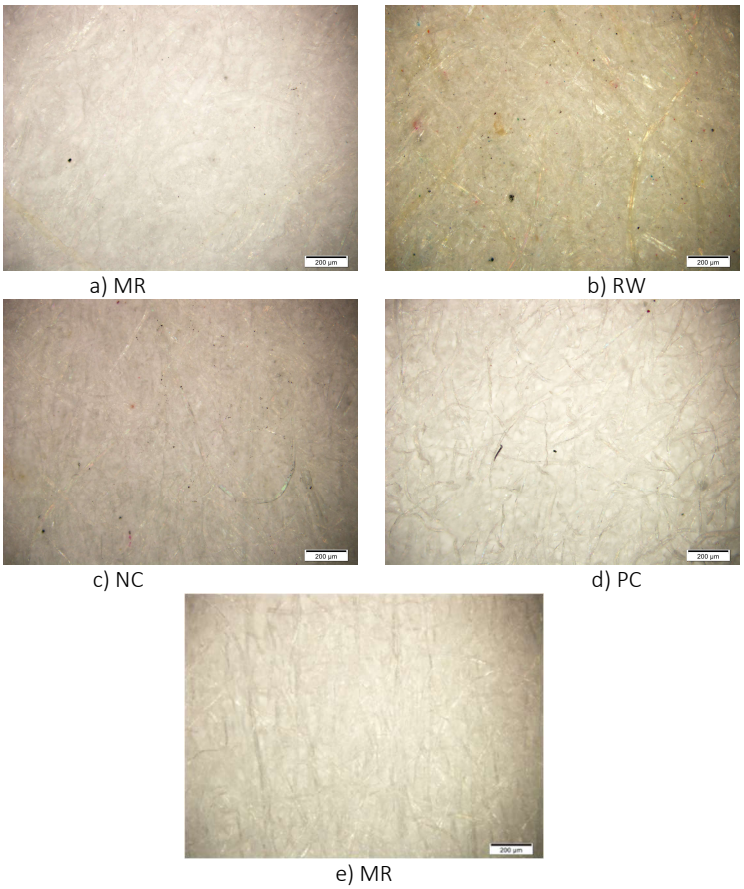
Figure 3 (part 1): The results of optical measurements of selected paper – printing substrates: a) whiteness; b) brightness



c)

Figure 3 (part 2): The results of optical measurements of selected paper – printing substrates: c) yellowness

Figure 4 shows the microscopic images of the paper-printing substrate surface at magnification 100×. As can be seen in Figure 4a, the surface structure of the reference sample MN, a paper based on virgin fibers, is uniform and interspersed with well-interwoven fibers of different widths, with almost no impurities. The papers made from 100% recycled fibers (RW and NC) have a surface structure made of thin fibers interwoven in all directions in the surface structure (Figure 4b, Figure 4c). The particles of recycled material are visible in the RW sample. Sample PC (Figure 4d) has a surface structure that is the most irregular compared to all the observed samples. The fibers are of a uniform width, long and without visible breaks. Sample MR has an interwoven fiber structure consisting of 30% hemp, 30% PCW, and 40% virgin fibers (Figure 4e). The hemp fibers are narrow and interwoven between virgin fibers, which have a uniform shape without breaks.



a) MR b) RW

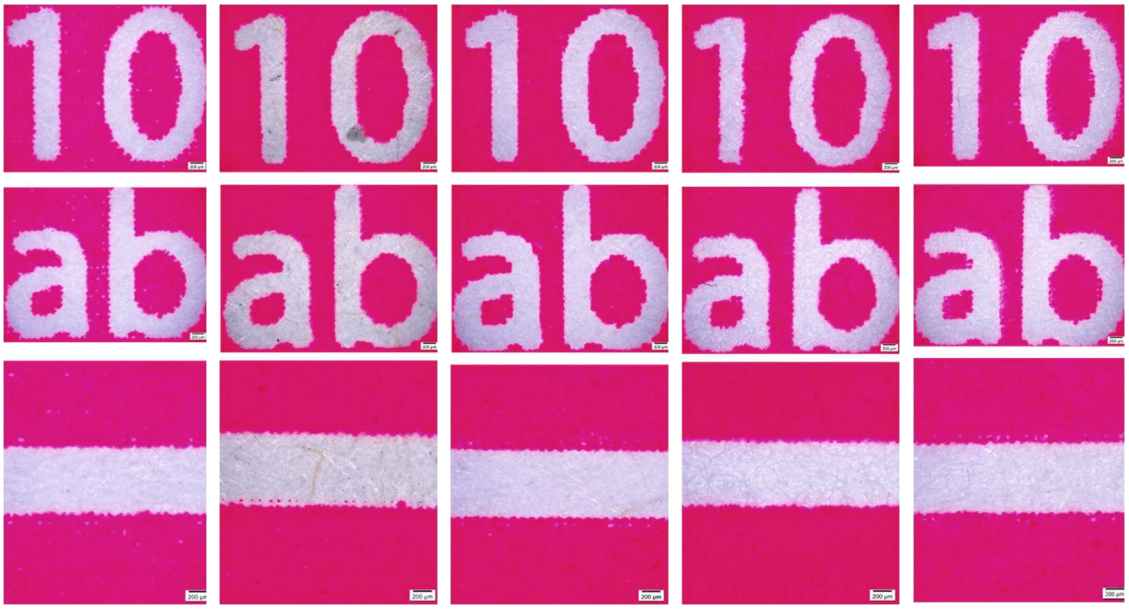
c) NC d) PC

e) MR

Figure 4: Microscopic images of the paper-printing substrate surface (100× magnification): a) MN; b) RW; c) NC; d) PC; e) MR

3.2 Properties of Printed Samples

Figure 5 shows microscopic images of the fluorescent printed edge elements and lines on selected printing substrates at 50× magnification. The edge elements and lines of the prints show irregularities in sample RW, while paper PC for example show greater smoothness. The selection of different paper substrates resulted in width of the printed lines screen-printed in negative (Figure 5, Table 3), which is the widest for MR, 738 µm with some irregularities, and narrowest for PC, 678 µm, where the line seems straighter and more precise (the nominal line width is 600 µm). Recycled RW and NC show a similar line width, but fluorescent prints result in a smoother line on NC substrate. This result could be related to possible fillers in NC paper composition, which contributes to more closed paper surface and better printability. The lines in the negative are wider on papers with higher absorptiveness (MR, RW); however, there was no significant growth of printed elements due to ink spreading or soaking on the paper surface.



a) MN b) RW c) NC d) PC e) MR

Figure 5: Microscopic images of the fluorescent printed edge elements and lines (negative) on selected printing substrates (50× magnification): a) MN; b) RW; c) NC; d) PC; e) MR

Table 3: The results of measured line width printed on selected substrates

Paper-printing substrate	Printed line width (µm)
MN	702
RW	757
NC	725
PC	678
MR	738

The results of measured spectral reflectance of the fluorescent prints on selected printing substrates (Figure 6) show similar trend for all samples, with curve peaking at two regions inside visible spectra, one at 440 nm and the other at 610 nm. A smaller peak at 440 nm results in spectral reflection between 32 and 50%. Spectral reflectance of fluorescent prints at 610 nm shows similar differences in the degree of spectral reflectance for all samples, with the highest peak resulting in 163 % for MR paper, followed by PC at 160 %, MN at 152 %, NC at 147 % and RW at 135%. These results are related to optical properties of the paper substrates, as well as their composition. A higher degree of whiteness and brightness results in higher spectral reflectance compared to recycled paper. Structural and surface properties of paper also affect the spectral reflection of fluorescent prints. The highest spectral reflectance of PC and MR can be linked to their lowest Bekk smoothness and highest bulk values of all measured samples. PC also resulted in high optical properties, which also contributed to high spectral reflection of fluorescence prints.

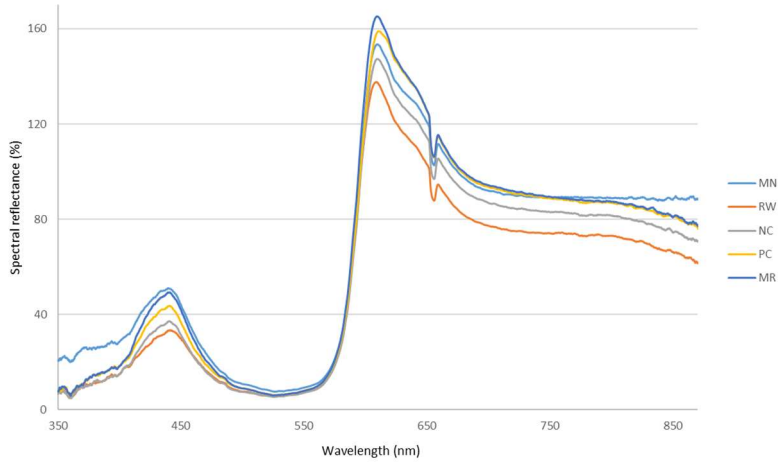
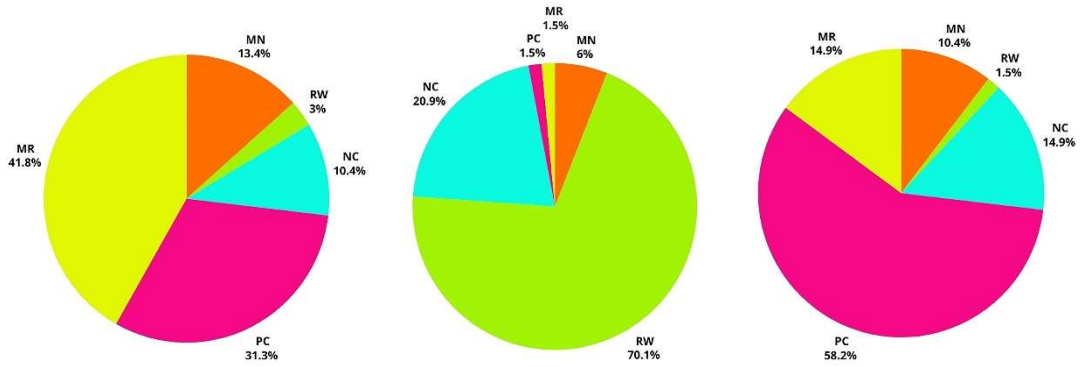


Figure 6: Spectral reflectance of the fluorescent prints on selected printing substrates

The survey was conducted to identify the most acceptable paper substrate for designs printed with fluorescent inks. Along with samples of motifs printed on all paper-printing substrates, respondents were asked to evaluate on which substrate does the printed element seem most noticeable (Figure 7a), on which substrate the printed element seems least noticeable (Figure 7b), and which solution of the printed element would they recommend (Figure 7c). The results correlate with the results of spectral reflectance of the prints, which is the highest for MR and PC, evaluated as the substates with most noticeable fluorescent prints (MR – 41.8% and PC – 31.3%). Even 70.1% evaluated sample RW as the least noticeable, which also confirms the lowest spectral reflection of this sample. 58.2% of the respondents would suggest PC paper as the solution for the printed element. These results are consistent with the results of spectral reflection, edge elements and printed lines conducted in this research.



a) b) c)

Figure 7: The results of the research survey: a) the printing surface on which the printed element appears most noticeable; b) the printing surface on which the printed element appears to be the least noticeable: c) the solution of the printed element proposed by the respondents

4. CONCLUSIONS

This study determines the impact of different uncoated paper substrates made from recycled and non-woody plant fibers on the optical performance of fluorescent prints. Papers from non-woody plants, made of cotton and hemp (MR, PC), demonstrated high optical properties, including whiteness and brightness, which enhanced the spectral reflectance of fluorescent prints. These substrates also provided smoother surfaces and better print quality compared to recycled papers (NC, RW).

Fluorescent inks performed best on cotton (PC) and hemp-based papers (MR), with the highest spectral reflectance values and improved line sharpness. Survey results supported these findings, showing a clear preference for non-woody plant-based substrates for visual appeal. Overall, cotton and hemp papers represent a promising, sustainable alternative to traditional fibers for high-quality fluorescent printing applications, with potential in packaging, signage, and security printing.
The result of this study suggests that further research into these fibers could yield even better results across more printing techniques.

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EVALUATION OF THE MIGRATION POTENTIAL OF COLORANTS AND ADDITIVES IN PAPERBOARD FOOD PACKAGING MATERIALS

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Abstract: *The increasing implementation of wastepaper collection and recovery has led to an increase in the use of recycled paper and board as food packaging materials. These materials, which are made entirely or partially from recycled fibres, are widely used for food packaging in Europe. However, the potential presence of contaminants in recycled pulp raises concerns about their suitability for food contact applications due to the potential for migration issues.*
In this study, three different paperboard food packaging materials from the Croatian market were tested for their chemical stability and migration of potentially harmful substances. The materials included a Kraftliner sample (made of predominantly virgin fibre pulp), a Brown Testliner sample (top ply made of virgin fibres, bottom ply made of recycled fibre pulp) and a printed French Fries Box (combination of deinked and mechanically recycled pulp). The French Fries Box also contained pigment coating and a partial internal print.
The research focused on testing the migration of colorants (EN 646) and fluorescent whitening agents (FWAs) (EN 648) using food simulants such as olive oil, 3% (m/v) aqueous acetic acid, deionized water, isooctane and saliva simulant. In these test methods the test specimen is placed between two glass fibre papers previously saturated with the test liquids and, after the contact time at room temperature, the bleeding of the colorants or FWAs onto the glass fibre paper is evaluated. In addition, the potential transfer of antimicrobial components, indicating the potential toxicity of the material, was also evaluated by testing the growth inhibition of the bacterium Bacillus subtilis (EN 1104). The results of all analyzes performed were compared with the purity requirements for materials set out in the German national regulation and CEPI's Food Contact Guidelines for the Compliance of Paper and Board Materials and Articles.
The results of migration of colorants were observed only in the Testliner sample in cases where food simulants such as water, acetic acid and saliva solution were used. Unacceptable bleeding of FWAs was confirmed in the French Fries Box sample where the highest level of bleeding was observed in the case when food simulant was water, and to a slightly lesser extent FWAs migrated into glass fibre papers saturated with acetic acid and saliva food simulant. The results of the microbiological tests were positive, as no inhibition zones for bacterial growth were detected in any of the tested paperboards, meaning that none of the samples released antimicrobial substances.

Key words: food packaging, recycled paperboard, colorant migration, FWAs, antimicrobial transfer

1. INTRODUCTION

In the European Union, the growing interest in environmental issues has led to the collection and recovery of increasing amounts of paper waste materials. According to Cepi Key Statistics, in 2022, 70.5% of all paper and board consumed in Europe was recycled, making it one of the most collected and recycled materials in the region (Cepi, 2022). Furthermore, 73.9% of the collected paper for recycling was utilized in packaging paper and board production. Compared to 2020 (73.9%) (Cepi, 2020) and 2021 (72.8%) (Cepi, 2022), the recycling rate has slightly declined, primarily due to reduced paper production and the high costs of electricity and gas, which have negatively impacted paper recycling mills. However, the current recycling rate of 70.5% still places Europe well ahead of the global average recycling rate of 59.9% in 2021 (EPRC, 2022).
In 2021, the European paper value chain pledged to recycle 76% of all paper consumed by 2030, aiming for a 76% recycling rate. The recycling rate is defined as the ratio between the recycling of used paper, including the net trade of paper for recycling, and the consumption of new paper and board. This commitment is outlined in the new European Declaration on Paper Recycling 2021-2030, indicating that the recycling rate will continue to rise with these efforts (EPRC, 2022).
As the collection and recycling of waste paper has been introduced on a larger scale, the use of recycled paper and board as packaging material for food has also increased. In many European countries, paper and

ORCID number is provided at the end of the paper.

board made partly or entirely from recycled fibres are used as primary or secondary packaging for food. However, depending on the origin of the recycled fibres and the way they are prepared and treated, it is possible that even after recycling, potentially harmful substances may remain in the recycled pulp in concentrations that can lead to unacceptable migration, making the recycled paper and board unsuitable for food contact applications (Jamnicki et al., 2015; FoodDrinkEurope, 2016). In recent studies on paper food packaging, various substances such as phthalates, solvents, primary aromatic amines and mineral oils have been detected in recycled pulp (Boccacci Mariani, Chiacchierini & Gesumundo, 1999; Summerfield & Cooper, 2001; Binderup et al., 2002; Biedermann, Uematsu, & Grob, 2011; Suciu et al., 2013; Pivnenko, Eriksson & Astrup, 2015; Vápenka, Vavrouš, & Votavová, 2016; Boccacci Mariani et al., 2015; Geueke, Groh & Muncke 2018). To ensure food safety in packaging made from recycled fibres, the recovered paper grade must be carefully selected, and the material must undergo appropriate treatment and cleaning processes. This ensures that the finished product complies with the general requirements of the EU Framework Regulation (EC) No. 1935/2004 (European Commission, 2004) and Regulation (EC) No. 2023/2006 on Good Manufacturing Practices (GMP) (European Commission, 2006). These regulations stipulate that materials in contact with food must not transfer harmful substances, alter the composition of the food, or impair its sensory properties (Boccacci Mariani et al., 2015; European Commission, 2004; European Commission, 2006).

However, aside from the general requirements outlined in these regulations, there is currently no harmonized legislation in the EU for the use of recycled paper in food packaging. As a result, some Member States have implemented their own laws. National regulations often define the chemicals permitted in the manufacture of paper and board and set limits for various contaminants in finished products (Von Wright, 2007).

The recommendation of the German Federal Institute for Risk Assessment (BfR), known as the *BfR Recommendations on Food Contact Materials* (BfR, 2023), is regarded as the most reputable regulation in Europe for paper packaging (Vápenka, Vavrouš & Votavová 2016). In the absence of uniform legislation across Europe, to help manufacturers of paper and board navigate the various regulations in force, the European paper and board industry, along with converting sectors and other associations, has published a guideline document entitled *Food Contact Guidelines for the Compliance of Paper and Board Materials and Articles* (CEPI/CITPA, 2019). This document, formally referred to as the *CEPI Industry Guideline*, along with the BfR recommendations, specifies migration limits for contaminants commonly found in recycled paper and board intended for food contact applications. Although these limits are not mandatory, paper manufacturers are encouraged to comply voluntarily if they wish to achieve higher safety standards for food packaging containing recycled fibres.

In this research, three different paperboard food packaging materials were subjected to testing for chemical stability in terms of not releasing colorants from recycled and/or coloured paper and board. Additionally, the potential migration of fluorescent whitened agents (FWAs) was tested, as well as the possible transfer of antimicrobial constituents indicating the potential toxicity of the tested samples. The results of the conducted analyses were compared with the quantitative restrictions laid down in the German (BfR) regulation (BfR, 2023) and CEPI Industry Guideline (CEPI/CITPA, 2019).

2. MATERIALS AND METHODS

Three different paperboard packaging materials were chosen for this study (Table 1) taken from Croatian market – a Kraftliner sample containing mostly virgin fibre pulp, a Brown Testliner sample having the top ply made of virgin fibres, and the bottom ply made of recycled-fibre pulp. Both linerboards were unprinted. The third simple was a printed French Fries Box used for fast food applications. French Fries Box was made of a combination of deinked and mechanically recycled pulp. The outer surface of the box was coated with pigment coating and contained a printed design on top. In addition, the inner, food contact side of the box, was also partially printed with yellow ink that covered approximately 40% of the inner surface.

Table 1: Properties of tested paperboard samples

	Basis weight (g/m^2)	Moisture Content (%)
Kraftliner	139	6.3
Brown Testliner	129	4.0
Printed French Fries Box	252	5.3

2.1 Determination of bleed fastness of FWAs and colorants

The transfer of fluorescent whitened agents (EN 648) (European Standard, 2006b) and colorants (EN 646) (European Standard, 2006a) from the paperboard samples were tested with test fluids such as rectified olive oil, 3% (m/v) aqueous acetic acid, deionized water, iso-octane and saliva simulant. In these test procedures, the sample is brought into contact with glass-fibre papers previously saturated with a test fluid (food simulant) and placed under a 1 kg load for 24 h. For each sample, the test was performed with one replication and the results are presented as the arithmetic mean of two measurements. Both sides of the paperboard were subjected to the tests. The staining of the glass fibre paper was evaluated comparatively with a series of fluorescent whitened papers under the UV light in the UV-A range (for the detection of FWAs) or against a grey scale (for colour fastness analysis). For both test procedures no staining of the fibre glass paper should be obtained, meaning that the value 5 on the evaluation scale must be reached – according to the German (BfR) regulation and CEPI Industry Guideline. This is especially important in case of packing the moist and/or fatty foods (CEPI/CITPA, 2019).

2.2 Determination of the transfer of antimicrobial constituents

The selected paperboard samples were tested for their effect on the growth of the bacterium *Bacillus subtilis*. The method outlined in EN 1104 (European Standard, 2005) is widely used for testing the antimicrobial activity of materials. This method is based on detecting the inhibition zone in bacterial growth, which results from the diffusion of antimicrobial agents in agar plates. In this test procedure, Petri dishes were prepared with *Bacillus subtilis*, and three test pieces from each paperboard sample were placed on the semi-solid nutrient medium. The plates were then incubated for 3 days at 30°C to allow bacterial growth. After incubation, the presence of an inhibition zone (an area with no bacterial growth) indicated the release of antimicrobial constituents. The test determines whether the paperboard samples release antimicrobial substances in quantities sufficient to inhibit bacterial growth, thereby reflecting the toxicity of the tested papers. Each sample was tested in duplicate. According to the German BfR regulation and CEPI Industry Guideline "the finished paper or paperboard must have no preserving effect on the foodstuffs with which they come into contact". This requirement applies to all types of foods (CEPI/CITPA, 2019). Samples with no evidence of an inhibition zone are considered to lack water-soluble antimicrobial substances. Therefore, overgrown samples (without an inhibition zone) are evaluated as suitable for food contact.

3. RESULTS AND DISCUSSION

The bleeding of colorants was evaluated by measuring the lightness difference (ΔY_{tristm}) of glass fiber filter paper before and after the migration (exposure) test. The surface of the filter paper, saturated with the prescribed food simulant solution and in contact with the test piece during the test, was measured with a spectrophotometer both before and after the migration test (measuring only the tristimulus value Y). The resulting lightness difference was then compared to a defined lightness scale, known as the Grey Scale (ΔY_{tristm}), in accordance with the EN 20105-A03 standard (European Standard, 2003). The results of the evaluation of colorant migration from one side (A) and the other side (B) of the tested samples are shown in Tables 2-4.

Table 2: Results of colorants migration from the Kraftliner sample

Kraftliner	H_20	CH_3COOH	Saliva simulant	Iso-octane	Olive oil
(A) $\Delta Y_{tristm.}$	0.20	0.53	0.55	0.33	2.98
GRADE	5	5	5	5	4-5
(B) $\Delta Y_{tristm.}$	0.56	0.40	0.44	0.39	1.18
GRADE	5	5	5	5	5

Table 3: Results of colorants migration from the Brown Testliner sample

Testliner	H_20	CH_3COOH	Saliva simulant	Iso-octane	Olive oil
(A) $\Delta Y_{tristm.}$	10.08	9.33	11.06	1.38	3.48
GRADE	3	3	2-3	5	4-5
(B) $\Delta Y_{tristm.}$	7.13	9.60	8.92	0.92	1.41
GRADE	3	3	3	5	5

Table 4: Results of colorants migration from the Printed French Fries Box sample

Printed Box	H_20	CH_3COOH	Saliva simulant	Iso-octane	Olive oil
(A) $\Delta Y_{tristm.}$	0.00	0.13	0.22	0.33	2.98
GRADE	5	5	5	5	4-5
(B) $\Delta Y_{tristm.}$	0.26	0.00	0.84	0.59	1.01
GRADE	5	5	5	5	4-5

Table 5 shows the criteria used to evaluate the migration of colorants from the tested samples onto filter paper. Based on the defined lightness difference ($\Delta Y_{tristm.}$), the tested sample is assigned values ranging from 1 to 5 (in 9 degrees, including half steps). According to the German BfR regulation and CEPI Industry Guideline value 5 on the evaluation scale should be obtained, meaning there is no migration of colorants to the foodstuff. Test pieces having a value less than 5 are declared unsuitable for contact with certain types of food, depending on the food simulant for which the negative rating was obtained.

Table 5: Comparison of the range of lightness difference values (ΔY_{tristm}) with the corresponding rating on the Grey Scale (EN 20105-A03)

Fastness grade	$\Delta Y_{tristm.}$	Tolerance
5	0.0	0.2
4-5	2.2	±0.3
4	4.3	±0.3
3-4	6.0	±0.4
3	8.5	±0.5
2-3	12.0	±0.7
2	16.9	±1,0
1-2	24.0	±1,5
1	34.1	±2.0

When reviewing the results for all tested samples, it is evident that only the Brown Testliner sample showed unacceptable results in the case of water, acetic acid, and saliva food simulants. This means that such a paperboard should not be used in contact with moist food, nor with food that has an acidic character. For all other tested samples, positive results were obtained for all standard food simulants, indicating that there is no risk of colorant migration from such materials.

Tables 6 and 7 show the results of the migration of fluorescent whitening agents (FWAs) from one side (A) and the other side (B) of the tested paperboard samples. The staining of the glass fibre papers on the side that was in contact with the sample was compared with a series of comparison fluorescent papers under a UV lamp. UV light in the UV-A range was used to illuminate the samples. The comparison filter papers were prepared as follows: One gram of the fluorescent whitening agent (Fluorescent Whitener 28, content 90%,

C.I. 40622, CAS number: 4193-55-9) was dissolved in one litre of deionized water to prepare stock solution (1000 mg/l), which was then diluted with water in four different ratios. Specifically, four different volumes of the stock solution (125 ml, 31 ml, 8 ml and 3 ml) were taken and each diluted with one litre of deionized water. The prepared diluted solutions were dripped onto glass fibre papers, which were then air-dried without exposure to light and used as comparison standards after drying. The evaluation criteria are listed in Table 8 (European Standard, 2006b). According to the German BfR regulation and the CEPI Industry Guideline, a score of 5 is considered positive, while lower results (4, 3, 2 and 1) are considered negative, indicating that the tested sample releases fluorescent whitening agents into certain types of food in quantities exceeding the permitted limits. Food simulants used in this test procedure were deionized water, 3% (m/v) aqueous acetic acid, saliva simulant and olive oil.

Table 6: Results of the migration of FWAs measured on side A of the samples

Side A of the sample	Kraftliner	Brown Testliner	Printed Box
Food simulant			
H_20	5	5	3
CH_3COOH	5	5	4
Saliva simulant	5	5	4
Olive oil	5	5	5

The results presented in Tables 7-8 show that significant migration of FWAs only occurred in the printed French Fries Box when water was used as a food simulant. To a slightly lesser extent, FWAs also migrated into glass fibre papers saturated with acetic acid and saliva simulants. This suggests that such packaging should not be used in direct contact with aqueous or acidic foods. Notably, stronger migration of FWAs from this sample was observed on the "A" side (the inner side of the box) when exposed to the aqueous medium, while the outer "B" side showed a more moderate migration (rating 4). As this carton is used for the packaging of French fries, which have a high fat content, the migration into the glass fibre paper saturated with olive oil received an acceptable score of 5. This indicates that this type of packaging can be safely used in direct contact with fatty foods as intended. Previous studies (MAFF, UK, 1995) have shown that FWAs are soluble in water and aqueous solutions, but not in the oily or fatty components of food.

Table 7: Results of the migration of FWAs measured on side B of the samples

Side B of the sample	Kraftliner	Brown Testliner	Printed Box
Food simulant			
H_20	5	5	4
CH_3COOH	5	5	4
Saliva simulant	5	5	4
Olive oil	5	5	5

Table 8: Evaluation criteria (EN 648)

Evaluation grade	FWA-solution	FWA mg/l
1	125 ml stock solution diluted to 1 l	125
2	31 ml stock solution diluted to 1 l	31
3	8 ml stock solution diluted to 1 l	8
4	3 ml stock solution diluted to 1 l	3
5	blank with distilled water	0

The results of testing the transfer of antimicrobial substances from paperboard samples showed that none of the analyzed samples released substances with antimicrobial properties, as no inhibition zones for the growth of bacterial cultures were detected (Figures 1-3). From a microbiological point of view, all analyzed

samples can therefore be considered safe for direct contact with food, as the bacterial culture *Bacillus subtilis* was observed to have overgrown the paperboard samples in all tested cases.



Figure 1: Overgrown cultures of Bacillus Subtilis on Kraftliner samples

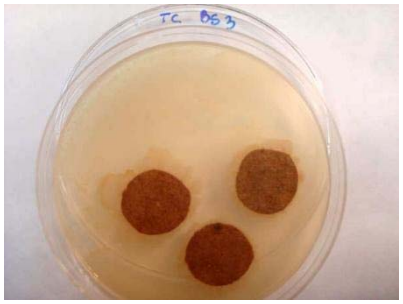


Figure 2: Overgrown cultures of Bacillus Subtilis on Brown Testliner samples

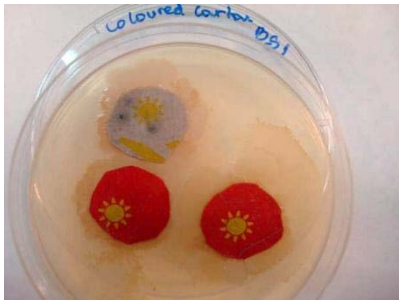


Figure 3: Overgrown cultures of Bacillus Subtilis on Printed French Fries Box samples

5. CONCLUSIONS

In this study, the chemical stability and migration of potentially harmful substances from three different paperboard food packaging materials available on the Croatian market, consisting of recycled and virgin fibres, were evaluated. Based on the results, the following conclusions can be drawn:

Migration of colorants was only observed in the Testliner sample when exposed to aqueous, acidic, and saliva food simulants. This indicates that such materials should not be used in direct contact with moist or acidic foods due to potential contamination risks. Other tested samples showed no colorant migration, making them suitable for various food packaging applications.

Significant migration of Fluorescent Whitening Agents was observed in the printed French Fries Box when it came into contact with water and to a lesser extent with acetic acid and saliva simulants. This suggests that the French Fries Box should not be used for packaging aqueous or acidic foods. However, it showed acceptable results when tested with olive oil, confirming its suitability for packaging fatty foods like French fries.

None of the paperboard samples released antimicrobial substances that could inhibit bacterial growth, as no inhibition zones were detected in any of the tests. From a microbiological point of view, all tested materials can therefore be considered safe for direct contact with food.
Materials made from virgin fibres or properly treated recycled fibres comply with safety guidelines and can be considered safe for food packaging based on the results of the food contact analyzes performed in this study, provided they are used with appropriate foods, especially with regard to moisture and acidity. To definitively prove that these materials are truly suitable for food contact, further testing is required, e.g. testing the concentration of certain chemical contaminants commonly found in paper packaging.
These results support the careful selection of paperboard materials for specific food contact applications, especially when recycled fibres are involved, to ensure food safety and compliance with industry regulations.

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STABILITY OF SILVER BASED CONDUCTIVE FILMS ON CELLULOSE BASED SUBSTRATES

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Abstract: *The possibility of integrating printed flexible electronic components into visual solutions that interactively communicate with the consumer represents a new direction in the development of sustainable solutions accessible to all target groups. Flexible electronic thin films are becoming one of the integral elements of visual communication, which means they must be incorporated into the design itself rather than being hidden beneath another element. Today's trends are increasingly directed towards the use of cellulose materials as more acceptable in packaging and other graphic products. In this regard, it was necessary to examine the mechanical, electrical, and colour stability of conductive thin films printed on cellulose substrates. This study examined the possibility of applying conductive silver-based film on cellulose based substrate through the examination of the electric conductivity of silver-based thin films by comparing the quality of prints on two substrates. Additionally, the resistance of printed thin films to double bending and rubbing was investigated. The values of electrical conductivity before and after mechanical testing were compared to explore the potential application of conductive inks in creating visually attractive and mechanically resistant silver-based conductive films. The research has shown that the substrate selection significantly affects the mechanical resistance of prints to bending. Additionally, despite significant visual changes in the conductive thin films, the electrical conductivity of the thin films did not change significantly.*

Key words: Conductive ink, cellulose based substrate, functional printing, mechanical resistance

1. INTRODUCTION

Printed sensors, including capacitive sensors, electrochemical sensors, and printed radio frequency identification tags, are some of the key beneficiaries of printing technologies, owing to their ability to be produced at low cost, on flexible substrates, and at high volumes. These sensors offer significant advantages in various industries, such as healthcare, environmental monitoring, logistics, and consumer electronics, where lightweight, compact, and easily deployable sensing solutions are required. The versatility of printing methods allows for the integration of these sensors into diverse applications, enabling the development of smart, connected devices and the expansion of the Internet of Things.

Various printing techniques are currently employed in the fabrication of electronic devices, including printed diodes (Ahmad et al., 2023), transistors (Arias et al., 2004), sensors (Shkodra et al., 2020), and antennas (Wiklund et al., 2021). Flexography, gravure, and inkjet printing utilize low-viscosity liquid inks, whereas offset, screen, and pad printing employ high-viscosity, paste-like inks (Izdebska 2016).

Printed thin films are created by depositing thin layers of functional inks onto a low-cost substrate that may be recyclable or biodegradable. The production process consists of three main stages: material selection, printing, and post-printing (Wiklund et al., 2021). The key materials used in printed thin films include inks with conductive, semiconductive, or dielectric properties, along with substrates typically made from synthetic or natural polymers.

Conductive inks on paper open new possibilities in the field of printed electronics, enabling the development of innovative and adaptable electronic solutions. This technology combines the advantages of paper materials with the electrical properties of conductive inks, allowing for the creation of flexible and lightweight electronic components that can be easily integrated into various applications. The use of conductive inks on paper can be applied in diverse areas, including environmental monitoring sensors, flexible circuits in wearable devices, and interactive applications in education and marketing.

One of the key benefits of this technology is the reduction in production costs, which facilitates faster and more economical prototyping and product manufacturing. Additionally, this innovation contributes to sustainability by using eco-friendly materials, which is particularly important in the context of the growing demand for sustainable electronic solutions. With the introduction of conductive inks on paper, we can anticipate advancements in the development of smart packaging, health monitoring devices, and other

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functional products that combine electronics with traditional materials, paving the way for new innovations and creative solutions in the industry.
Previous studies examined the performance variability of paper-based printed antennas, focusing on the effects of the printing process, changes in permittivity due to ink carrier absorption, and temperature. Surface roughness, thickness, and reflection coefficient were evaluated, with the screen-printed antenna showing the best performance (Ahmad et al., 2023). The impact of altered permittivity from ink absorption and temperature was also explored.
Advantages of eco-design in printed electronics are numerous, including more efficient material utilization, reduced energy consumption during both manufacturing and operation, decreased reliance on hazardous substances, and enhanced recyclability (Kunnari et al., 2009). In that sense the aim of this work is to explore the possibility for using conductive silver-based films on cellulose substrates by evaluating the electrical conductivity of these thin films and comparing the print quality on two different substrates. The research also assessed the resistance of the printed thin films to double bending and rubbing. The electrical conductivity values were compared before and after mechanical testing to investigate the feasibility of using conductive inks for producing visually appealing and mechanically durable silver-based conductive films.

2. MATERIALS AND METHODS

2.1 Materials

Since the goal is for the antenna to become an integral part of the design, atypical shapes to test their stability were created. The patterns for printing were prepared in Adobe Illustrator (Figure 1).



Figure 1: Patterns for printing a) sample for resistance measurement, b) sample for rub test, c) sample for double folding test

The screen-printing technique was used for printing, utilizing a capillary photosensitive film. The mesh used for creating the printing form in this study is SEFAR PME mesh with a mesh count of 140 lines per cm, and the base material is polyester, specifically poly(ethylene terephthalate). The form was exposed for 2 minutes in a screen-printing exposure machine. In this study, Saral HSCSilver 600 high-conductivity ink with a high solid content of 86% silver was used (Thermo Fischer 2012). The silver particles are dispersed in a solvent based on diethylene glycol monoethyl ether. The ink density is 3.7 g/cm³. This ink is designed for screen printing, with a recommended mesh count of 61 lines/cm and a thread diameter of 64 µm. It is suitable for printing mainly on polymer materials. This ink dries at a relatively low temperature (Thermo Fischer 2012). In this study the ink was cured (sintered) at 70°C for 10 minutes. The thickness of the dry ink layer is 19 µm. Prints were made on two different types of paper with the same weight, i.e., 200g/m², one being satin-finished and the other coated paper from the same manufacturer. Ten prints with the same patterns were made on each type of paper.

2.2 Electric resistance testing

Two-point resistance measurement with a multimeter was conducted on all line prints. Two-point resistance measurement is a straightforward technique used to determine the electrical resistance of a component by connecting two probes directly to its terminals. A small current is passed through the component, and the voltage drop across it is measured, allowing resistance to be calculated using Ohm's Law. This method is commonly employed due to its simplicity and effectiveness in providing quick resistance values. Electric resistance testing was conducted on samples printed with patterns in Figure 1a.

2.3 Mechanical testing

Two mechanical tests, resistance of paper substrates and prints to double bending and rub and abrasion tests, were conducted. The test is conducted by measuring the number of double bends a sample of specific dimensions (15 x 100 mm) can withstand before breaking. The paper sample is secured in clamps so that it passes through a vertical slit in a metal plate and is loaded with 9.81 N. Moving the plate back and forth causes the sample (specimen) to undergo double bending. Double bend testing was conducted on samples printed with patterns in Figure 1c.

By testing the resistance of prints to abrasion, the resistance of the finished (dry) print to the removal of the ink layer due to friction is determined. This occurs either from rubbing two prints together or from rubbing the test print against another material. For the preparation of the test, circular paper samples are cut, with the substrate having a diameter of 115 mm and the printed sample having a diameter of 50 mm. the prints were subjected to a rub resistance test using a Hanatek Rub and Abrasion Tester in accordance with the BS 3110 standard. Rub resistance test was performed on samples printed with patterns in Figure 1b.

The core of the device consists of two disks with different radii that are in contact over their entire surfaces. Driven by an electric motor, the disks rotate at the same angular speed. During testing, the sample and the substrate made of the same material are placed on the disks, and the pressure between them is regulated by placing weights of different masses on the top disk. The ink removed from the surface of the print due to rubbing is transferred to the abrasion substrate. An air supply tube removes the particles of dislodged ink from the sample during the test, preventing additional abrasive action of the dislodged particles on the sample. After a specified number of abrasions (10, 20, and/or 40), the device stops. The samples (prints) and the abrasion papers are visually assessed to determine whether the resistance to abrasion is satisfactory. The assessment is carried out by comparing the transfer of printing ink from the tested sample to the abrasion substrate. The samples are then evaluated with scores from 1 to 5, where 1 is the highest score and is awarded to the sample with the greatest resistance, and 5 to the sample with the least resistance, according to the following scale:1 - no visible fingerprint smudging (no smudging) 2 - slight signs of fingerprint smudging 3 - noticeable fingerprint smudging 4 - significant fingerprint smudging 5 - very pronounced fingerprint smudging

3. RESULTS AND DISCUSSION

The number of double folds for unprinted satin paper (MS0) ranges from 65 to 281, with an average of 151 and a standard deviation of 79 (Figure 2). Exposing unprinted satin papers (MS) to 70°C for 10 minutes shows no significant change, maintaining an average of 156 and a standard deviation of 43. In contrast, printed satin paper (MSP) exposed to the same conditions shows a significant drop in double folds, with values between 8 and 32, averaging 16 and a standard deviation of 9. This indicates much lower resistance to double folds compared to unprinted satin paper. Unprinted coated paper (MG0) ranges from 270 to 543 double folds, averaging 410 with a standard deviation of 91, making it more resistant than satin paper. After exposure to 70°C for 10 minutes, coated paper (MG) shows values between 147 and 364, with an average of 273 and a standard deviation of 77, which is lower than unexposed coated paper. After printing and exposure, double folds range from 10 to 84, averaging 42 with a standard deviation of 26. Graph 1 illustrates that printed papers (MSP, MGP) have significantly lower mechanical resistance to double folds than unprinted papers (MS0, MS, MG0, MG). The mechanical resistance of satin papers changes little after exposure, while coated papers show substantial differences, affirming that coated papers are more resistant due to filler additions. The standard deviation for sample types is extremely high, which suggests a significant level of variability in the data collected. This variability can undermine the reliability of the results and may lead to inaccurate conclusions. Therefore, increasing the number of measurements is essential to enhance the statistical robustness of the findings. A larger sample size will help to reduce the impact of outliers and random errors, ultimately providing a clearer picture of the true trends and patterns. By obtaining more measurements, a more accurate assessment can be achieved and ensured that the results are applicable to broader contexts.

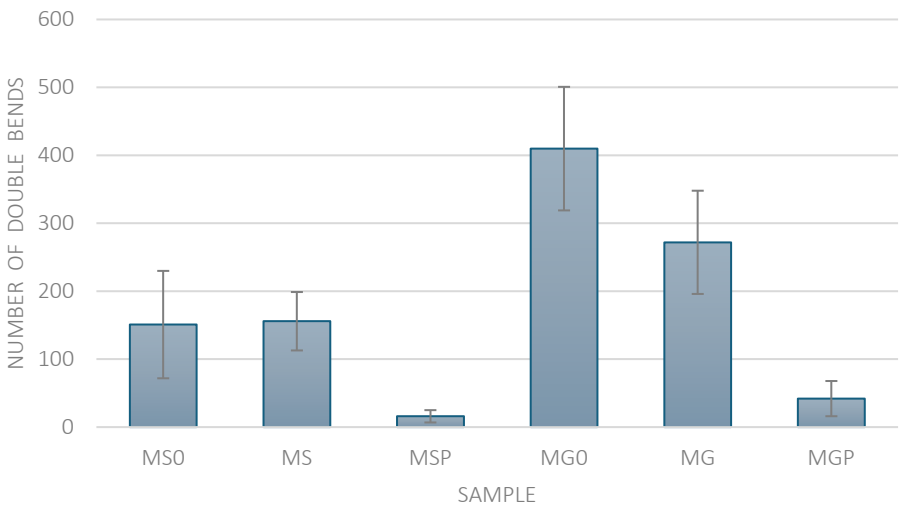


Figure 2: Comparison of the results of double folds for coated papers (MG0 - original paper, MG - paper exposed in the oven, MGP - printed thin film exposed in the oven) and satin papers (MS0 - original paper, MS - paper exposed in the oven, MSP - printed thin film exposed in the oven)

As for rub resistance tests, in Figure 3, the initial print before rub resistance test (MG_0) is shown alongside prints after rub resistance tests with no weights applied at 10 (MG_1) and 20 rotations (MG_2). Here, the rub resistance is not excessively visible, and the print largely retains its original appearance.

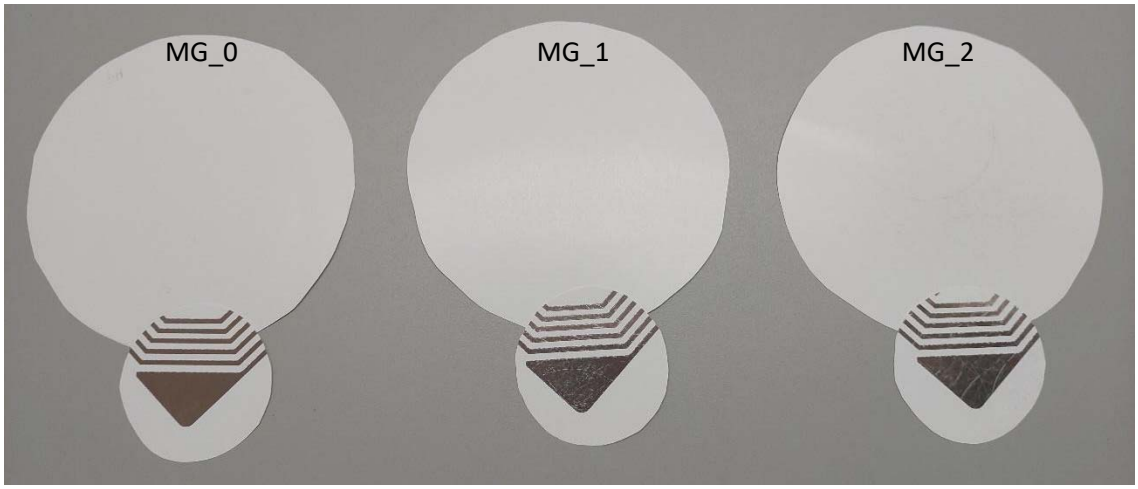


Figure 3: MG 0,1,2

In Figure 4, prints after 30 (MG_3), 40 (MG_4), and 50 rotations (MG_5) without weights are shown. Here, the abrasion on the prints is more noticeable, resulting in lower scores during visual assessment. Although little ink remains on the substrate, the prints themselves are visibly damaged.

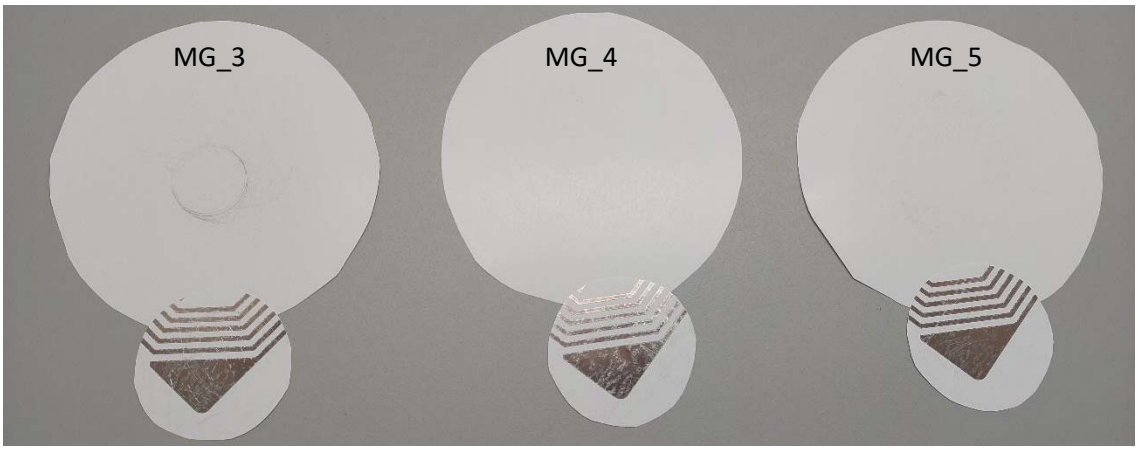


Figure 4: MG 3,4,5

In Figure 5, the initial print (MG_0) is displayed alongside prints after 10 (MG_6) and 20 rotations (MG_37) with weights. While it was anticipated that adding weights would adversely affect the abrasion, no significant differences are evident when compared to the prints tested without weights.

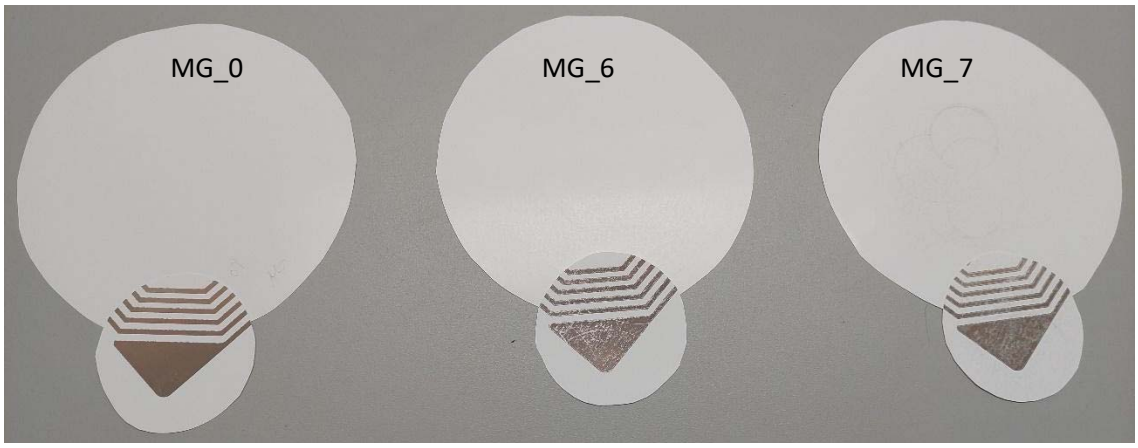


Figure 5: MG 0,5/,6

Figure 6 displays prints after 30 (MG_8), 40 (MG_9), and 50 rotations (MG_10) with weights. Here, the smudging is significantly more pronounced, evident both on the substrate and on the prints themselves, which show clear signs of damage. These observations are also corroborated by the results of the visual assessment.

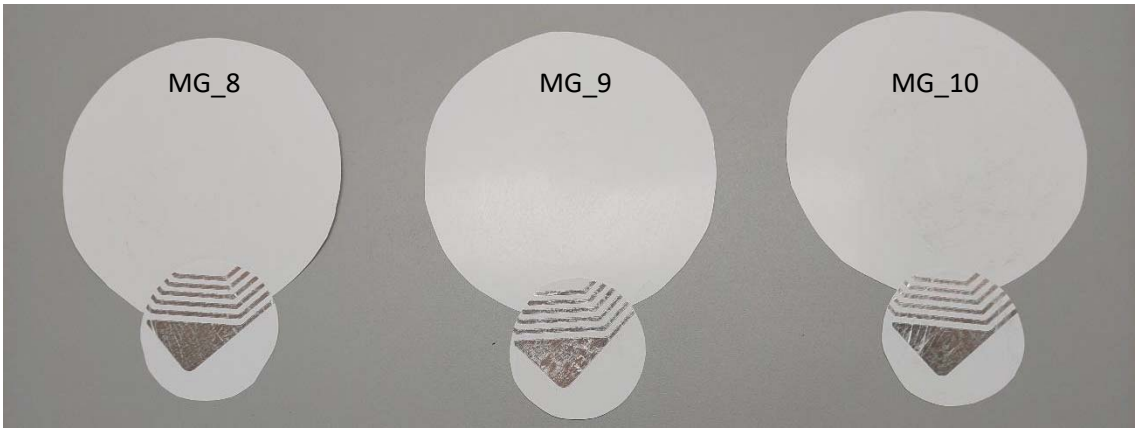


Figure 6: MG 8,9,10

The results show that prints with fewer rotations received higher ratings (Table 1), as there was minimal ink transfer to the substrate and fewer imperfections in the prints. In contrast, as the number of rotations increases, the effects of rubbing becomes much more evident. Abrasion is particularly noticeable on satin paper. The most significant negative impact is observed in the prints subjected to 50 rotations with weights. Figure 7 presents the initial print (MS_0) along with prints after 10 (MS_1) and 20 rotations (MS_2) without weights. In these samples, abrasion is minimal, and the prints have largely maintained their original appearance.

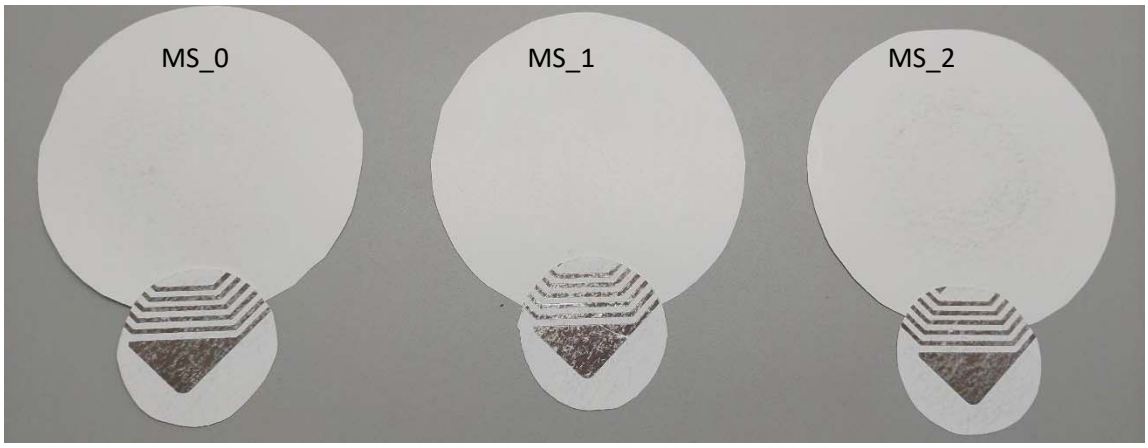


Figure 7: MS 0,1,2

The abrasion of prints after 30 (MS_3), 40 (MS_4), and 50 (MS_50) rotations without weights is illustrated in the Figure 8. The abrasion is most pronounced after 30 rotations, while it becomes less noticeable at 40 and 50 rotations, leading to prints that exhibit less overall damage. While ink transfer to the substrate is minimal, the prints exhibit visible damage, though still within acceptable limits (Figure 9). The most significant damage is observed in the print that was tested with the frequency of 40 with weights (Figure 10). The prints after 30 and 50 rotations are quite similar, with less noticeable damage.

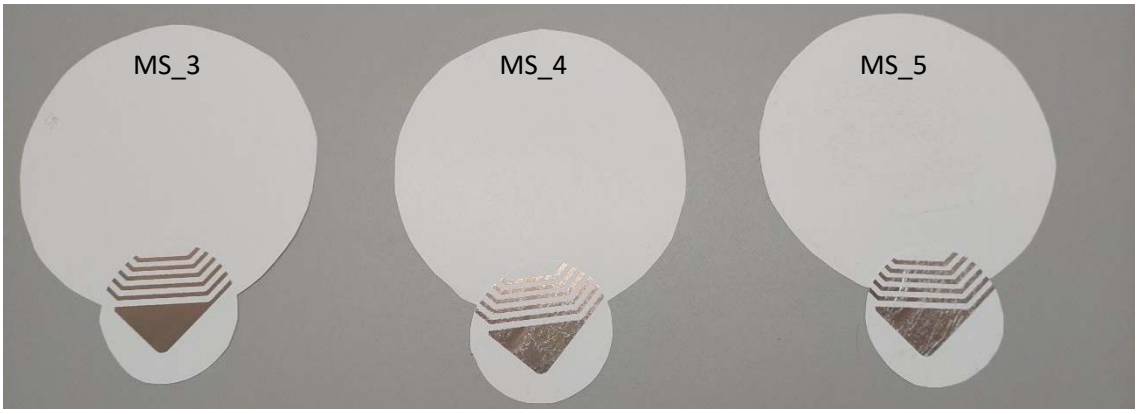


Figure 8: MS 3,4,5

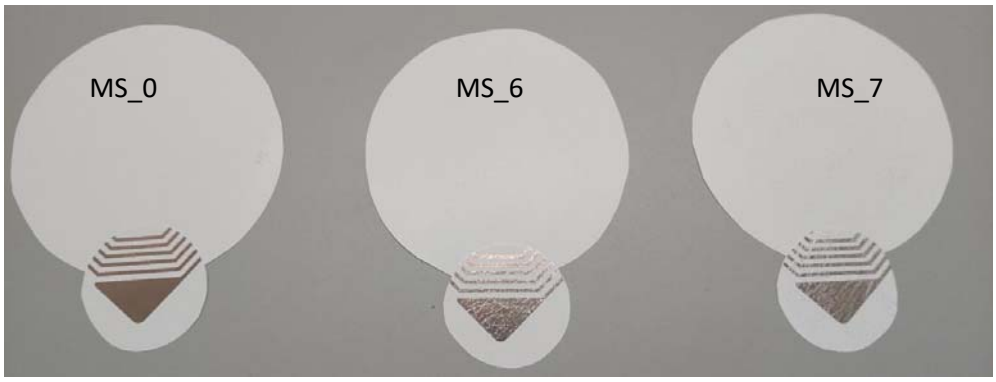


Figure 9: MS 0,6,7

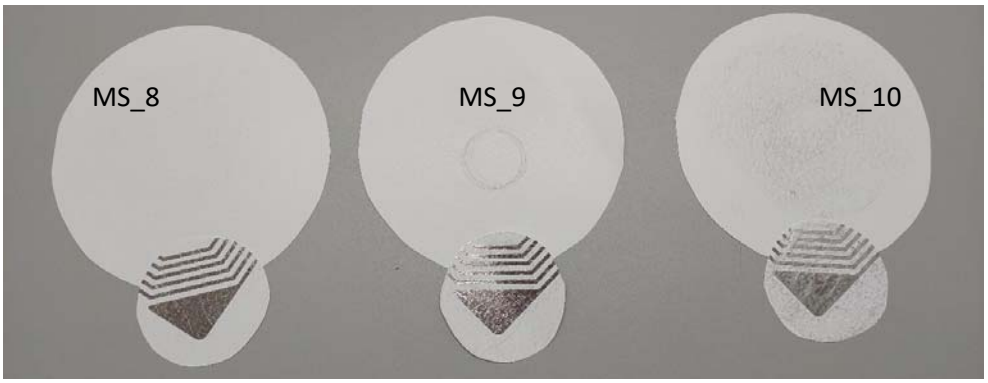


Figure 10: MS 8,9,10

The visual assessment of coated paper is notably better. In comparison to satin paper, abrasion is less prominent across multiple samples (Table 1). When comparing the results for rub resistance on satin and coated paper, it is clear that less ink transfers from prints made on coated paper, making these prints more durable.

Table 1: Evaluations of the visual assessment of prints on coated papers (MG 1-10) and satin papers (MS 1-10)

Sample	Grade	Sample	Grade
MS-1	2	MG-1	2
MS-2	2	MG-2	1
MS-3	3	MG-3	4
MS-4	4	MG-4	3
MS-5	4	MG-5	2
MS-6	2	MG-6	3
MS-7	3	MG-7	4
MS-8	3	MG-8	3
MS-9	4	MG-9	4
MS-10	5	MG-10	3

The average electrical resistance of the selected line on the coated paper measures 135 ohms, in contrast to 51 ohms for the satin paper. The standard deviation is significantly greater than any individual measurement, indicating inconsistency in the obtained prints. The values obtained from measuring the resistance of lines printed on paper can be highly unbalanced due to several factors. Firstly, the inherent variability in the printing process itself can lead to inconsistent ink deposition, resulting in uneven conductivity along the printed line. Additionally, the properties of the paper substrate, such as its texture and moisture content, can affect how the ink adheres and interacts with the surface, further contributing to variations in resistance. Lastly, environmental factors, such as temperature and humidity, can also impact the electrical properties of both the ink and the paper, leading to fluctuating resistance measurements.

4. CONCLUSIONS

The research results show that conductive thin films based on silver printed using screen printing on fibrous substrates exhibit variable properties in response to various external factors, such as mechanical bending, abrasion, and exposure to high temperatures. Thin conductive films printed on coated papers demonstrated greater resistance and stability compared to those on satin papers, highlighting the importance of selecting an appropriate substrate for applications in smart packaging solutions. However, challenges such as reduced mechanical resistance after printing and heat exposure indicate a need for further research and optimization of the process. Although silver-based conductive inks provide a solid foundation for the further development of printed electronic components on paper substrates, implementing them in mass production will require additional improvements to achieve long-term durability and sustainability. These results represent a step forward in the development of sustainable smart packaging that integrates advanced technologies while preserving the environment. Future research should focus on sintering the prints at higher temperatures to enhance their conductivity, although higher-temperature sintering may cause the paper to become more brittle and less resistant to external mechanical impacts, such as double bending. Therefore, the study should be conducted on a variety of papers to identify one that is less negatively affected by exposure to high temperatures. Additionally, to ensure the results are as relevant as possible and to discount measurements with excessive deviations, future research must involve a significantly larger number of measurements to identify the best printing substrate and the optimal finishing method for the prints.

5. ACKNOWLEDGMENTS

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IMPROVEMENT OF TRADITIONAL PAPERS SURFACE AND AS USE FINE ART PAPER

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Abstract: *The objective of this study is to promote a more dynamic utilization of traditionally produced papers for artistic purposes. Specifically, the aim is to enhance the suitability of papers made through traditional methods using bast fibres from hemp, flax and linden plants for drawing and painting. To achieve this goal, a polysaccharide-based biopolymer material was employed during production. This biopolymer material was utilized in two ways: during the papermaking process and subsequently as a surface coating, where it was combined with starch. The visual quality and printability of the resulting papers, both produced and coated, were assessed.*
In our research, seaweed was utilized as a biopolymer to contribute to sustainability efforts. The inclusion of seaweed extract improved both the surface and barrier properties of the papers. By integrating bi-based seaweed into this study, we aim to introduce a new dimension to traditionally produced papers while promoting the principles of the circular economy.
This preliminary study aims to lay the groundwork for future research by providing insights that enhance the quality of artistic papers in both traditional and industrial paper production contexts.

Key words: Traditional paper, coating, printing, alga, seaweed, biopolymer

1. INTRODUCTION

Since its invention, paper has held a significant place in our lives, and although it has been continuously developed over time, its basic production method has remained the same. Paper was first produced in China and brought to Europe in the 11th and 12th centuries. After observing the paper mills in Italy, a German entrepreneur, Ulman Stromer, established the first paper mill north of the Alps, in Nuremberg. The printing revolution, initiated by Johann Gutenberg's invention of the printing press, was able to progress due to the prior establishment of paper mills such as Stromer's (Bloom, 2001).
Etymologically, the word 'paper' is derived from the Ancient Greek word papyrus, which was used for the Cyperus papyrus plant. The papyrus refers to a thick, paper-like material produced from the pith of the Cyperus papyrus plant, commonly used for writing in ancient Egypt. Before the industrialization of paper production in China, the most common source of fibre was recycled fibres obtained from used textiles, known as rags. These rags were made from hemp (Cannabis sativa), flax, and cotton. In Rajasthan, India, rare Islamic papers were made from hemp or grass stalks, dyed with plant-based colours, and polished by rubbing the sheets with a smooth stone (Khadi papers). The invention of paper from softened plant fibres is mostly attributed to the Chinese eunuch Ts'ai Lun (105 AD). The exact date of the first production of paper in India remains unclear; however, some sources believe that paper was independently invented in India during the Buddhist period, around 250 BCE (Mukherjee & Keshri, 2018).
The annual production of petroleum-based packaging and other products continues to increase, depending on usage. In 2018, it reached 360 million tons, with 10% to 20% of this increase, which ranges between 22% and 43% annually, ending up in landfills and oceans. As a result, the consumption and consequently the production of paper, which serves as an eco-friendly alternative to plastic due to its recyclability, is steadily rising. In response to this, researchers have increasingly focused on developing fully bio-based polymer films in recent years. Edible and biodegradable films, such as those made from starch and ulvan, have also seen increased attention in innovative studies due to their sustainable properties. In this context, studies are being conducted to develop packaging using ulvan and starch as alternatives to plastic packaging.

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In this study, rather than using ulvan for packaging production, it was preferred for enhancing the properties of paper through surface coating. In 1996, a bachelor's thesis on paper production from seaweed was conducted in the Forest Products Chemistry and Technology Laboratory at Istanbul University-Cerrahpasa Faculty of Forestry. Since the produced paper exhibited low-quality properties, it was observed that seaweed alone was not suitable for paper production. As a result, it was decided to mix seaweed with wood fibres for production. Taking this drawback into account, and drawing on the idea that using seaweed on the surface of paper, rather than in its production, would be more interesting in light of recent innovative studies, this preliminary study was initiated. For this study, film coating experiments were carried out to improve the printability of handmade papers used in “Fine Art” printing by coating their surfaces with ulvan obtained from the extraction of green algae Ulva Lactuca sp.

The impact of paper, as a writing material, on people is too significant to be overlooked. Paper's primary function is to carry and disseminate information, but it is also widely used as packaging and as an artistic material. Since its invention, the paper has been continuously developed from a technical perspective. The journey of paper, which began 2,000 years ago with Ts’ai Lun in China, also marked the beginning of communication and artistic developments. Over the years, the paper has continued to serve as a medium for art, extending beyond writing to include everything from calligraphy to modern multi-colour prints. From this perspective, handmade papers are considered a unique art material, particularly because the natural beauty of their fibres contributes to artistic expression. Even the imperfections in these papers are seen as part of their charm, adding depth to the artwork. In this context, handmade papers can be regarded as canvases designed specifically for artists, who use them to create artwork with the help of paints and printing techniques.

In recent years, advancements in digital printing solutions have positively changed artists' perspectives on fine art edition productions. Technological improvements in material availability and print quality have made fine art printing more feasible. However, fine art printing still requires special attention to every aspect, from the substrate materials and printing inks to the printing and drying processes. Fine art printing involves reproducing paintings, photographs, drawings, and more using a digital printer and high-quality papers made from plants such as flax and hemp. The goal of this printing process is to produce long-lasting prints that remain faithful to the original work in terms of colour and detail. For this reason, both the ink and paper are crucial. The surface coatings of the papers used for artistic printing are expected to preserve colours and extend the lifespan of the artwork (Carnie, 2024).

In this study, handmade papers were produced as artistic papers using flax, hemp, and linden bast fibres. To improve the printability of the produced papers, a surface sizing process was applied. As an innovative approach, rather than traditional sizing methods, the surfaces were sized with seaweed extract. Seaweed, a type of microalgae, is categorized as green, brown, or red. Green seaweeds, as shown in Figure 1, are diverse, and our study material, Ulva Lactuca spp. (Figure 3a and b), is also an edible seaweed.



Figure 1: Varieties of Green Seaweeds

Algae are diverse in terms of their habitats and characteristics, ranging from single-celled forms like Chlorella sp. and diatoms to large, multicellular forms such as brown algae. Algae, which play a promising role in carbon sequestration, contribute to 50% of global photosynthesis. Algae used as raw materials in papermaking are seen as an innovative and alternative resource in addressing global environmental issues such as deforestation and global warming. Algae contain hemicellulose and cellulose but lack lignin, which is a desirable trait. When wood is used as a raw material in pulp production, lignin must first be removed from the material. However, when algae are used, this process is unnecessary. Nonetheless, algae alone are not suitable for producing high-quality paper; they need to be reinforced with appropriate annual plant

or wood fibres. Green seaweeds, which are an important part of coastal ecosystems, are rich sources of polysaccharides and amino acids. Studies have shown that the main components of Ulva seaweeds are cellulose and hemicellulose, with little to no lignin content.

2. METHODS

Samples of Ulva Lactuca spp. were collected from the shores of Sinop and Sinop-Gerze, located along the Black Sea coast of Turkey (Figure 2), during June and July 2024. The algae samples naturally grow on the rocky shores of the coastline. The collected seaweed samples (Figure 3a and b) were first washed with tap water and then with distilled water to remove sand and other debris. They were subsequently dried in an oven at 40°C. The dried seaweed samples were ground at the Oozden & KBA workshop. Until they were used, the samples were stored in a dry container at room temperature.

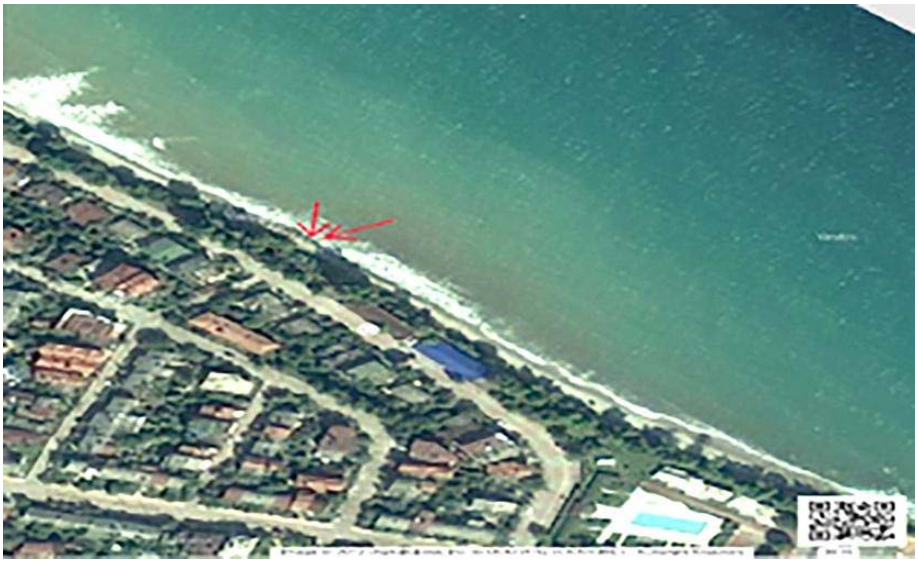


Figure 2: Ulva Lactuca Sample Area Sinop-Gerze Coast (from Google Map)



Figure 3a and b: Green Algea-Ulva Lactuca Spp. from Blacksea-Sinop and Gerze

For this preliminary study, traditional papers were produced using pulps made from flax, hemp, linden, and cotton bast fibres through traditional methods at the Oozden & KBA (Öznur Özden & Paper, Dye Workshop) studio (Figure 4). The papers were produced in A4 size, with an average weight of approximately 80g/m². No additives were used during the production of these papers.



Figure 4: Hemp pulp and hemp, linen, cotton and linden papers

From the ground samples of Ulva Lactuca spp. (Figure 5a and b), Ulvan was extracted to form Ulva films (Figure 6). Ulvan is a sulfated polysaccharide found in the cell walls of Ulva Lactuca spp. and is soluble in water. The Ulvan content in Ulva varies between 8% and 29% depending on the species (Wahlström, 2020). For this purpose, Ulvan, a polysaccharide, was dissolved in hot water extract, and 0.1% boric acid was added to the solution as a cross-linking agent. The suspension was plasticized by the addition of 2% glycerol. To achieve a homogeneous suspension, it was mixed with a magnetic stirrer at 50°C for 25 minutes and then stirred at room temperature for an additional hour (Sulastri et al., 2021). The prepared suspension was applied to the surfaces of the handmade papers both transversely and longitudinally using a brush. Subsequently, fine art prints were made on the coated paper samples. Ulvan hydrogel films were prepared by ionic cross-linking with boric acid and the addition of glycerol as a plasticizer.



Figure 5a and b: Dried and Ground Ulva Lactuca

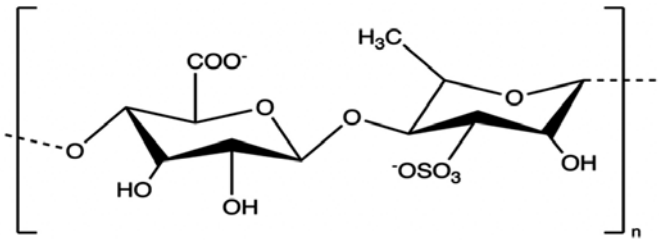


Figure 6: Chemical structure of ulvan (Wahlström, 2020)

The papers to be used for fine art printing were produced at the Oozden & KBA workshop. Handmade papers were created using pulps obtained from cooked flax, hemp, and linden bast fibres. The surfaces of the produced papers were coated with Ulvan hydrogel films extracted from seaweed, utilizing the method applied in Özden's natural tannin coating study (Özden, 2018). Test prints were made at the Fine Art Sanatsal Baskı Ltd. Studio using a Canon Pro 4100 model Ink Jet printer with 12 colours. In the Canon inkjet printing setup, an ICC (International Colour Consortium) profile was created using the i1-x-rite colour production calibration device, and the test print results were evaluated.

3. RESULTS

The International Colour Consortium was established in 1993 by eight industry suppliers with the aim of creating, supporting, and promoting the standardization and development of an open, vendor-independent, cross-platform colour management system architecture and components. As a result of this collaboration, the ICC profile specification was developed. The purpose of the International Colour Consortium® profile format is to provide a cross-platform device profile format. Device profiles can be used to convert colour data created on one device to the native colour space of another device. The acceptance of this format by operating system vendors allows end users to transparently transfer profiles and images with embedded profiles across different operating systems. This capability provides immense flexibility for both users and vendors. For example, it ensures that users can maintain colour accuracy when their images are transferred between systems and applications. Furthermore, it enables a printer manufacturer to create a single profile for multiple operating systems.
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Through the development of these profiles, the printing process is tailored to the specific paper and printer being used, with different profiles generated depending on the printer brand. The appropriate colour profile for the type of paper used in the inkjet printer is created using the i1-x-rite colour production calibration device. When a colour profile is produced, this software facilitates communication between the computer and the printer. This communication helps ensure that the colour codes of the visual display on the screen are reproduced identically by the printer. The only notable difference is that while screens operate based on RGB (light-based) colour, printers rely on the CMYK coding system (dependent on the white of the substrate), making it possible to achieve a success rate of 95% to 98% in print results, though a 100% match is typically unattainable. However, this success is made possible through the use of profiles. This can be likened to the precision required in the screen resolution of the CMYK printing process in a printing house. Naturally, it is often difficult for the eye to perceive this result. The outcome of the print varies depending on whether the paper is matte or glossy. Just as in printing house results, glossy papers exhibit higher colour gamuts, resulting in stronger colour perception and more vibrant and accurate outcomes in inkjet printing. This situation may differ according to the type of paper, and it is also possible for the final result to be assessed and concluded from the artist's perspective. Another important aspect is that there is generally a tendency to prefer matte papers in the artistic printing process. This preference may be due to their closer association with the characteristics of a canvas surface, enhancing the uniqueness of the artistic expression and presentation.
The visuals of the printing results applied to the coated handmade papers are evaluated below:

3.1 Fine Art Print Result on Linen + Cotton + Seaweed Coated Paper

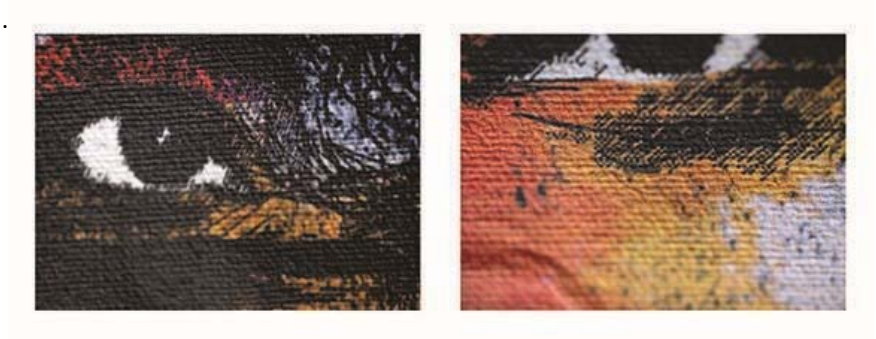
A fine art print designed in 2019 by one of the researchers, Yeter Beriş, was utilized for this test print. In previous years, fine art prints of this work had been printed on Hahnemühle brand fine art paper, and the resulting prints were jointly evaluated by the artist and the printing master, Mr. Selçuk. The researchers successfully produced the first test print on paper coated with seaweed over linen and cotton, utilizing a Canon inkjet printer and generating a profile based on the natural results obtained from the i1-x-rite colour production calibration device. The initial test was positively assessed due to the accurate results attributed to the paper's coating properties (Figure 7a, b, and c).



a) b) c)

Figure 7a, b and c: Fine art printing and profile process on linen + cotton moss-coated paper

As a result of this printing process, close examination with a magnifying glass revealed that similar to other internationally recognized fine art papers, the ink density was of high quality and that the ink did not spread on the surface even in the case of the finest ink structures. Despite the natural colour of the handmade raw paper, the ability to obtain a profile in the first test print was positively received. Consequently, the formation of profiles in the initial trial and the observation during the magnification examination that the details were very sharp and that the inks did not spread were confirmed (Figure 8a and b).



a) b)

Figure 8a and b: Close-up view of the fine art print result on Linen + Cotton paper with moss coating

3.2 Fine art print result on Hemp + Seaweed coated paper

In the printing conducted on hemp moss-coated paper, as in the previous test, the first test printing was performed using the i1-x-rite brand colour production calibration device. The result was a natural profile, enabling fine art printing. Due to the coating properties of the paper, it was positively evaluated that the first test yielded accurate results, similar to those of the linen and cotton moss-coated paper (Figure 9).



Figure 9: Fine art printing and profile process on Hemp + Seaweed coated paper

As a result of this print; when the moss-coated hemp fine art print paper on which artistic printing was made was examined closely with a magnifying glass, it was observed that the ink density was high quality and that the ink structure was not damaged even as a result of the thinnest linear printing, just like the Linen+Cotton+Moss coated fine art paper, and that there was no dispersion on the surface. Although the handmade raw paper had a darker natural colour than the surface colour of the Linen+Cotton+Moss coated fine art paper, the fact that a profile could be obtained in the first test print was evaluated positively with high appreciation. In this paper, the profile formation in the first trial the sharpness of the details in the loop examination of the printing result and the ink not dispersing on the surface were met with high appreciation (Figure 10a and b).



a) b)

Figure 10a and b: Close-up view of the fine art print result on Hemp + Seaweed coated paper

3.3 Fine art print result on seaweed-coated and Uncoated Linen art paper

In this preliminary study, printing was conducted to address the question of whether it is possible to produce profiles using the natural-coloured linen fine art print paper prepared in both coated and uncoated forms, alongside algae-coated cotton-blend linen and hemp papers. Tests conducted on algae-coated or uncoated papers produced from linen, utilizing the i1-x-rite brand colour production calibration device, revealed that profiles could not be established (Figure 11). Due to its darker natural colour compared to other papers, it was unable to produce a natural profile, preventing any successful printing. The negative evaluation was based on the fact that the initial tests did not yield accurate results, unlike those obtained from the algae-coated linen-cotton or hemp-algae-coated papers, which can be attributed to the natural colour of the paper rather than its coating.



Figure 11: Fine art printing profile process on moss-coated linen paper

4. DISCUSSION

For fine art prints, the papers used must be acid-free and lignin-free to ensure structural longevity. Green algae are a suitable raw material for paper production due to their higher cellulose content compared to brown and red algae. The inks used for printing must also have a long lifespan to be accepted. Handmade papers can provide these characteristics. As seen in the visuals of the papers utilized in this preliminary study, the hemp artistic paper produced in its natural raw colour was accepted with the most positive evaluation regarding profile production and print suitability. Conversely, it was found that another artistic paper produced from linen, regardless of whether it had an Algae coating on its surface, was not suitable for profile production due to its natural raw colour. However, when blended with natural and acid-free bleaching methods or cotton to lighten its colour towards white, it was observed to be suitable for profile production and printing. Accompanying this preliminary study, the next phase aims to assess papers produced through natural and acid-free bleaching methods, allowing for re-bleaching based on the findings of this preliminary study, to be used in subsequent printing tests.

5. CONCLUSIONS

In conclusion, this preliminary study has demonstrated that seaweeds not only serve as a raw material for paper production but also as a suitable material for paper surface sizing. Turkey, being a country surrounded by seas on three sides, is fortunate in this regard. It is well known that the seaweeds we utilize have diverse applications across various fields. Notably, they are used as food due to their nutritional value, and they also have significant applications in the medical field. The positive outcomes of our study may pave the way for the exploration of new areas of application in the future. We propose that similar to other countries, efforts should be made in our country to cultivate these seaweeds beyond merely relying on those found in our seas.

6. ACKNOWLEDGMENTS

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EDUCATION

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MODERN ENGINEERING EDUCATION IN GRAPHIC TECHNOLOGY AT UNIVERSITIES

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Abstract: *This paper explores the cultivation aims and methods for students majoring in graphic technology at universities in the era of the Internet and Artificial Intelligence. The graphic technology major, with an engineering focus, originated from traditional printing technology. By referencing the Washington Accord—an agreement for engineering degree accreditation, this paper introduces the demands of modern engineering education. Tracing back to its traditional focus on the printing industry, the social demands for the graphic technology major have shifted to include cross-media presentation and the reproduction of graphics and images across various media, not just paper. The new social ecosystem requires talent capable of solving complex technical problems and designing innovative print-related products by applying knowledge from multiple disciplines. The development of related printing technologies and the methodologies that support the cultivation of such talent are described in this paper, including the application of printing theories in cross-media contexts, the design thinking approach, STEAM skills training, and aspects of product innovation. These analyses strengthen the related theories in printing and expand the cross-media content and design thinking components when building the cultivation system for students. When we organized activities that brought together students from different disciplinary backgrounds, aiming to enhance their STEAM skills, their enthusiasm could be observed in their designs and products. While the methods suggested in the paper are still in the conceptual stage, they are continuously being promoted and developed.*

Key words: graphic technology, engineering education, product-centred, design thinking.

1. INTRODUCTION

The Internet and Artificial Intelligence (AI) era shows extremely different from the previous time, which is filled with abundant knowledge and is developing at a very rapid pace. It demands new talents from human beings to adapt to rapid social change. A university takes on the responsibility of cultivating students' abilities to serve society. It must understand the needs of society and the demands of the era, and then design a reasonable training plan for students that incorporates strategies to meet the demand for social talent.

The graphic technology major at universities has an engineering focus and originated from the traditional printing technology major, which concentrated on knowledge, theories, and techniques related to printing on paper substrates (Soyang, 2023). However, it has now expanded to include a wide range of other media substrates. That is why the development trends of the printing industry will be analyzed first. The basic tasks of print manufacturing involve the presentation and reproduction of graphics and images. Traditionally, these tasks are primarily focused on the paper surface using printing method. However, the media used for image and graphics have now expanded to include digital display on computer, network, mobile phone. A question arises: are printing-related technologies still solely focused on paper-based scenarios today? Certainly not. The mature technologies used in the traditional printing industry emphasize microscopic control over the final presentation of colour and details, such as the control over halftone dots, grayscale tones, ink transfer, ink dot formation, colour balance and so on. This approach is sufficient to manage detailed changes on seemingly less complicated displays or other material surfaces. We refer to these application scenarios as cross-media. Many methods or approaches can be transferred from print media to these new media. That means mastering the technology and workflow used in the printing industry is key to adapting colour or details control in other industries for image and graphic presentation.

Given the above cross-media service context, another question arises: what kind of talent is needed for the cross-media graphic technology major in engineering education? The Washington Accord is an

ORCID number is provided at the end of the paper.

international agreement between bodies responsible for accrediting engineering degree programs (IEAS, 2014). It establishes and benchmarks the standards for professional engineering education. The talent standards include the skills, knowledge, and experience necessary to solve complex technical problems, design and develop innovative products, and contribute to engineering projects, among other things. In the traditional education system for printing technology, we usually emphasized skills, knowledge and experience, which are the focus of the first stage of education. In modern society, these aspects can now be acquired and addressed more easily, narrowing the gap between professionals and others. What is professional education in graphic technology at the next stage? Following the Washington Accord, the first aim-solving complex technical problems-has been supported by the traditional training methods. This paper emphasizes expanding knowledge of media beyond just paper. Designing and developing innovative products is the focus of the second aim. The third aim, contributing to engineering projects, can be achieved by integrating the abilities developed in the first two aims and applying knowledge from different disciplines.

The following related works outlines the conditions -such as the printing theories that can be applied in cross-media industry, and Design Thinking, STEAM education-that support the realization of our training plan. Some specific innovative methods used in academic course development are presented. It is noted that the implemented methods are still being promoted, but it is believed that the completed education system will be effective in developing students' talents, preparing them to adapt to the challenges of the future.

2. RELATED WORKS

2.1 Printing theories that can be transferred to cross-media industry

Colour and tone changes are basic factors controlled in graphic presentations.

2.1.1 Colour control theory

No matter the colour presented on a paper surface, display, or any other material, the final result will be perceived and evaluated solely by the human visual system. The colour control process in printing generally focuses on the RGB and CMYK colour modes and their conversion relationship. However, almost all digital media such as display monitors can be colour-controlled using the additive RGB light mode. All pigment-coloured materials can be based on subtractive CMYK colour mode. No other industry encompasses more theories and experience in colour conversion between RGB and CMYK than the printing industry. Nowadays, most colour theories are generalized across different media surfaces, despite the specific requirements of various colour presentation devices. For example, by following the colour theories and rules established in 2D printing, colour control issues in 3D printing, monitor displays, and video displays can be addressed, with additional considerations for the imaging schemas of different system.

2.1.2 Visual tone and detail control theory

Visual tone is another key factor for image or graphics presentation alongside colour. For easier control of colour in the printing process, a grayscale is separated into many fine dots, allowing for a mixture of inked and non-inked regions to create the visual effect of greyness. This is the 1-bit halftoning technology, the simplest method for accurately representing continuous tones on a material surface.

With the advent of digital printing methods, multi-level halftoning technology was developed to address the limitations of low-quality imaging. This technology is also used in some displays and medical imaging to simulates continuous tone changes. Digital printing technology is widely used across various media surfaces today. Industries involved include clothing and textiles, home decoration, advertising and exhibitions, and even flexible electronic devices.

2.2 Design thinking and STEAM education

Knowledge sharing and acquisition have become more convenient and accessible in a short time for humanity, thanks to the popularity of Internet and AI technology. The future society seems more uncertain and challenging. Undergraduate education is responsible for making students capable and adaptable in

facing future changes. Design thinking methodology and STEAM skills will become most important for students and their future development.

2.2.1 Design Thinking

Design Thinking is a problem-solving approach that emphasizes understanding users, challenging assumptions, redefining problems, and creating innovative solutions (Shelburn et al., 2020). It is characterized by a human-centred focus, iterative prototyping, and cross-disciplinary collaboration.
During the long history of the publishing industry, considerable experience has been gathered in composing images, text, and graphics on pages for paper-based products, ensuring a comfortable viewing experience for readers. The page design and layout should follow different scenario rules, even taking into account the readers' age. However, cross-media scenarios face many new materials and tools environments without established rules to follow, making the application of User Experience (UX) essential. UX refers to the overall experience and satisfaction that a user has when interacting with a product (Berni & Borgianni, 2021). It encompasses all aspects of the end-user's interaction to use the product, as well as the evoked emotions and perceptions. One of the important aspects is the layout of image and graphics on page. UX process can ensure its user-friendly effectiveness.
UX analysis is the foundation of Design Thinking. Design Thinking can also help create more innovative print-related products beyond traditional printed pages.

2.2.2 STEAM education

With the knowledge gap shortening between professional and others in AI era, STEAM skill will play an important role in effectively integrating and utilizing interdisciplinary knowledge (Razzaq, Townsend & Pisapia, 2013). STEAM skills refer to the specific abilities and competencies developed through the five key education areas: Science, Technology, Engineering, Arts, and Mathematics (Carter& Barnet, 2021). The goal of STEAM education is to foster innovation, creativity, critical thinking, and problem-solving skills by connecting these disciplines in meaningful ways. STEAM skills provide the technical and creative foundation, while Design Thinking offers a methodology to apply these skills effectively in problem-solving and innovation. Together, they empower individuals to tackle complex challenges with both analytical and creative strategies.

2.3 Conditions supporting innovative print-related product design

A product can be described in terms of its shape, material, appearance, and interactive functions with the user. With the development of new materials and the blending of interdisciplinary techniques in recent years, print-related products can now be presented in unique and innovative styles that go beyond conventional books or packaging boxes. The production process involves product shaping, such as pop-up structures created through die cutting; appearance decoration, such as foil stamping; new substrates with textured or patterned elements; and products with lighting and sound controlled by microchips. (Jiong & Huaming, 2021). All the aspects above mentioned support the thinking and design of the education plan for the graphic technology major.

3. OUR METHODS

In the new teaching plan, fundamental courses in printing are prioritized as the core, complemented by cross-media content. A theory course in Design Thinking is introduced, along with activities that promote interdisciplinary communication among student teams, particularly emphasizing collaboration between the arts and engineering disciplines.

3.1 Course design to strengthen print-related theories

The core courses cover the entire printing process, from prepress and press to postpress, including material analysis, process planning and quality control, as illustrated in Figure 1. The prepress phase is expanded into include premedia. Print manufacturing, a process that reveals macroscopic appearance through microscopic control, provides excellent way to train students' systematic thinking skills.



Figure 1: Core academic specialty courses in the curriculum plan

3.2 Cross-media content integration

Course content on web page and database technology is added as a supplement to premedia. This knowledge helps students move beyond the traditional focus on printing media, as illustrated in Figure 2, enabling them to recognize that all media can be unified within a common framework (Drew, 2010).
Visual and optical image-related content can help expand application scenarios in camera imaging field. We invited Colour Space, a Chinese company specializing in camera imaging quality checks, to design a practical course for students. This course helps students understand imaging theory and evaluation methods, as illustrated in Figure 3, similar to how an image engineer would, thereby expanding their knowledge from paper-based imaging to digital media-based imaging.



Figure 2: Cross-media technology



Figure 3: Visual imaging quality checkers

3.3 Training in design thinking methodology

A UX design course is introduced to train students in design engineering skills. After learning the principles and methodology of UX Design, students are asked to explore a specific project, including user demand analysis, persona design, ideation, prototyping and testing, as illustrated in Figure 4. The scientific approach to product development focuses not only on technology but also on the user.

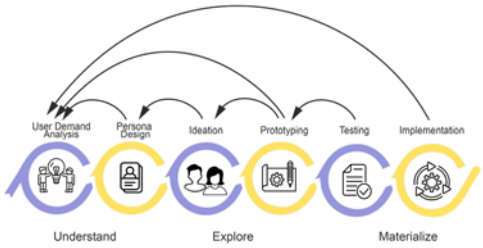


Figure 4: Design thinking process

3.4 Activity in Innovative Product Creation

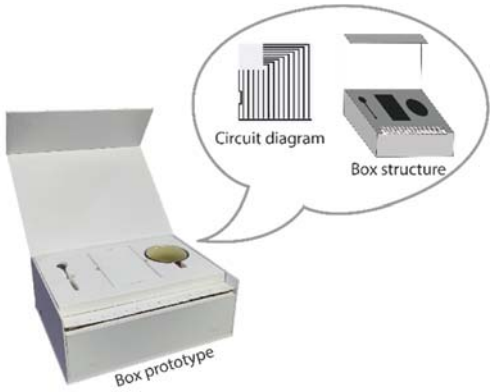
A competition is organized for students at our university, where they will design and manufacture an innovative print-related product. The activity requires participants to be divided into groups with members from different disciplinary backgrounds, creating a STEAM skills environment. After completing the products, their projects are ranked and awarded. Students are encouraged to design innovative products focusing on aspects such as function, shape, material, and the application of techniques. Some of the students' works are shown in Figure 5.



a. Pop-up structure featuring Chinese traditional cultural elements



b. Cotton paper with special texture



c. Chip and circuit control in a packaging box



d. Multi-color foil stamping work

Figure 5: Students' works

4. CONCLUSIONS

Amid current society development, modern university education should prioritize developing systematic thinking to enhance the student's mindsets rather than viewing knowledge transfer as the most important task. Graphic technologies are utilized not only by the printing industry but also by industries involved in colour and detailed presentation. This paper proposes that cultivating innovative, product-based, and systematic design engineering talents is a crucial training aspect for students majoring in graphic technology at universities. The training process involves learning print-related theories, integrating cross-media content, mastering design thinking methodologies, and immersing students in a STEAM skills environment. The formidable challenge of discipline gaps in university education can be addressed or alleviated by prioritizing the promotion of team collaboration.

The methods proposed in this paper cannot yet be claimed as successful. They remain in the conceptual stage and need further promotion and development. It is hoped that this paper will receive more global attention and support, encouraging collaboration in advancing the development of university majors related to graphic technology.

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DEVELOPING LISTENING COMPREHENSION IN ENGLISH FOR GRAPHIC ENGINEERING AND DESIGN

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Abstract: *When teaching English for Graphic Engineering and Design at the tertiary level, it is important to train students to follow professional lectures and presentations and grasp this speech genre. English language classes could be organised to develop this significant skill through systematic training, which includes both the preparation phase, crucial for the activity's success, and the active listening phase. Competence differentiates each phase by adopting and mastering specific strategies. The most crucial method involves anticipating the presentation's topic and key terms, while the next step involves listening to the presentation. The process includes the following steps: a. anticipating the content; b. separating relevant from irrelevant data; c. tolerating ambiguity in the listening data; d. mentally summarising the presented data; e. drawing conclusions about unknown facts based on context; and f. elaborating and connecting previous knowledge with new information. With competent instruction from the teacher and his guidance through the entire process of acquiring and mastering the skills of understanding lectures and presentations in English for Graphic Engineering and Design, the listed strategies can help students gain competence in this field of specific professional knowledge and advance their professional and academic careers.*

Key words: listening comprehension, listening preparation, active listening, approaches.

1. INTRODUCTION

The ability to observe is crucial for successful collaboration, and developing listening skills can lead to enhanced communication in professional environments, as proficient listening skills are essential for professional communication. Students' ability to understand lectures in English for Specific Purposes (ESP) at the tertiary level includes their individual abilities, prior language knowledge, and linguistic predisposition. The degree of previously acquired language competence, which is related to knowledge of written language, also influences the ability to understand lectures delivered in ESP. One can successfully extend and apply this ability when listening to lectures, where spoken language takes the place of written language. However, it also includes new approaches specifically designed for successful understanding of spoken discourse, such as following professional lectures and presentations as well as taking notes while listening to them.

According to Rost (2011), understanding spoken language is an internal process that is not directly observable, unlike other language skills. Assisting students in improving their listening skills can help them concentrate and increase their attention span. Educators can help students remember more of what they hear by encouraging them to pay attention with techniques so students are able to focus on what others are saying rather than being self-absorbed and only concerned with them. We usually measure the mastery of this skill by checking the understanding of the spoken language, which involves asking questions that allow us to determine the general and detailed understanding of the presented material.

According to the renowned American psychologist Anderson (2000), listening comprehension, which is the most important component of effective communication, is necessary for productive collaboration. It is critical for someone to learn effectively and unfolds in several stages.

1. Perception as the process of focusing on spoken or written language, enabling the selective retention of certain parts in short-term memory.
2. Breaking down the spoken text into its constituent parts and creating a mental image of the text
3. Mentally connecting the created representations with their meaning and storing them in long-term memory.

Moreover, Rahimi & Katal (2013) noted that when students fail to master the aforementioned stages, they only reach the level of language perception, meaning they are unable to integrate new information with

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their existing knowledge and, consequently, cannot memorise the presented material. However, consistent and systematic application of various approaches is necessary to master the skill of understanding spoken language through listening. Therefore, different approaches are responsible for acquiring competence in understanding spoken language such as:

1. *Tolerating ambiguity in the lecture*. It involves accepting that many parts may be unclear and unknown at the time of listening. Using this approach helps to reduce the possible frustration of hearing words that we do not know the meaning of at that given moment or parts of the lecture being unclear due to the current language barrier.
2. *Summarising the presented and discussed material.* It entails mentally compiling information from the full presentation or a specific section of it.
3. *Drawing conclusions.* which may involve guessing the meaning when unknown words or assumptions about the contents of the missing information exist.
4. *Expounding on the subject matter.* It facilitates the reactivation of prior comprehension and results in connections between previously acquired knowledge and new data. Thus, it fosters thorough understanding and integration into the current knowledge framework.

The listed approaches refer to the understanding lectures from a profession or academic discipline, with the indication that this type of lecture represents a specific oral genre that abounds not only in professional terminology but also special structural organisation that reflects the type of profession or science to which it belongs (Ahmadi & Motaghi, 2021; Bozorgian & Shamsi, 2023).

2. UNDERSTANDING PROFESSIONAL LECTURES IN ENGLISH FOR GRAPHIC ENGINEERING AND DESIGN

It is possible to successfully implement the practice of understanding professional lectures in English for Graphic Engineering and Design at the university level, provided that the teacher collaborates with an expert in the field the students are studying who actively uses the English language and with students who are motivated to improve their language skills. Such an expert's engagement is based solely on his enthusiasm, which is valuable for the design of this language teaching segment. Also, students should be continually encouraged to frequently listen to audio-visual recordings of professional presentations from the Internet, both during the process of acquiring the competence to understand spoken material and after completing this type of training. This type of material is highly suitable as a basis for acquiring the relevant competence, as it allows students to listen to the material as many times as necessary and to revisit any parts that were not entirely clear. Focused practice can facilitate the learning of primary context comprehension, vocabulary expansion with new words, phrases, and idioms, and familiarization with a variety of accents. Consequently, learners' comprehension increases as they engage in more active listening. Listening to a recording multiple times, as opposed to once, will significantly enhance its comprehension.

Furthermore, the professional materials will motivate and encourage students to continue listening. Learners should be aware that if they are unable to comprehend all of the information they are hearing, they should not become frightened. Translating into Serbian will be of no assistance to them. In order to enhance their ability to listen effectively, learners should be encouraged to engage more with their colleagues and native speakers. Also, in order to prevent monotony, learners should participate in a variety of challenging activities (Chang, Millett, & Renandya, 2019), including professional collaboration through the internet and social media. It would be desirable to provide students with the opportunity to hear from real lecturers, enabling them to assess their own progress in acquiring competence in understanding English lectures, based on a comparison of their level of competence in understanding professional English (Chang, 2022).

3. GETTING READY TO LISTEN TO PROFESSIONAL LECTURES

It is a well-known fact that improving language skills requires a meticulously planned preparatory phase, just as crucial as improving the ability to comprehend spoken language from professionals in certain academic disciplines. In addition to the fact that this phase is mandatory before listening to any spoken

language, it provides the opportunity to establish beneficial communication between the foreign language teacher and his students, who, on the same task, easily become aware of the importance of mutual cooperation. The teacher's role in the preparatory phase of the mentioned activities involves collaborating with the students to conceptualise the upcoming lecture, thereby guiding them to employ strategies that are pertinent to this phase (Dalman & Plonsky, 2022). We can divide the approaches used in the stage of preparation for listening to lectures into two groups: 1. those that predict presentation concept and subject matter, and 2. those that anticipate the main words or concepts in the lecture. These approaches encourage students to actively contemplate the lecture's topic, thereby focusing their attention during the lecture. Specifically, discussing the presented content with their preconceived notions and assumptions can encourage students to attentively follow the presentation (Wallace, 2020). Furthermore, students may prepare and discuss some general questions on the topic, as their answers consistently align with the fundamental concepts discussed in the lecture. By precisely focusing on the fundamental elements of the presentation, students can better follow and comprehend the lecture. Additionally, it will enhance their ability to distinguish between important and less important ideas, a crucial skill for comprehending each spoken material holistically. It is known that concentrating attention on less important details in spoken material results in a poor understanding of the entire material (Mahdavi & Miri, 2017).

To anticipate the concepts and words related to the subject matter in the lecture, it is beneficial to discuss them beforehand with the students. If they are unfamiliar with some words, they may consult a bilingual dictionary on graphic engineering and design and take notes before the lecture begins. The most common spoken discourse in English for Graphic Engineering and Design, like most engineering sciences, falls into the following categories (Chang, 2022):

1. presentation of procedure and its sequences;
2. comparing or contrasting procedures, phases, stages, or results;
3. defining cause and effect stages or phenomena;
4. listing results, effects, procedures, elements, etc.

4. LISTENING VIGOROUSLY TO PROFESSIONAL LECTURES

Many students of Graphic Engineering and Design aspire to successfully understand the conference lecture and participate in conference activities, as this requires interactive listening skills. This is a very advanced stage of listening comprehension because it entails social interaction in small groups, which is a true listening test. In interactive listening, learners receive new information and identify it continuously, either in pairs or in groups. In addition, they should resolve communication issues and respond quickly. This phase, which involves both comprehension and production, directly promotes speaking skills.

Understanding a conference lecture requires focusing on the introduction. The introductory portion of the spoken material serves as a guide for further listening. The introductory parts of academic and professional lectures, regardless of the diversity of the scientific discipline they deal with, are characterised by a uniform structure, which means that their constitutive parts are almost identical. A successful introduction should include the following steps:

1. emphasising the importance of the topic and stating prior knowledge on the topic,
2. overview of previous research work,
3. establishing the starting point which involves highlighting the gap in knowledge and shedding light on the problem,
4. highlighting the goal of the work or research and presenting its structure.

The introduction, which gains the attention of the listener, has two clearly defined functions. Firstly, it presents the lecture's framework by providing essential details about the topic, form, structure, and objective. Secondly, it creates a context for the lecture's content by linking the discussed topic to the listener's prior knowledge while also highlighting its importance and significance within a specific scientific field of expertise. Students should be aware of this and practice understanding it.

Also, in order to be successful and understand the speaker, each student should make his own concise interpretation of the main spoken message during the lecture. Given that this is a cognitively demanding process, it is crucial to gradually guide the student through the process of listening to lectures, emphasizing the key aspects of this process. Video lectures from the internet are suitable for practicing the skill of

understanding presentations, and students could do them individually depending on their own interest or specialized field of expertise. All these approaches, with the exception of the one that focuses on the introductory part of the lecture, offer students practical examples and guidance for their implementation. A teacher can demonstrate each approach individually by presenting the entire recorded lecture to the students, then breaking it down part by part (Zeng & Goh, 2018). Returning parts of the recorded lecture and listening to it together with the students allows the teacher to direct the attention of the students and to organise the listening process in a way that is necessary to acquire this language skill. In order to enable students to understand lectures in English, the teacher should encourage students to use the following approaches during listening (Zeng & Goh, 2018):

1. separating relevant material from irrelevant material,
2. drawing conclusions about the meaning of unknown words based on the context,
3. elaborating and connecting previous knowledge with new information.

Another important approach to apply while listening to a lecture is to separate the very important from the less important material in the lecture. Modern electronic devices, commonly used in modern lectures, can successfully accomplish this task (Chamundeshwari, 2023). Power Point (PP) presentations, when expertly and skilfully designed, represent a good guide through an academic lecture. This kind of presentation helps to emphasise the most relevant elements in the presentation of the material, and the cognitive effect of this kind of presentation is far greater than in a lecture that is reduced to only the spoken word because it connects the senses of sight and hearing and thus helps to remember the presented material better. The use of PP presentation is often conditioned by the type of scientific or academic discipline, so they are very common in the field of graphic engineering and design.

Making inferences about the meaning of unknown words based on context is a general approach that applies to any type of listening material. This implies that mastering this skill through frequent exposure to spoken material in English for Graphic Engineering and Design can only improve it. In practice, it has been shown that experts from a certain field, even when they are not extremely successful speakers of a foreign language, will understand words and expressions from their profession much more successfully, even than native speakers who do not know that profession (Bozorgian & Shamsi, 2022). It makes sense that the listeners can only retain the material if it aligns with their existing knowledge about the presented subject. To make this easier, they should be encouraged to take effective and purposeful notes when listening to professional lectures in a foreign language (Bozorgian, Yaqubi & Muhammadpour, 2022).

In addition to focusing the students' attention on the lecture as a whole, it is also crucial to focus their attention on specific groups of words that are typical of both oral and written academic discourse. Discourse markers serve as linguistic signals, drawing the listener's attention to significant moments in the lecture and enhancing its coherence (Chang, 2018). Discourse markers regulate the logical relationships between ideas and play a role in managing the flow and structure of discourse. In English, students should practice and successfully apply the most common discourse markers that connect the subject and clearly point to its important elements while listening to the presentation. The following discourse markers should be practiced:

1. cause - Effect (as a result, since, consequently, accordingly, therefore, ...),
2. explanation (namely, for instance, ...),
3. expansion (in addition, beyond this, furthermore, ...),
4. recognition (still, yet, rather, though, ...),
5. contrast (to the contrary, in comparison with, however, despite, nevertheless...),
6. conclusion (hence, thus, therefore, after all, ...).

Additionally, an effective lecture will guide the audience by reminding them of previous points (as we have seen...), announcing what will be discussed in the next section (well, the following point...), and drawing their attention to specific sections of the lecture (Let's see...). In a concluding statement at the end of the lecture, the previous points should be summarised (Pan et al., 2018). Therefore, students should be aware of all this when they listen to a professional lecture.

5. KEEPING NOTES DURING THE LECTURE

Students should be constantly encouraged to take notes during conference lectures, just as they would in their professional or academic disciplines. According to Pan et al. (2018), students utilise this approach more effectively when they receive training and experience, and they should leverage the positive transfer from their mother tongue to effectively memorise the oral material presented in a foreign language. Rather than interfering with the listening process, taking notes should encourage the listener to fully concentrate on the presentation. It is important to note that the introductory part of the lecture serves as the starting point for writing down the information. Specifically, writing down information from the introduction provides a framework on which the student can rely during the lecture itself, and not knowing such a framework makes it difficult to follow and understand the entire presentation (Mahdavi & Miri, 2017). While listening to a lecture, it is crucial to accurately record and communicate the presented ideas, ensuring they align with the speaker's intended meaning. Giving a secondary idea a central place in the notes, or vice versa, can completely destroy the original intention and meaning of a lecture, potentially leading to misinterpretation.

When using this approach, students should immediately review, rewrite, and supplement their lecture notes. Thus, students will complete the outline of the lectures they listened to and organise their notes into a meaningful and coherent whole. Furthermore, frequent practice of this approach and ongoing professional language vocabulary enrichment improve note accuracy and precision. It is known that not all note-taking is equally effective; it depends on the listener's personal abilities and training in this skill in the native language. An ESP teacher could significantly improve its quality by providing systematic instructions on how to use this approach. One such instruction is to never write entire sentences when taking notes, but rather write down their elements and key words, use abbreviations, and use the native language as little as possible.

6. CONCLUSION

Although they are seldom given the recognition they deserve, listening skills are essential for the acquisition of a foreign language. Some individuals consider listening to be a passive activity. However, it encompasses much more than simply assimilating information from another individual. Learning to observe in the target language facilitates the development of the other three skills - speaking, reading, and writing.

This paper aimed to highlight the importance of enhancing listening comprehension in the English teaching for Graphic Engineering and Design at the university level, given the increasing need for students to comprehend professional lectures in English these days. The current need for students to actively follow English-language lectures in graphic engineering and design highlights the need to enhance their knowledge in this area. This entails connecting to the European higher education network and creating conditions for student mobility within the European academic space. It is a very complex and demanding language skill that necessitates a high level of both linguistic and professional competence. Numerous factors contribute to the mastery of this skill and its success, including the students' individual abilities, language aptitude, and prior language knowledge. Furthermore, it relies on adequate training and practice of other language skills. Despite the complexity of acquiring competence in understanding English lectures, students can still master it with individual commitment and persistence.

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INTRODUCTION OF PEER EVALUATION IN THE STUDY OF COMPUTER GRAPHICS - OBSERVATIONS ON THE POSSIBILITY OF INVOLVING STUDENTS IN THE EVALUATION PROCESS OF 3D VISUALISATIONS

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Abstract: *This study examines the impact of incorporating ICT-enhanced peer evaluation throughout the course of 3D modelling, including midterm and final assessments. Rubrics for peer evaluation were developed to ensure structured and consistent assessment of student work, focusing on criteria such as clarity, objectivity, feedback and overall effectiveness. The practical component involved designing peer assessment forms, implementing these assessments in the classroom and comparing teacher and student assessments. As part of the study, students were required to create 10 landscape-themed visualizations using various 3D modeling techniques, textures, and rendering strategies. Assessments were conducted mid-semester and at the end of the course, with students evaluating their peers on communication, modeling, texturing, and stylistic coherence. The results suggest that clearly defined criteria and motivational strategies are essential for successful peer assessment. It was found that students tended to evaluate their peers more leniently than teachers, indicating a possible bias in peer assessment. Effective implementation requires continued engagement and input from educational experts to optimize the assessment categories and ensure meaningful peer feedback.*

Key words: ICT-assisted peer evaluation, study of 3D computer graphic, qualitative analysis, quantitative marks

1. INTRODUCTION

Peer-to-peer evaluation, also known as peer assessment, is an educational approach in which students evaluate each other's work based on predefined criteria. This method has gained prominence in recent years as a means of improving student learning outcomes, promoting critical thinking and encouraging active engagement in the educational process (Topping, 1998). The theoretical foundations of peer evaluation are rooted in constructivist theories of learning, which assume that learners construct their knowledge through active participation and social interaction (Vygotsky, 1978). One of the main benefits of peer evaluation is its potential to deepen learners' understanding of the subject matter. By participating in the evaluation process, students must use their critical thinking skills to analyze and provide feedback on the work of their peers. This process not only strengthens their own knowledge, but also familiarizes them with different perspectives and interpretations of the same material. Studies have shown that students often learn as much from evaluating others as they do from evaluating themselves (Falchikov & Goldfinch, 2000). This reciprocal learning process is an effective tool for improving the cognitive and metacognitive skills that are essential for academic success. Peer assessment also encourages students' independence and sense of responsibility. When students take on the role of assessor, they are more willing to take responsibility for their learning. This greater responsibility can lead to higher motivation and engagement, as students are aware that their contributions have a direct impact on the learning experiences of their peers. In addition, the process of constructive feedback helps students to develop important interpersonal skills such as communication, empathy and the ability to give and receive criticism in a constructive manner (Nicol, Thomson & Breslin, 2014). Another significant benefit of peer evaluation is its ability to improve formative assessment in educational settings. Traditional assessment methods, such as exams and standardized tests, often provide limited feedback and do not necessarily promote deep learning. In contrast, peer evaluation allows for continuous, formative feedback that can accompany students throughout the learning process. This continuous feedback loop helps students identify areas for improvement and refine their understanding prior to final assessment (Hattie & Timperley, 2007). In addition, peer assessment can contribute to the development of self-assessment skills that are critical for lifelong learning. By being assessed by their peers, students become more familiar with assessment criteria

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and quality standards. This familiarity enables them to apply these standards to their own work, improving their ability to self-assess and regulate their learning (Andrade & Valtcheva, 2009). Despite its many advantages, peer review is not without challenges. Issues such as bias, lack of reliability and students' discomfort in assessing their peers can hinder its effectiveness. However, these challenges can be mitigated through structured training, clear guidelines and the use of technology to facilitate anonymous assessments (Sluijsmans, Dochy & Moerkerke, 1999). In summary, peer-to-peer evaluation is a valuable pedagogical tool that enhances learning by promoting critical thinking, student autonomy, and self-assessment skills. Its effective implementation can transform the learning experience, making it more interactive and student-centered. Future research should focus on the development of best practices and technological solutions to overcome the challenges associated with peer evaluation and ensure its effectiveness and acceptability in different educational contexts. With the goal of making the class more interactive to evaluate and comment on the partial and final results of student projects in the Basics of 3D Modeling course, we introduced analytical and holistic assessment rubrics and asked students for their opinions on the implementation of the assessment. Thus, the focus of the study was to test the appropriateness of the implemented evaluation method in Computer Graphics, to evaluate the process of deriving such assessment lessons, and to gather opinions on the motivation for the continued use of peer evaluation during the pedagogical lessons of the course.

2. METHODS

The experimental part of the study included the preparation of peer assessment forms, the preparation of a lesson using this type of assessment method, the implementation of an assessment lesson, the evaluation of the assessments received from the teachers of the lesson and from the students, the comparison of the results and a critical evaluation of the sense of introducing peer assessment and the determination of directions for future study lessons. The objectives of the study work in the subject were to create 10 visualizations on the topic of landscape, which included different levels of detail of the models. The work therefore included 3D modelling and visualisation using simple and more complex modelling techniques, texturing, determining materials, placing lights and cameras, and determining the optimal settings for use. Assessment surveys (MS Forms, Moodle workshop) were created for the mid-semester products, when students submitted concepts, ideas, references and designs, and for the final products. The peer evaluation of the interim results took place in March 2024, the final products at the end of May 2024. In the evaluation both at the beginning of the work and at the end, students had to evaluate their fellow students from the point of view of comprehensive communication of the topic, i.e. whether the student clearly presented the goals and purpose of the work, they also evaluated the modelling and texturing, lighting and camera techniques used and what style their fellow students achieve and the level of visualization.
60 students from the Basics of 3D Modelling course participated in the peer assessment, but this number decreased during the assessment process.
Both analytical and holistic rubrics were used in the assessment. The analytical rubric is structured in detail and includes separate evaluation criteria. Each criterion is divided into several performance levels. The holistic rubric considers the entire product, without breaking it down into individual criteria.
Analytical rubrics with grades from 1 to 4 were defined for specific visualization features in terms of geometry, textures, lighting, stylization and degree of visualization: Holistic rubrics finally evaluated the product visualization as a whole with a single grade. The grades were then converted into a scale from 1 to 10, which is used in higher education in Slovenia. The products were also evaluated by two teachers (i.e. the teacher for the lectures and seminars and the teacher for the exercises). The evaluations of the students and the teachers of the pedagogical classes were compared. An example of an analysis rubric and the evaluation criteria are shown in Table 1.

Table 1: Analysis rubrics and evaluation criteria for 3D visualizations.

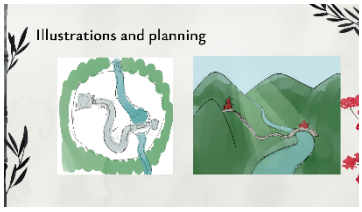
Analysis rubrics	Criteria for achieving grades from 6 - sufficient to 10 - excellent.
1. Študent/ka je cilje projektnega dela na temo Pokrajine / Landscape vizualiziral/-a: 4 Zelo kakovostno 3 Večinoma kakovostno 2 Delno kakovostno 1 Ni kakovostno 2. Študentka/študent je modele scene predstavil/-a glede na celoten koncep projekta: 4 Zelo natančno, z veliko detajli 3 Večinoma natančno, z nekaj detajli 2 Delno natančno, z malo detajlov 1 Ni natančno in brez detajlov 3. Študentka /študent je nivo materialov in tekstur uprizoril/-a v vizualizacijah: 4 Zelo Detajlno 3 Zmerno Detajlno 2 Minimalno Detajlno 1 Pomanjkljivo Detajlno 4. Ocenite kakovost in smiselnost tekstur in materialov, ki so uporabljeni v vizualizacijah: 4 Realistično 3 Sprejemljivo 2 Potrebuje izboljšave 1 Zelo nerealistično 5. Ocenite upodobitev osvetljevanja in luči na sceni: 4 Natančno, atmosfersko z veliko mero smiselnosti osvetljevanja 3 Rahlo ne v skladu s sceno in modeli ter teksturami in materiali na sceni 2 Precej ne s sceno in modeli ter teksturami in materiali na sceni 1 Neuporabno brez smisla za virtualno osvetljevanje	**Grade 10** - Geometry: with a lot of details, relief structures are solved with geometry, objects of more complex shapes (characters, demanding technical objects), significant use of digital sculpting; Textures and Materials: Advanced and physics-based materials and textures with details, UV mapping or digital painting; Lighting: advanced lighting techniques, global lighting, volumetric effects, caustics. **Grade 9** - Geometry: with many details, relief structures are solved in places with geometry, objects of more complex shapes (characters, demanding technical objects), use of digital sculpting; Textures and Materials: Advanced and physics-based materials and textures with details, UV mapping or digital painting; Lighting: advanced lighting techniques, global lighting. **Grade 8**- Geometry: with some details, objects of moderately complex shapes (middle LOD), digital sculpting in places; Textures and Materials: Advanced and physics-based materials and textures with details, UV mapping and folder usage; Lighting: advanced lighting techniques, global lighting. **Grade** 7- Geometry: simple geometry, objects without complex shapes (Low LOD), no digital sculpting, geometry errors in places, visible artifacts; Textures and materials: use of colors for textures, use of projection mapping, no use of maps or only in places, in places errors in textures and materials; Lighting: local lighting, without volumetric effects, harsh shadows, etc. **Grade** 6 - Geometry: very simple geometry, objects without complex shapes (Low LOD), no digital sculpting, geometry errors, visible artifacts; Textures and materials: use of colors for textures, use of projection mapping, no use of maps or only in places, errors in textures and materials; Lighting: local lighting, without volumetric effects, lighting irregularities, sharp shadows, etc.

When creating the questionnaire on students' opinions on the implementation of peer assessment, we started from the proposal given by Digitalna UL (digital support of the University of Ljubljana), which we adapted with the aim of focusing on peer assessment. The survey contained 17 questions, of which 4 questions were directly related to the implementation of peer assessment, while the other questions were more general in nature and related to the use of ICT in the course or the implementation of the course itself. Students rated on a scale of 1 to 5, with 1 meaning that they disagree with the statement and 5 meaning that they fully agree. The survey on opinions about the implementation of peer evaluation was sent to students in September 2024. Despite repeated requests, only 10 students completed the survey.

3. RESULTS

The results of the concepts and ideas during the semester and at the end of the semester in the form of renderings are shown in Figure 1, along with references, base models, and renderings that were evaluated by both students and teachers.

Show 1 – Initial ideas



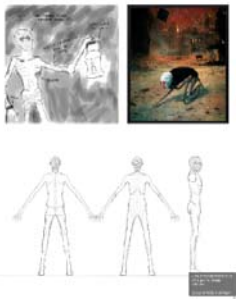
Show 2 - Models

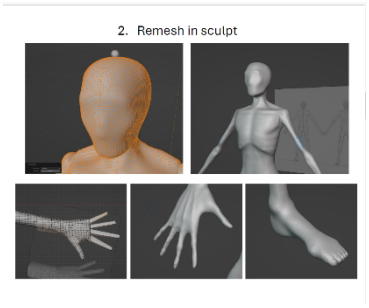


Show 3 - Final renderings



Author: Sara Klepac







Author: Max Pozderec

Figure 1: Initial ideas, models and final renderings using the example of two students' project work.

In answering the survey, we focused on questions directly related to the implementation of peer assessment and the use of ICT in the course. Students used a number from 1 to 5 to indicate how much they agreed with the following statements. Value 1 stands for the answer "I do not agree at all", value 2 for the answer "I do not agree", value 3 for the answer "I can not decide", value 4 for the answer "I agree" and value 5 for the answer "I completely agree".

Figure 2 shows the students' agreement with the following statements about the general use of ICT in study tasks:

I enjoy working with ICT - statement 1, I have no problems working with ICT - statement 2, I like to use ICT - statement 3, I think I know how to use ICT well - statement 4, When we use ICT in exercises/seminars/lectures, I prefer to leave the work to my colleagues - statement 5, Working with ICT is boring - statement 6, I prefer to avoid working with ICT rather than actively engage in work - statement 7, In order to feel more confident in using ICT, more time should be devoted to independent work with ICT in exercises/seminars/lectures - statement 8, It would be more useful if, instead of ICT, forms of work that do not involve the use of ICT were used in the pedagogical process - statement 9, More attention should be paid to training students to work with ICT in the study process - statement 10, The use of ICT in the course made it easier for me to communicate with the teacher (e.g. Moodle, MS Teams, Forms) - statement 11, Using ICT made it easier for me to follow course announcements (e.g. Moodle, MS Teams, Forms) - statement 12, By using the Internet, I can better follow the latest developments in my field of study - statement 13, Thanks to the use of ICT, I can start learning anywhere - statement 14, In general (we), the use of ICT in this course enabled the study material to be organized in a way that made sense to me - statement 15, Overall, the use of ICT in this course increased the frequency of my interaction with the course instructor and other students - statement 16, The use of ICT increases the possibilities of cross-curricular integration within the study program - statement 17, In this course, I used ICT (shows on MS Teams, MS Forms peer assessment, shows on Moodle and Moodle workshop) to continuously check my understanding of the study content, on the basis of which I planned the further learning process - statement 18, In this course, I evaluated my own work using ICT (submissions on MS Teams, MS Forms peer assessment, submissions on Moodle and Moodle workshop), based on which I upgraded my knowledge - statement 19, In this course, I evaluated the work of my peers using ICT (MS Forms peer assessment, Moodle workshop) - statement 20, In this course, using ICT (shows on MS Teams, shows on Moodle), I received feedback from the course provider about my work (assignments, products, etc.) - statement 21, I was able to monitor my learning progress in this course - statement 22.

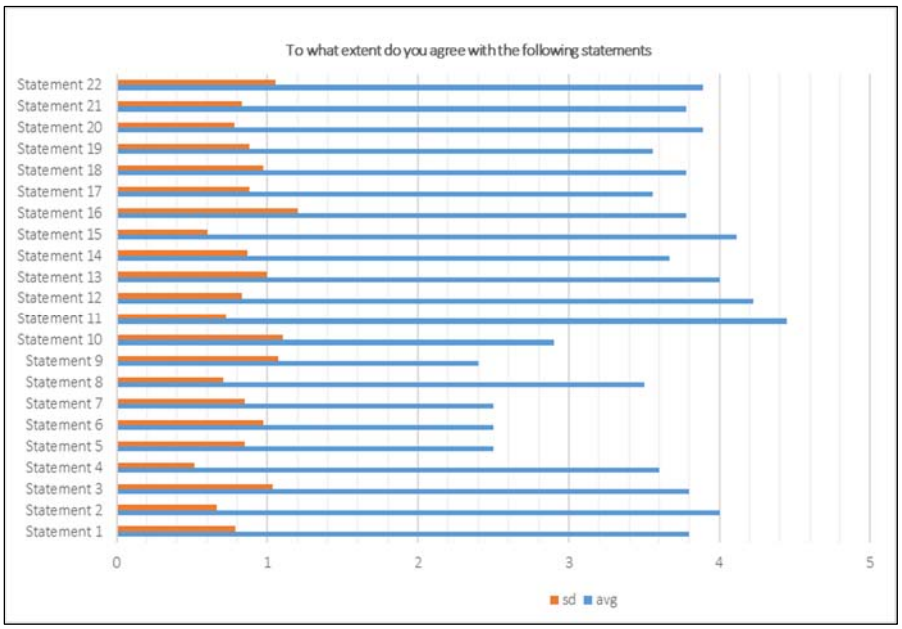


Figure 2: Use of ICT by students (sd-standard deviation, avg-average value, No. of respondees=10)

Figure 3 shows the extent to which students were involved in the use of ICT technologies during the course semester. Here in Figure 3, activities 1-4 represent the following statements:
Activity 1 – "Involved in a real-time (formative) test of knowledge with the help of ICT, which allowed you real-time feedback", Activity 2 – "Involved in the final (summative) assessment of knowledge with the help of ICT", Activity 3 – "Evaluating the work of peers using ICT", Activity 4 – "Evaluating your own work using ICT".

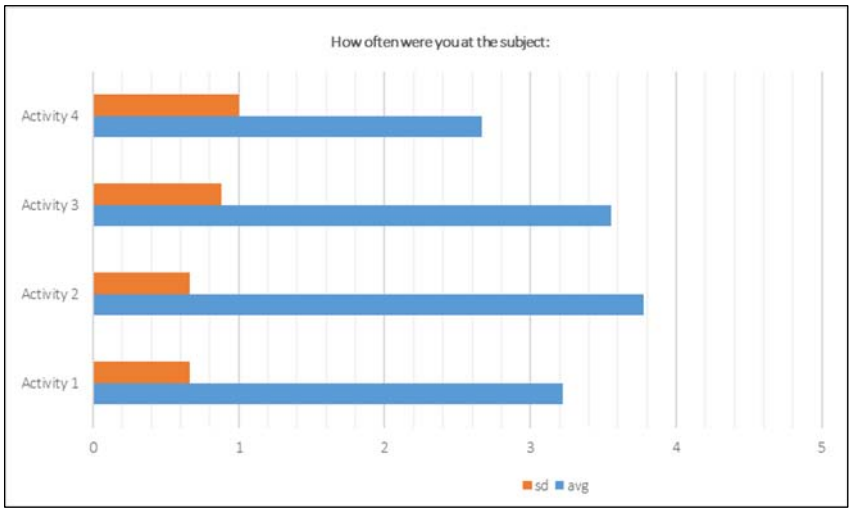


Figure 3: Students' evalutation of the invovlement of ICT methodologies (sd-standard deviation, avg-average value, No. of respondees=10)

Figure 4 presents methods for assessing student satisfaction with teaching:
Method approach 1 – The assessment method of this course (e.g. live, distance learning, combined study method, hybrid study method), Method approach 2 – Implemented activities with ICT- supported peer assessment in the course, Method approach 3 – The use of ICT- supported peer assessment to support the learning process, Method approach 4 – Communication with peers (classmates) during the assessment (interim and final results) of the course.

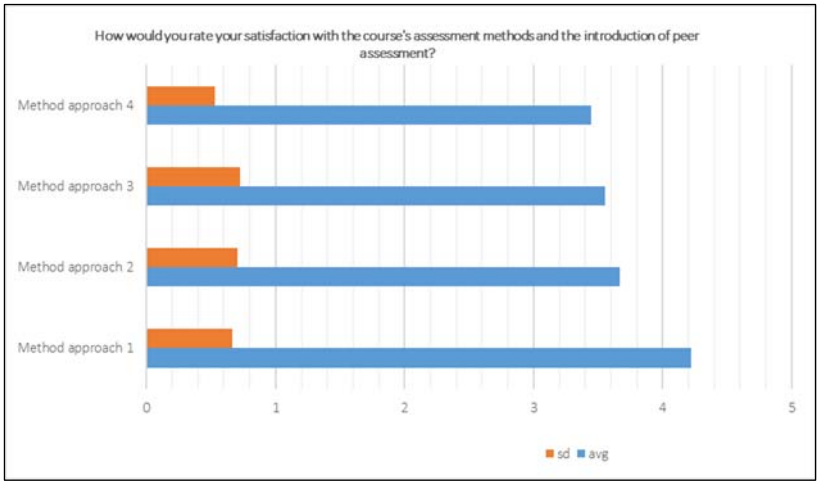


Figure 4: Course's assessment methods (sd-standard deviation, avg-average value, No. of respondees=10)

4. DISCUSSION

Both the midterm and final submissions of the students showed moderate student engagement in fulfilling course obligations. Figure 1 shows the midterm and final results of the two projects that received the highest grades. We found that most students prepared the material for both shows at the last minute, just before the show, which suddenly took place on the MS Teams (Assignments) platform. A comparison of student and teacher evaluations of the products showed that students rated each other's work slightly better. The average grade given by the students to their classmates' project work was 8.45 (sd 0.62), while the average grade given by the teachers was 8.30 (sd 0.90).

The results in Figure 2 show that students have no problems with the use of ICT and are happy to include it in their work process. They agreed that the use of ICT in the course made it easier for them to communicate with the teacher follow the messages in the course, and they were able to follow the innovations in their field of study better and organize their study materials more easily and meaningfully.

The survey results presented in Figure 3 show that students actively participated in the ongoing and final assessment of knowledge using ICT. They also actively participated in evaluating the work of their peers. Participation in ICT-based feedback on project work and summative assessment was rated by students as 3.21 and 3.68 respectively. Participation in peer assessment was rated 3.54 and the evaluation of their own work was rated 2.65.

Figure 4 shows that the students were very satisfied with the method of assessment in the subject Basics of 3D modeling by the teachers (grade 4.21). They were slightly less and therefore moderately satisfied with the activities carried out with ICT-based peer assessment in the subject (grade 3.65) and with the use of ICT-based peer assessment to support the learning process (grade 3.47). They were least satisfied with the communication between the peers during the assessment (grade 3.42).

We were supported by experts in educational science in the design, procurement of suitable procedures and implementation of the peer evaluation. Only in this way was it possible to successfully integrate the process. It was very important to clearly define the evaluation criteria. The results showed that targeting students and defining the introduction of peer evaluation is the key to successful implementation. It was also found that the introduction of peer evaluation alone is not enough to improve student interaction, but that it is necessary to motivate students to evaluate each individual project. In our experience, we had to encourage students to grade the project work for each participant individually so that they actually did so (even if they used their mobile phones to access the evaluation questionnaires). A comparison of the number of grades given by students for their classmates' project work fell by 50% at the end of the course compared to the beginning, despite the continued assessment of grading. The result opens up possibilities for further research on how higher assessment motivation could be maintained throughout the class despite the use of an ICT-based assessment method. However, the results showed that the grades given by the foreign teachers corresponded relatively well with the grades given by the students to their classmates' project work. In any case, it was noticeable that the students rated their classmates' products slightly higher and that the range of grades was narrower (most grades 8 and 9, i.e. very good) than the teachers' grades (greater proportion of grades 7, i.e. good).

5. CONCLUSIONS

The purpose of the research was to examine the impact of introducing ICT-assisted peer evaluation in regular semester and reviews of interim and final results of project concepts and visualisations in the subject with the topics about 3D computer graphic and visualisation. With this aim, we have created peer assessment rubrics that provide a structured assessment tool. The assessment rubrics and clearly defined assessment categories helped us to assess student products (by teachers and students) in a consistent way. We propose that in the definition of the assessment approaches, categories, criteria and rubrics, the basics of educational sciences should be involved as the didactics is crucial beside technical part for the quality of the assessment. Based on our results, the students of the course of 3D modelling are highly confident with the use of ICT technologies. As expected, the students are significantly including ICT in studying occupations of 3D computer graphic. Our results showed that there was a tendency of higher grades that students use to evaluate their peers' project work compared to the grades given by the course teachers. The range of student marks was smaller than the range of teachers' marks, what might show also the lower objectivity of the students' marks.

Students were positive about using ICT-oriented methods to evaluate their classmates' work but were less confident in evaluating their own work (lower scores).

Based on the results of the introduction of the rubrics and evaluation criteria for peer assessment, we believe that the method is important for the development of the course and especially for the more active participation of students in self- and peer- evaluation, which also increases their motivation to deepen their work in the course. We see possibilities for improvement in the redefinition of analytical rubrics, a clearer presentation of the goals of peer evaluation, a reorganization of the submission and evaluation method in MS Teams, and motivational strategies that would engage students more seriously in the evaluation process for the duration of the entire class period devoted to evaluation.

6. ACKNOWLEDGMENTS

We would like to thank Digital UL for their help and support, which, with its expertise, enabled us to introduce peer-to-peer strategies in computer graphics classes through a pilot project.

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GAME DESIGN STUDIES: THROUGH THE EDUCATIONAL PRISM

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Abstract: *One of the most challenging and maybe most important tasks of working as a professor and instructor is creating a purposeful and engaging curriculum program. To convey the right theoretical information and practical knowledge, professors go through an iterative process of learning through self-education, teaching, correcting, and adjusting their teaching approach. One must embark on the journey of self-discovery, proper communication, and willingness to change and adapt the curriculum to meet the requirements of industry standards, students, and technology. This paper aims to give insight into the iterative process of creating a curriculum program and practical tasks for students in the third year of Graphic Engineering and Design studies on the subject of Computer Games. Also, the process of transferring skills, acquired by working as an instructor for Unreal Engine and Unreal Editor for Fortnite and collaborating with the game designers, in the classroom will be discussed. As a result of this paper, some guidelines for designing curriculum programs for teaching game design and game development are proposed.*

Key words: video games, education, curriculum program

1. INTRODUCTION

To most, games are often observed as activities meant to enrich leisure time; something that is done to relax by themselves or in the company of others. By playing games players are provided with a sense of advancement and fulfilment by following specific rules and overcoming obstacles. If the educational system is observed in a similar way to games, one can find oneself in the gamified world of education, either as a student or as a professor. Students follow a specific set of rules and overcome different obstacles to acquire the skills and knowledge necessary to cope with the future challenges of the real world. On the other hand, educators are in the role of "game designers" who tailor their "mini-systems" to be similar to games or even include different types of games for a better understanding of the curriculum and at the same time provide better engagement.

When it comes to game design and game development for education there are different approaches in the research community. The report from MIT's Education Arcade (Klopfer, Osterweil & Salen, 2009) stated that researchers who advocate for game-based learning tend to adopt one of two very different approaches to designing games for formal education. The first approach is to use commercial games (e.g., World of Warcraft and Civilization) in education. The second one generally avoids commercial games and focuses on educational games that help supplement traditional academic subjects. The two approaches mentioned above tend to be more instructional in the way that teachers want to have a finished, downloadable teaching product as the party responsible for teaching the child.

Kafai and Burke (2015) adopted and wrote about the constructivist approach to using games in education. Contrary to instructional approaches, the constructionist approach is learning by making games. In Piaget's (1951) work, games of construction are considered the highest form of gameplay, as games require children to build representations of the world according to their understanding. Kafai and Burke (2015) emphasize the idea that knowledge about rules, worlds, and interactions is, in this way, represented in a public entity (which is the game) and that playing and making games highlights the personal, social, and cultural dimensions of constructionist learning. They stated that making video games could help understand the social, economic, and civil power of making and sharing.

This paper describes how these two approaches were applied, tested, discussed, and modified for different purposes with the goal of creating a better learning environment and for students to build better creative projects for their portfolios. Alongside, the authors implemented the approach where the presence of the teacher and their advice and mentorship are at students' disposal.

ORCID numbers are provided at the end of the paper.

1.1 Teaching with CoI in mind

While digital learning finds its roots in the broader use of computers, there was both an explosion of new research and a revisiting of the old ones. One such important research that has increased in popularity recently is surrounding the Community of Inquiry (CoI). Coined by Garrison, Anderson, and Archer (1999), CoI embodies an educational experience. CoI consists of three core elements: social presence, cognitive presence, and teaching presence. All these three elements, interlacing, further support discourse, set climate, and select content, are represented in Figure 1.

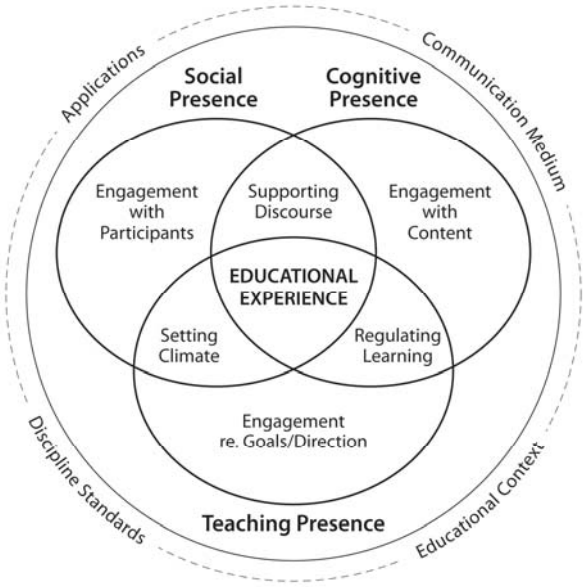


Figure 1: CoI framework

The CoI survey was developed and first tested by researchers in 2008 to aid understanding and implementation of CoI (Arbaugh et al., 2008). The survey consists of 34 questions distributed among the three key elements. Like the general CoI framework, it is actively researched today while maintaining its reliability and validity (Stenbom, 2018).

2. METHODS

In this section, the author will present the use and examples of one of the key elements: Teaching Presence. However, in this case, the implementation of teaching presence is done for real-life lessons, with the hope that if there is ever a need to transfer lessons to the online environment, the transition will go smoothly.

2.1 Teaching Presence in the practical part of the university course in Computer Games subject

The practical part of this university course is acted out in the computer classroom. Students are divided into six work groups, and each workgroup meets once a week in the computer classroom for 3 hours and 15 minutes (short break). Furthermore, each student workgroup consists of 16 students, allowing the teaching assistant (TA) or the professor to give individual attention to each student in need. This subsection is written from the experience gained from 2 semesters where the authors held six student workgroups per week, spanning two school years.

At the start of each semester, students get introduced to the topics and goals for the semester, allowing students to have realistic expectations of the course. This is important because most of the students never worked with the software (Unreal Engine) that is taught in the class, and the end goal of the class is to provide students with a good enough set of skills that they can employ, with the guidance of the TA or Professor, to complete their projects by the end of the semester.

What was noticed is that very often, a student or a small group of students was already familiar with the advanced concepts of computer games and even the game engine used in the computer lab. While that

can be challenging for lecturers, especially since students felt comfortable enough to ask questions about our approach, it was a great opportunity to discuss the class topic more engagingly. One of the most noticeable advantages of motivating students' engagement was that it lead to organic transfer of knowledge, both in student-student and lecturer-student relationships. Allowing students to express their agreements and disagreements in a safe environment was also a great way to build community.
The first year, students weren't given time during the computer class to work on their projects, so they were only following along with what the teacher did. In this approach, the transfer of knowledge was mainly one-directional, and examples done in the classroom were not specifically related to their projects. Only the main principles and skills are acquired.
During the second year, for the same course, a new method was employed (derived from transferring knowledge from other courses and conversations from industry specialists). This method was more in accordance with the CoI framework (described above). Since the computer class is project-oriented, each session had some amount of time reserved for working on the student projects in the classroom environment. The project work usually happened after the necessary part of the lecture was done, and students were encouraged for 15 minutes to simulate a meeting within their project groups to organize what every individual was working on during the previous week and what were the plans for this class. When the 15 minutes were up, each group presented what they were working on, what they planned to work on in the next week, and the issues they were facing. Other teams were motivated to ask questions and offer solutions without negatively impacting the grade for any of the teams.

2.2 Educational work at different courses and game jams outside of university

In the second part of this study, examples of curriculum are examined. Two different programs are described in this paper and one game jam each one organized by Epic Games Novi Sad (Epic Games Novi Sad, 2024a), 3Lateral (3Lateral, 2024), and Materriya Talent and Community Development team (Materriya, 2024) in collaboration with university professors.
The first one is the World Building Fellowship: Unreal Editor for Fortnite (UEFN) program (Epic Games Novi Sad, 2024c). Thirteen participants have passed through the program which lasts eight hours a day, five days a week for three weeks in total. The program consisted of lectures and practical work in Unreal Editor for Fortnite and the task was to create a game environment utilizing given game genres and mechanics. This course was tailored for professionals who have at least three to five years of experience in the game industry, 3D/CG art, concept art, and architecture, or for anyone who would benefit from learning how to integrate real-time world building into their projects.
The second course is called UEFN: Game Crafting program (Epic Games Novi Sad, 2023). Three iterations of the course are done from October 2023 till October 2024. One was held in October 2023, the second one in February 2024, and the third one in September 2024. The first iteration of the program had a total number of sixteen participants, and the second and third iteration had fourteen participants each. Each iteration of the program lasts three working weeks. Every week participants had three lecture days (Monday, Wednesday, Friday) and working days on Saturdays and Sundays (first iteration both days for three hours and second and third only one day for four hours). Participants had the task of creating assigned game environments using UEFN and Fortnite Creative by utilizing given game genres and mechanics. This course was tailored for students in the final years of their studies at the university.
The third program was the UEFN Game Jam (Epic Games Novi Sad, 2024b) where participants had the task to make a video game (island) for Fortnite by utilizing UEFN and Fortnite Creative tools during the span of two days (Saturday and Sunday) in the form of competition. Each day participants work for eight hours for a total of 16 hours after which they need to present playable games in Fortnite. There were a total number of seven teams consisting of three members (a total of 21 participants). Every team had two working stations at their disposal. Unlike the first two programs described in this chapter, this program concentrated on mentor work rather than giving lectures about specific subjects.

3. RESULTS AND DISCUSSION

Results presented here are based on working hours and the distribution of the activities throughout the whole program. These activities are separated into three main categories: (1) follow along type of class, where students learn some new lecture by watching and replicating what the lecturer does; (2) working independently on their projects (with the help of a mentor) and (3) presentation of their projects in front of the group. Seven different methodologies are presented for seven different teaching activities:

university classes for Computer Games subject for two distinct semesters (Methodology 1 and 2); world building in Unreal Engine program for professionals (Methodology 3); three game crafting programs in UEFN (Methodologies 4, 5, and 6), and game jam in UEFN (Methodology 7).

3.1 Approach for teaching Unreal Engine at the university course in Computer Games subject

Working hours for Methodology 1 and 2 are presented in Table 1.

Table 1: Distribution of working hours in Computer Games subject at the university

	Number of hours in one class	Total number of hours in semester	Teaching hours per class (follow along)	Number of hours working in a team	Mentor consultation hours
Methodology 1	3	42	3	-	-
Methodology 2	3	42	1.5	1.5	1.5

In the case of Methodology 1 students had 42 hours of follow-along type of class where they did not have time to work on their semester projects. Their individual work was done out of the classroom and without mentorship. Mentorship was provided only during the private sessions and only for two hours a week (28 hours per semester for the whole generation of students). Because this was the first time they were working in an Unreal Engine environment, and they were not familiar with C++ coding or visual scripting (Blueprints) their task was only to make an environment and to make a story through world building and animating cameras. No game mechanics were required to be implemented.
Methodology 2 was different in a way that students had 21 hours throughout the course (50%) of follow-along type of class instead of 42, and 21 hours (50%) of working on team projects where the teacher was at their disposal for questions and mentorship. Besides that, students had the opportunity to come to the private sessions for two hours a week, which gave them a total of 49 hours (21+28) of consultations throughout a semester with their teachers. The result of this approach was not only the 3D environment of the game but one functional mini game with employed game mechanics.
It can be seen from Table 1, that Methodology 2 gave more "room" for working on assignments (projects) during the class with the multifaceted benefits. One benefit of such a learning-by-doing approach utilizing the Teaching Presence of CoI framework is that students had each week more hours with the teachers discussing their assignments. The second one is that they implemented freshly acquired knowledge from that day on their projects. The third one is that not only Teaching and Cognitive but also Social Presence were employed since students worked, discussed, and interacted during the class and they were solving problems in a similar way they would in a real working environment. Also, this approach freed up time after class for some other activities. And finally, the projects were done on time due to the time management advantages of this approach.

3.2 Approach for teaching Unreal Editor for Fortnite for world building aimed at professionals

Working hours for Methodology 3 are presented in Table 2.

Table 2: Distribution of working hours in World Building in Unreal Editor for Fortnite for professionals

	No. of hours in one day/class	Total no. of hours during course	Teaching hours per class (follow along)	No. of hours on individual projects	Mentor consultation working hours	Project presentation of milestones
Methodology 3	6	75	40.5	28.5	28.5	6

Methodology 3 had almost double the number of course hours (75h) with the distribution of 40.5 hours (54%) for the follow-along type of lectures, 28.5 hours (38%) for working on their projects/mentor hours and estimated 6 hours (8%) for the presentation of their projects in front of the group. Presentation in front of the group with specific milestones every week gave participants of the project a sense of responsibility and orientation for their project.
The goal of this program was to familiarize professionals, who already worked for 3-5 years in the industry, with the possibility of UEFN and the final product was a 3D game environment with implementation of basic game mechanics. This is why most of the time (54%) was spent in a follow-along type of class. This program took place after the course where Methodology 2 was implemented, hence

some knowledge was transferred from university classes to the education of industry professionals regarding the percentage of follow-along compared to practical work on the projects, which gave good results.

3.3 Approach for teaching Unreal Editor for Fortnite for undergraduates

Working hours for Methodologies 4, 5, and 6 are presented in Table 3.

Table 3: Distribution of working hours in Unreal Editor for Fortnite: Game Crafting program for undergraduates

	No. of hours in one day/class	Total no. of hours during course	Teaching hours per class (follow along)	No. of hours on individual projects	Mentor consultation working hours	Project presentation of milestones
Methodology 4	3	51	24	24	24	3
Methodology 5	3	45	24	18	18	3
Methodology 6	3	48	10.5	34.5	34.5	3

In the case of Methodology 4, participants attended a total number of 51 hours of which 24 hours (47.06%) were the follow-along type of lecture, 24 hours (47.06%) were reserved for working on their own projects, and 3 hours (5.88%) for the presentation of the milestones in front of the group. Methodology 5 had a different distribution of follow-along type of class (53.33%), working on projects (40%) and presenting milestones in front of the group (6.67%). In the case of Methodology 6, follow-along type of class occupied 21.88%, working on projects 71.88%, and presentations in front of the group 6.25%.

This program evolved through three different Methodologies. The first one was focused on 50%-50% distribution between follow-along type of class and working on their projects which led to satisfying results, but the game worlds were majority done with predefined game assets from Fortnite which didn't make a distinct look in the great sense. The second iteration of the program (Methodology 2) had more accent on follow along type of class (53.33% compared to 40% for individual work) to teach students how to use non-Fortnite assets to get a more distinct look that is different from Fortnite's native. The result of this approach was more unique game environments but with scarce game mechanics. The third iteration hits the middle spot between the first two regarding final games. The focus of this iteration was on game mechanics and some basics of creating an environment with non-Fortnite assets which gave more time for working on the individual projects. The result of this approach was more interesting games, mechanics wise, and a more "Fortnitey", yet unique look.

3.4 Approach for mentoring Game jam done in Unreal Editor for Fortnite

Working hours for Methodology 7 are presented in Table 4.

Table 4: Distribution of working hours in Game Jam in Unreal Editor for Fortnite

	No. of hours in one day/class	Total no. of hours during course	Teaching hours per class (follow along)	No. of hours on individual projects	Mentor consultation working hours	Project presentation of games
Methodology 7	8	16	1.5	13.5	13.5	1

In the case of Methodology 7, the nature of the program (game jam) was such that participants had to finish a game in 2 days, so the focus was on their projects (84.38%) with the short introductory/orientation lecture at the beginning of the program (9.37%) and final presentation of the finished games (6.25%).

This Methodology is not comparable to the previous one but is here just to solidify the premise that more work was handed to the students to work on their projects with only the necessary instructions (follow-along type) and that a more time left for mentoring can lead to finished projects in less time.

4. CONCLUSIONS

Observing Table 1-4 as well as their explanations one obvious trend can be noticed. By increasing the number of hours reserved for working on individual projects a lot of benefits can be derived not only for

students but also for teachers (mentors). One such benefit is that by leaving more time to help students achieve their goals, teachers have the opportunity to work on a variety of projects and hear a lot of new and interesting ideas which broadens their knowledge and also gives them experience on how to approach similar projects and problems in the future. If the participants have prior knowledge in the matter and/or are professionals from the industry, teachers can acquire new skills and points of view which then can be transferred to the university classroom and other programs.

Following the CoI framework and survey and shaping the lessons to support the teaching presence element, lecturers and students were able to build open and enjoyable learning environments. Removing the stress of grading (although in the case of the university students they were still graded at the end of the course) students felt free to exchange ideas while allowing the lecturer to provide feedback and guide each team towards realistic solutions. However, sometimes, the in-classroom discussions are not enough for some, usually more ambitious teams. This leads to either office hours or e-mails from the students. Regarding office hours, students are offered multiple online options, such as Google Meet, Zoom, Discord, and traditional ones. Some students prefer writing emails, and that poses a different set of challenges. Students tend to send more emails the closer the deadline; therefore, it is imperative to motivate them to ask questions early on. Another interesting fact is that some students prefer to work at later hours of the day, and therefore send e-mails at that time. While it is important to set a boundary around working hours, in some special cases, when students must work while studying, it ends up being more productive to exchange emails with them at the most suitable time.

This research showed also that mentoring knowledge acquired from courses outside of university and from interacting with industry professionals can be and, in the authors' opinion, should be transferable to the university and vice versa. This transfer is done not only by means of providing useful tips and tricks to the students but also by means of crafting a better curriculum program through experimenting with different teaching methodologies.

5. ACKNOWLEDGMENTS

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GRAPHIC MATERIALS AND PROCESSES EFFICIENCY



https://doi.org/10.24867/GRID-2024-p85 Original scientific paper

PREPARATION OF ECO-FRIENDLY INKS FOR PRIMARY & SECONDARY PACKAGING

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Abstract: *In this period of the 21st century we can see synthetic pigments everywhere. The primary reason for the widespread use of such synthetic chemicals is that they are cheaper than natively generated substances. The goal of this work is to create ink using an eco-friendly pigment produced from Indian-Almond leaves. In general, the prints over the FMCG packages are to communicate the people about the product inside the packages without. The organic pigments have been extracted from the Indian-Almond leaves at various stages of maturation using an aqueous extraction method. Furthermore, the pigments are combined with solvents, binders, and printing paste to apply the ink to the substrate's surface. These are non-toxic and commonly utilized in FMCG Packages. This allows us to boost the use of eco-friendly inks in FMCG packaging instead of synthetic chemicals-based inks.*

Key words: Natural pigment, Eco-friendly, Terminalia Catappa, Almond leaf, Non-toxic ink, Printing inks.

1. INTRODUCTION

The Chinese and Egyptians, since ancient times, have been using colour pigments on a larger scale. Chlorophyll is a green pigment, along with other coloured pigments in plants, which takes part in photosynthesis for the absorption of as much light energy as possible. Plant pigments are very diverse compounds like porphyrins, carotenoids, anthocyanins, and betalains. Plants, animals, and minerals are the origin sources of pigments. The six carotenoids found in plants include lutein, beta-carotene, zeaxanthin, antheraxanthin, violaxanthin, and neoxanthin. All of these have non-toxic short-term and long-term toxicity profiles, which therefore pose no risk to humans even upon long-term ingestion and have no adverse impact on health. Furthermore, poisonous pigments of plants have not been detected in any extract from plant species.

Carotenoids are a class of liposoluble plant pigment which has a characteristic appearance in three colours such as red, yellow, and orange. The unusual, conjugated double-bond structure of the molecules determines the colour difference. Water and organic solvents such as acetone, methanol, ethanol, and isopropanol are effective in extracting these colours. They are categorized into xanthophylls such as lutenin and xanthophylls or carotenes such as beta-carotene and astaxanthin according to the presence of oxygen-containing functional groups at the ends of the long hydrocarbon chain (Richins et al., 2010). Carotenoids are tetraphene's, which are made up of eight isoprene units, making them the most abundant plant-derived chemicals in the terpene class. The most common carotenoid found among plants is lutein. It is a yellow pigment that can be obtained from fruits and vegetables. Two of the rarest carotenoids include lactucaxanthin, which is found in carrots, and lutein epoxide, which can be found in some woody species. More than 600 carotenoids are known to exist in nature. Due to the additional health effects of some of them, such as protection against neurological diseases, retinal degeneration, and inflammation, they have uses in food and feed processing too. The extracted colorant and pigment can also be used as ink (Umale & Mahanwar, 2012).

Among the most popular processes used for the extraction of plant pigments, one can distinguish the aqueous extraction using water and organic solvents; however, important factors include cast, toxicity, and flammability. consumption: ages compared with other processes are that this water extraction process is cost effective, simple, fast, with less solvent consumption; the yields and qualities of the extracts are improved, and it is better for industrial applications. Some of these dyes are hydrophobic in nature, like phenolic compounds and carotenoids; therefore, they can hardly be dissolved in water. Consequently, to improve the mechanism of extraction of natural dye by breaking membranes of plant cells and releasing or transferring colours in water, water extraction can be improved with the application of an acidic, neutral, and basic concept at different temperatures. However, the type of solvent applied, the temperature, and the pH all play a major role in determining extraction yields and the subsequent physical and chemical properties of plant pigment extracts, which in turn provide the solubility of a solute. Thus, applying the

ORCID numbers are provided at the end of the paper.

aqueous extraction in different contexts can yield fluctuating yields and alter the pigment concentrations (Khan et al., 2014).

Terminalia catappa is a big tropical tree from the Combretaceae family of leadwood trees. It is from Asia, Australia, the Pacific, Madagascar, and the Seychelles. The oval, glossy, dark green, leathery leaves are 10-14 cm wide and 15-25 cm long. They are deciduous trees; they have a dry season. Before the fall, they turn yellow-brown or reddish pink because of phenolic compounds contained in them, such as violaxanthin, lutein, and zeaxanthin (Thomson & Evans, 2006).

The other names for Terminalia catappa are country almond, sea almond, and tropical almond, which grow mainly in the tropics of Africa, Asia, and Australia. In India, these trees commonly occur in some of the states like Tamil Nadu, Maharashtra, Karnataka, Andhra Pradesh, and Kerala. This plant is a monoecious angiosperm, belonging to the Combretaceae family, which includes the leadwood trees. This tree reaches treetop heights ranging between 20 to 45 meters and is very resistant to drought, wind, and salt. Leaves contain flavonoids such as punicalin, punicalagin, and tercatin, saponines, and phytosterols. Because of this high chemical content, leaves find a lot of application in therapy. For example, the leaves which fall in Taiwan are used as herbal remedy against liver diseases. The leaves are used to make an herbal tea that treats dysentery and diarrhoea in China. The leaves may also hold chemicals that inhibit cancer (Boonsong, Laohakunjit & Kerdchoechuen, 2012).

Its extracts have been shown to be active against Plasmodium falciparum strains, both sensitive (HB3) and chloroquine resistant (FcB1). Left in the aquarium, the leaves retain the capability to decrease pH and heavy metal content of water. It is quite effective against bacteria and parasites for many types and has been used for a long period. It is also believed to inhibit fungus growth on fish eggs.

Printing over the package in the packaging industry is generally done with petroleum-based inks to show the brand name and product information. To create an attraction regarding brand visibility, they use some attractive coloured synthetic dyes/pigments. Packaging industries use methyl alcohol, isopropanol, alongside traditional ingredients like titanium dioxide and propylene glycol. To replace these conventional chemicals, identify the organic compounds present in the Indian almond tree leaf which have multiple colouring compounds. Extraction of pigments from the collected leaves at different maturity stages will be mixed with appropriate solvents and binders to prepare organic and eco-friendly inks for primary and secondary packaging.

2. MATERIALS AND METHODS

2.1 Collection of Materials

The concept of collecting raw materials at the right time to get a desired output. T. Catappa leaves in three different colours such as green, yellow brown, and reddish pink are collected from Anna University, CEG campus, Chennai. As T. Catappa leaves are available, samples are collected and immediately processed with no storage before analysis (Figure 1).

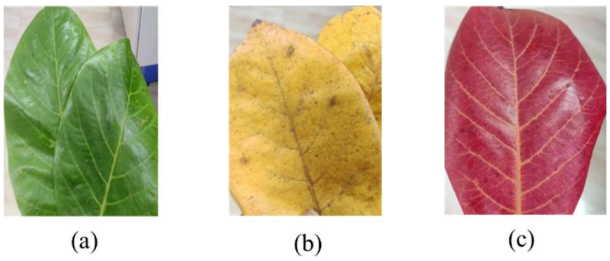


Figure 1: Different coloured leaves

2.2 Methods

Several types of extraction methods getting referred for the processing, like:

- ultrasound Assisted Extraction,
- microwave Assisted Extraction,
- acid Method of Extraction,
- alkaline Method of Extraction,

- aqueous Method of Extraction,
- fermentation - Extraction,
- reflex Boiling - Extraction,
- soxhlet - Extraction.

From these we choose the aqueous extraction method. Because this is a simple and cost-effective method.

2.2.1 Aqueous Method of Extraction

The Aqueous extraction method used only leaves in two colours, because this study has been conducted throughout the summer, and there will be an insufficient quantity of red leaves. Thus, this experiment compared green and yellow leaves.
The leaves of T. Catappa were cleaned with distilled water to remove dust particles before chopping into small pieces by following this extraction procedure.

Green leaf:
150g of chopped leaves along with 1liter of distilled water, which underwent maceration for various time periods up to 14 days (Figure 2). The sample solution was agitated every 24 hours and filtered into container bottles by using cotton cloths. Thus, the isolated pigment being examined using Thin Layer Chromatography (Figure 3).

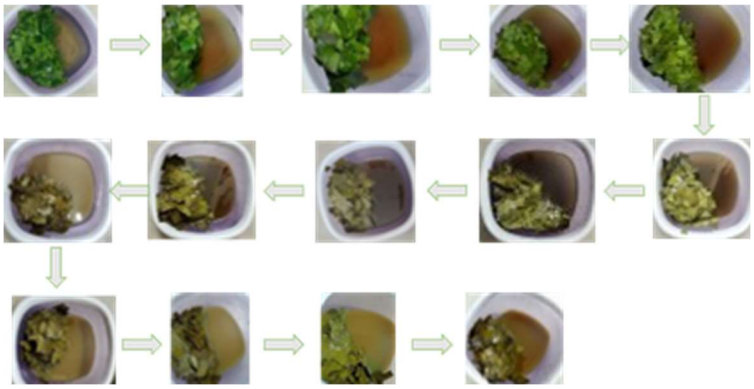


Figure 2: Colour changes of the green leaf solution from day 1-14



Figure 3: Green leaf extracts

Yellow leaf:
Weight of cut leaves 16.5g was added with distilled water 200ml which underwent maceration for a variety of times ranging from 2 days to 4 days (Figure 4). Sample solution was agitated every 24 hours and filtered into container bottles through cotton cloths. The Thin Layer Chromatography was applied to analyze the isolated pigment (Figure 5).

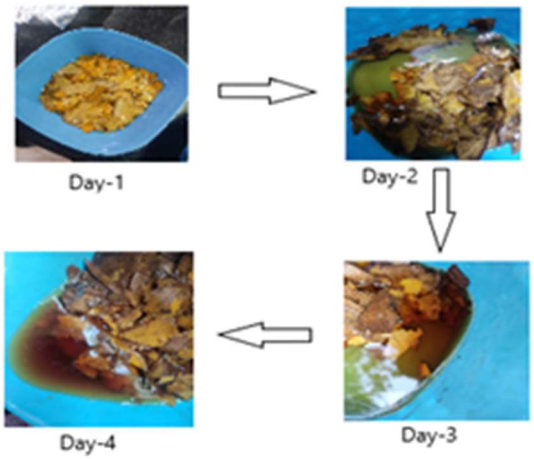


Figure 4: Colour changes of the yellow leaf solution from day 1-4



Figure 5: Yellow leaf extracts

Red Leaf:
Added 15g of cut leaves with 200ml of distilled water, it was allowed to undergo maceration at various times ranging from 2-4 days (Figure 6). Shake sample solution every 24 hours and filter it into container bottles through cotton cloths. Thus, pigment isolated has been analyzed by using Thin Layer Chromatography.



Figure 6: Red leaf extract

2.3 Pigment

The green, yellow, and red-coloured extracts were centrifuged for four hours. After which, the centrifugate is removed and the residue is cooked in a hot air oven for one hour. In this process of heating, the water evaporates, thus leaving the extracts in either pastry or powdery form.

2.4 Binder & Solvent

The binder's function is to disperse and carry the ink pigment onto the substrate, stabilize pigment and additive dispersion, avoiding setting, and confer properties to the prints, such as ink transfer behavior, setting, and drying characteristics. There are several natural binders. With this in our mind, we decided to make use of corn starch. Because of the affordability of its cost.
The binder preparation comprised 100% corn starch. For this, 2g of cornstarch was added to 100 ml of distilled water and continuously stirred at 54°C for 5 hours with a magnetic stirrer at 900 RPM (Figure 7).



Figure 7: Binder

When ink is introduced to a printing plate or cylinder from a cartridge, the solvents are employed to maintain the ink liquid until it is transferred onto the surface that will be printed on. Here water has been used as the solvent for the prepared ink.

2.5 Preparation of ink

Ink has been prepared by dissolving pigments in a solvent and adding binder. The proportions of pigment, solvent, and binder are 1:1:1 in addition with the xanthan gum as an additive (10% of total ink volume) and the prepared ink applied on both the paper and film (Figure 8). The drying time of the ink on the paper has been shorter than the film. The density and colour values have been determined by using a spectrophotometer.



Figure 8: Ink prepared by green, yellow and red pigment

3. TESTING AND RESULTS

3.1 Phenolic compound identification

The purpose of this test is to find out if the extracts contain any phenolic compounds. As a result of the displacement of the chloride anions by the aromatic rings, ferric chloride interacts with the aromatic alcohol to generate a purple solution. 5 ml of ethanol poured into the tiny baker. Ferric chloride has been

added in three drops (it does not react with aliphatic alcohol). 1 ml of extract has been added to the solution. The solution immediately generates dark purple hue complexes. The presence of phenolic chemicals in the extracts is indicated by this colour change (Figure 9).

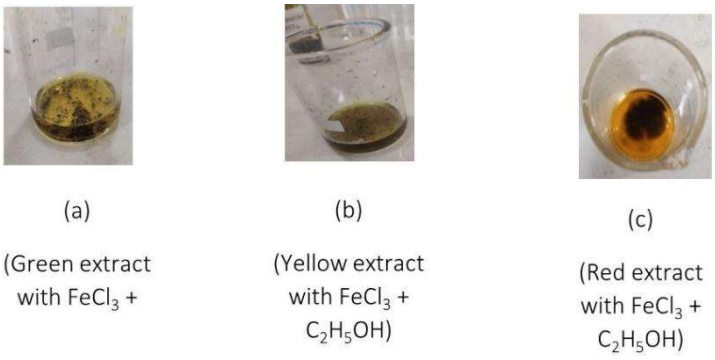


Figure 9: Testing the extracts with Ferric Chloride and Ethanol

3.2 Colour value and ink density

The Spectro densitometer is used to measure the color value and density of ink applied in a 1x1 cm² area on 75 GSM white paper and LDPE film. We measured three times to determine the approximate values of hue and density, and then subsequently averaging the values (Figure 10).

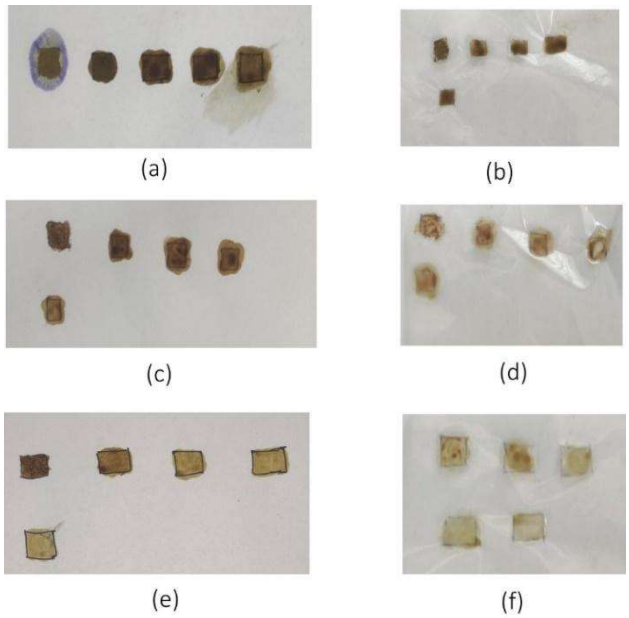


Figure 10: Colour patches in paper and LDPE Film

Here (a), (c), (e) are the figures representing the green, red, yellow inks extracted from the same colour of the leaves applied on the paper substrate. Then, the remaining (b), (d), (f) are the figures representing the green, red, yellow inks applied on the film substrate.

The drying time for the ink on the paper substrate is nearly 3 minutes, and for the film substrate it is nearly 15 minutes at room temperature. After a while of drying, the ink on the film gets peeled-off as a layer. Because both the substrate film (LDPE) and the binder (corn starch, a semi-crystalline biopolymer) used for colorant mixing are polymers.

The colour difference has been calculated by using the Equation (1):

$$\Delta E = \sqrt{((L1 - L2)^2 + (a1 - a2)^2 + (b1 - b2)^2)} \quad (1)$$

Where:

ΔE = colour difference
L1 = lightness value of the reference
L2 = lightness value of the sample
a1 = “a” value of the reference
a2 = “a” value of the sample
b1 = “b” value of the reference
b2 = “b” value of the sample

For reference, we take the printed patches with a colorant and binder ratio of 1:0, and for the sample, we take the remaining 1:1, 1:2, 1:3, and 1:4 in both the paper and the film.

3.2.1 Result for colour value and density

We can see from Figure 11 that there is a decrease in colour difference in paper when the binder ratio rises, and a similar drop in colour difference in film.
We saw from Figure 11 that the colour difference in both the paper and the film grows as the binder ratio increases.
Based on graph 3, we can see that as the binder ratio rises, the colour difference in paper likewise rises; however, in film, the colour difference reduces as the binder ratio rises (Figure 11).

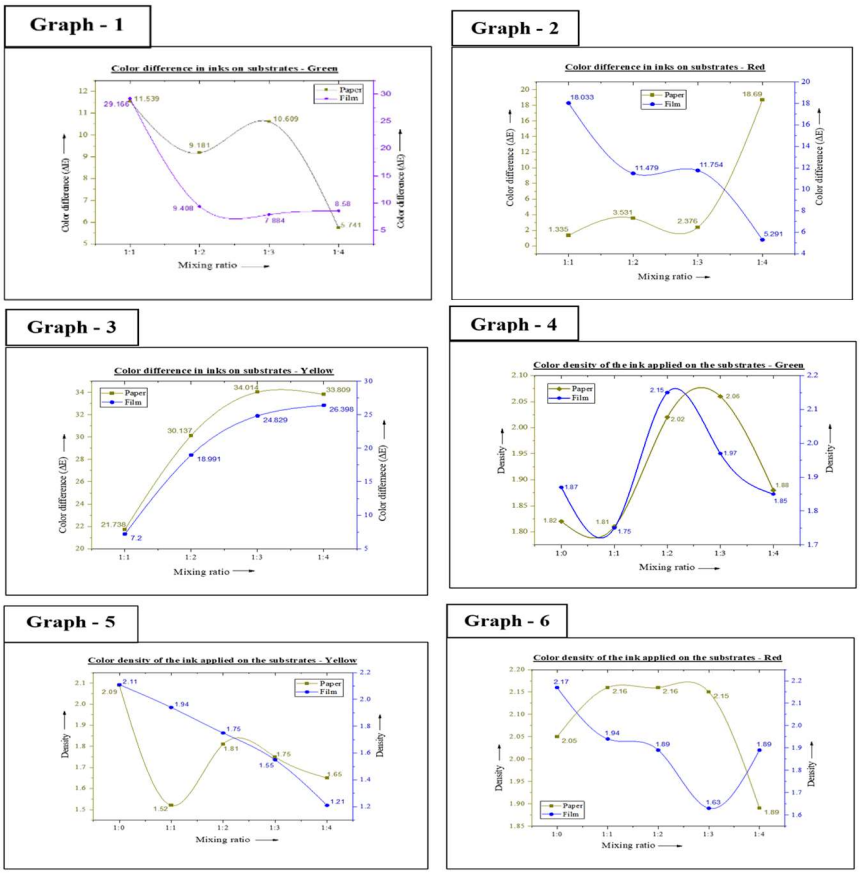


Figure 11: Colour difference and colour density graphs

3.3 Thin-layer chromatography

Silica gel plates had been activated through an oven for two hours at 100°C. The mobile phase was methanol to dichloromethane (DCM) in a 5:10 mixture. Extracts were spread out to 0.7cm from the bottom of the silica gel plate using a capillary tube with the appropriate spacing, and the silica gel plate was left to expand (pigment segregation) for about 8 minutes in a beaker comprising a mobile phase. The beaker has a lid. Pull out the TLC plate from the container when the solvent face is about 0.4cm from top of the plate.

An Rf value is a measure of the rate at which the pigment travels along the plate and is determined by dividing the total length travelled by the spot by the total length travelled by the solvent. The Rf values for each pigment have been derived by Equation (2):

$$Rf\ value\ = \frac{Total\ lengt\ \ travelled\ by\ a\ solute\ (Pigment)}{Total\ length\ travelled\ by\ a\ solvent} \quad (2)$$

Figure 12 depicts a chromatogram of TLC. The pigments have been separated, as evidenced by their respective spots. The Rf value of each site has been determined, and the results are compared to literature. Table 1 shows the identification of pigments from T. Catappa leaf extract using TLC. Spot 1 has an Rf of 0.39. It has been recognized as chlorophyll B. Spot 2 has an Rf of 0.78. It has been recognized as anthocyanins. Spot 3 has an Rf of 0.43. It has been identified as Lutein-Chlorophyll.

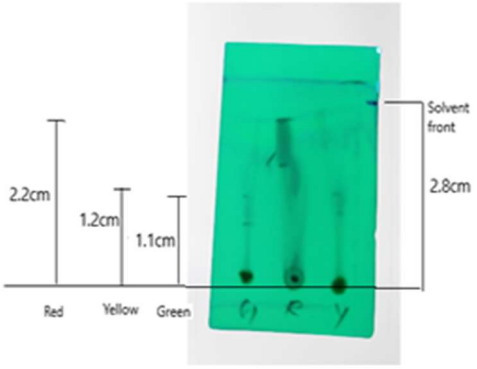


Figure 12: Thin layer Chromatography

Organic solvents can dissolve photosynthetic pigments including beta-carotene, xanthophylls, and chlorophylls. A thin silica film can be used to separate and identify pigments extracted in an organic solvent.

Table 1: Pigment confirmation

Colour of the Extract	Experimental Rf value	Literature Rf value	Pigment
Green	0.39	0.42	Chlorophyll b
Red	0.79	0.78	Anthocyanin
Yellow	0.43	0.42	Lutin-Chlorophyll

3.4 Rub resistance

Rub resistance test is used to check how much cycle of rub can be withstand by the print over the substrate (Figure 13). This test can be taken to the printed sample with the various weight of 0.5, 1 & 2 LBS at various CPM of 21, 42, 85 & 105 depending on the printed sample.



Figure 13: Rub Resistance Tester

The rub resistance test results that the print over the 75GSM white paper for 50 cycles at 42 CPM speed has no removal of ink from the substrate (Figure 14).



Figure 14: Before and After rub test

From the rub test, even though the substrate getting torn-off, the ink not getting removed from the paper substrate.

4. CONCLUSION

In the research done on T. Catappa leaf pigment extracts, violaxanthin, lutein, and zeaxanthin responsible for red, green, and yellow colours were present respectively. This work further illustrates that ethanol as a solvent can also identify such chemicals with specificity. Moreover, the advantages of aqueous extraction besides being low-cost operation go to facilities that are sensitive to environmental concerns, a minimum of energy usage, and being nonflammable and nontoxic. The Terminalia catappa leaf is made up of flavonoids, phenolic compounds that have antibacterial, anticancer, and antioxidant activities. Colorants can be used in the packaging industry to give attractive colour to improve their visual appeal. Also, they print detailed information of the product over the packages to instruct the consumers. The main advantage of pigments extracted from Terminalia catappa leaves is that they are biodegradable and renewable. In future, it may look at employing the pigment as a colouring agent in ecofriendly printing inks for degradable paper bags to replace the synthetic inks. As an alternative to artificial colours, the pigment derived from T. catappa leaves can be used to reduce the number of synthetic pigments used.

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DEVELOPMENT AND RECYCLABILITY OF STAINLESS STEEL-BASED NATURAL CONDUCTIVE INK FOR SUSTAINABLE RFID TAG ANTENNAS

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Abstract: *Due to developing economies and increasing fast consumption, products are constantly in motion globally, causing the need to monitor the products from production to sale and to keep track of their stocks regularly. At this point, smart technological products such as RFID tags make tracking easier and contribute to the smooth progress of business by containing product information. However, these tags, attached to almost every product, contain printed electronics and, therefore, valuable metals. These metals, thrown away after the product is purchased, cause e waste and environmental pollution. It may be possible to recycle these metals for reuse at the end of the tags' life. Therefore, in addition to the durability of the printed RFID tag antennas, recyclability also becomes important in sustainability. In this study, a natural conductive ink containing macroparticles of stainless steel and natural resin was developed. RFID tag antennas were printed by screen printing on PE-coated papers using this novel ink. The recycling of metals on the printed tags was studied using the deinking technique Ingede 11. Screen-printed tag antennas on paper were deinked, and the rates of metal particles remaining in paper residues and wastewater were determined. The results indicate that the metals' particle size and the interaction and adhesion of ink to paper are important for a successful deinking process in conductive inks.*

Key words: deinking, printed electronics, sustainability, recyclability, conductive ink, RFID tag

1. INTRODUCTION

Printed electronics have been widely used in sensors, antennas, and radio frequency identification (RFID) tags. RFID tags are the most used printed electronic components in commercial applications. They are widely applied in automotive, logistics, textiles, food and health industries for pallet or item level tracking. In addition, RFID tags are utilized to monitor manufacturing processes from beginning to end in some sectors for inventory management, authentication, and security. Over time, RFID printing technology has significantly advanced. Thus, the development of high-performance and low-cost conductive inks is becoming important for producing RFID tags. Besides, recyclability studies of the metals in conductive inks have been started due to the shortage of metals on earth and environmental issues caused by their wastes. The wastes of these rare earth metals can be recycled and reused as raw resources for new products to achieve a zero-waste economy. Metallic inks, such as silver inks, have been mostly preferred due to their high conductivity (Jansson et al., 2022; Riaz & Riaz, 2017) in RFID tag production. However, the high cost and corrosion problems of silver limit its application and the adoption of silver-containing conductive inks (Zhou et al., 2024). Additionally, a sintering process is needed to improve their conductivity and reinforce the ink-substrate bonding (Pan et al., 2018). Copper and aluminium can be used in conductive inks to obtain high conductivity (Rida et al., 2009). But they still have several negative aspects, like being incompatible with flexible electronics, and the costs of coating and high-temperature sintering to prevent oxidation (Campbell et al., 1999). There are studies for adopting new materials, such as stainless steel, for affordable and high-performance conductive inks to overcome these problems (Duman et al., 2021). However, the additional and essential point that should be considered for these materials is reusability (Hayta & Oktav, 2019). The RFID tags are thrown away after the end of their life cycle. According to IDTechEx forecasts, 39.3 billion passive RFID tags have been sold in 2023, up from 33 billion in 2022, indicating a 20% year-on-year increase (Chang & Das, 2024). When environmental sustainability is considered, the metals on RFID tags make up a respectable amount that can be recycled. Thus, recyclability and biodegradability of the substrate materials have become another important issue for RFID tags. Paper is a good alternative as a substrate for printed electronics because it is a light, low-cost and biodegradable material (Özdemir &

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Oktav, 2023). Little research has been done on recycling RFID tags to reuse the metals in producing new tags (Atkinson, 2017; Déprès et al., 2023; Huttle, 2009; Pogačar, Bolanča-Mirković & Gregor-Svetec, 2024; Southwell, 2023). All were applied to silver-printed tags, and most of the silver from the ink ended up in recycled paper residues or wastewater. The effectiveness of the deinking was not good enough due to the silver particle size. To recycle the metals, the deinking process was applied to the paper-based printed RFID tags. First, the samples were prepared and aged in the oven to conduct the deinking process. Then, a pulp was produced by adding the deinking chemicals and defibrated. The fibres swelled in the solution, and then paper fibre residues were collected using a loose filter. Afterwards, a magnet was immersed in the filtered water solution to collect the stainless steel particles passed through the filter. For a successful deinking process, an electromagnet can be used not to lose any metal particles when removing them from the magnet. Additionally, the hydrophobicity of the ink, the particle size of the conductive materials inside the ink, and the ink's interaction with the substrate are also important. In screen printing, the absorption and penetration of ink into the paper structure causes the conductive ink to adhere to paper surfaces (Kavčič, Karlovits & Zule, 2020). This research aims to analyze the recyclability of paper-based printed RFID tags using a conductive ink containing stainless steel macroparticles. The INGEDE 11 method was used for deinking the screen-printed RFID tags. Stainless steel ink particles in paper residues were analyzed using their zoomed images, and their extracts in wastewater were determined. Possible health risks of using stainless steel as a conductive ink should be considered; some particles can be released into the water in industrial recycling and deinking practices within the e-waste sector.

2. MATERIALS AND METHODS

2.1 Printing

In the presented work, RFID tag samples were screen printed using stainless steel spherical powder as a conductive element to examine the recyclability of metals in RFID tags. Type 316 Stainless Steel powder with 5 µm particle size and 99.8% purity and natural pine tree resin (Hayta & Oktav, 2020) were mixed to obtain a natural conductive ink and used with 40% ratios of stainless steel in weight due to our previous work (Duman et al., 2021). Type 316 steel contains 2-3% molybdenum, increasing corrosion resistance and strength at high temperatures, and 0.08% carbon. PE-coated standard bulk paper (285 g/m^2) was used as a substrate to substitute the RFID tags. The screen mesh with 77 mesh count was used to screen print the RFID tags, which was made of polyester fabric with a printable antenna design. A 15 cm rubber squeegee with 70 Shore A hardness, 75o and 3 bars pressure was used, and 26 N/cm screen tension was applied for the screen in printing. Before printing, the prepared ink with stainless steel and pine resin was heated at 40°C for 10 minutes to obtain homogeneously dispersed steel particles in the ink. The printed RFID tag antennas had a line thickness of 0,35 mm and were printed in one layer using a semi-automatic screen-printing machine. Then, the samples were aged at 60°C for 72 hours in an oven, simulating 3-6 months in a normal environment according to INGENE Method 11:2018 used for recycling (Figure 1).

2.2 Adhesion

Zoomed images are obtained on stainless steel containing ink printed on PE-coated paper to determine conductive ink adhesion on the paper substrate and the paper fibre residues after deinking.

2.3 Deinking

The efficiency of deinking was evaluated with the help of the INGEDE Method 11. The samples were cut into pieces after the ageing process. A solution was prepared from tap water and mixed with deinking chemicals, as shown in Figure 1. The paper samples were immersed in the solution and then defibrated in a laboratory defibrillator for 20 min at 45°C by keeping the pH value at 9.0. Afterwards, the mixture was filtered using a coarse paper filter. The zoomed images of deinked paper residues, captured with a scanner (300 PPI), were used to evaluate their surface properties. The amount of stainless steel particles was measured in the deinked fibre residue and the related water extract.

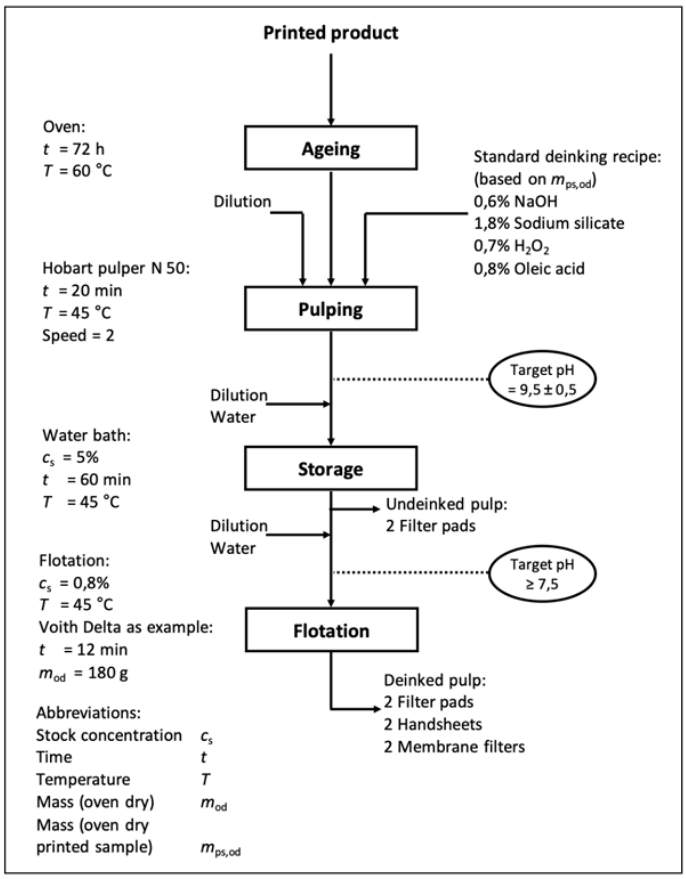


Figure 1: The standard procedure of the Ingede Method for testing the deinkability of printed papers (Ingede Method, 2018)

3. RESULTS AND DISCUSSION

The adhesion of conductive ink to the substrate is a key factor that can significantly affect deinking, and the homogenous distribution of the metals is vital for strong signals for RFID tags. As shown in Figure 2, the stainless steel particles were homogeneously distributed as desired in the printed samples on paper. The ink was heated before printing and samples were cured after printing to eliminate agloramation of metal particles. After printing the samples, the pulp is prepared, defibrated using the Ingene method and filtered to remove the paper fibre residues from the solution, as seen in Figure 3. The stainless steel particles were settled down in the remaining solution.

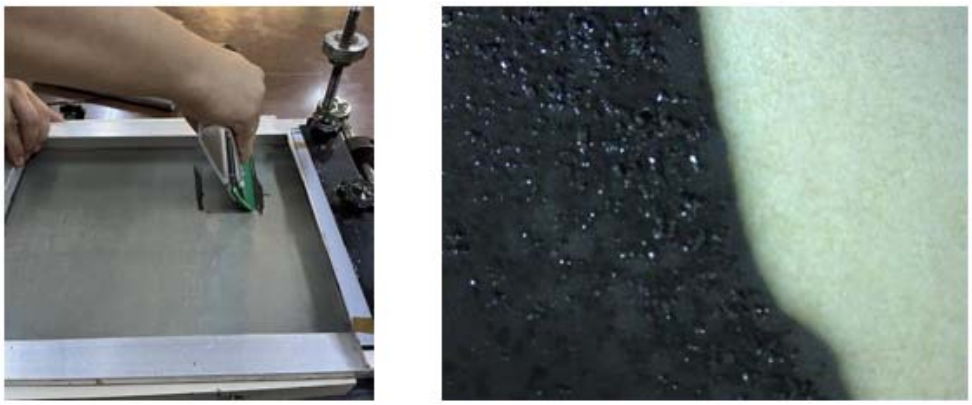


Figure 2: The photo of the screen-printing process for sample printing and the zoomed image of the printed sample with stainless steel containing conductive ink, respectively, from left to right

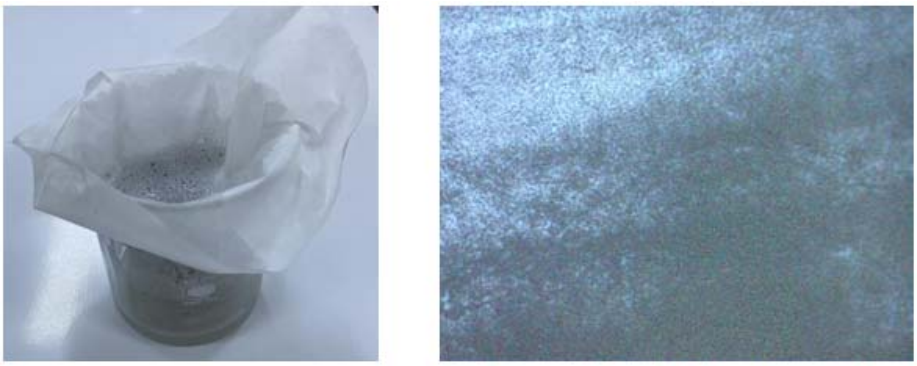


Figure 3: Filtration process of the pulp and stainless steel particles settled down in the wastewater after filtration of paper fibres, respectively, from left to right

The total weight of paper residues and stainless steel particles obtained as a result of the deinking process, as seen in Figure 4, is presented in Table 1. Approximately 90% of stainless steel particles are recycled by deinking printed samples. By deinking, the PE coating of the paper was removed together with the ink from the paper. Paper fibres in the pulp residues contain a few stainless steel particles, as seen in Figure 5, which can hardly be seen on the surface of the paper fibre residues. This can be attributed to the fact that ions in stainless steel bind more strongly to coatings than fibres.

Table 1: Stainless steel content of un-deinked and deinked printed PE-coated paper samples

Sample	Total Sample Weight (g)	Total Stainless Steel Particle Weight (g)
Unprinted paper	0.47	0
Un-deinked paper	0.69	0.09
Deinked paper residues	0.66	0.08



Figure 4: Wastewater, paper fiber residues and stainless steel particles obtained by the deinking process, respectively, from left to right

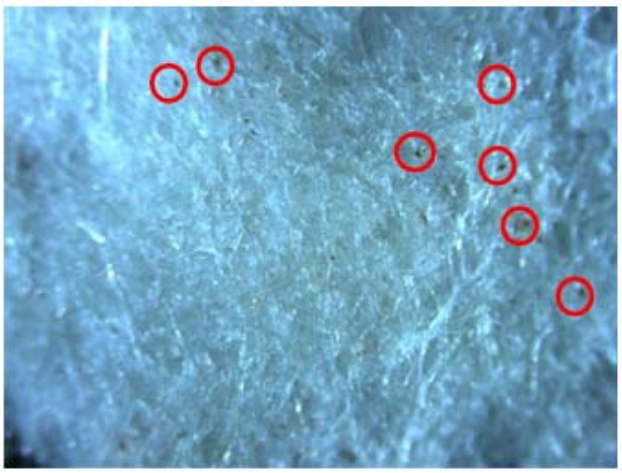


Figure 5: Stainless steel particles, circled in red, on the filtrated paper fiber residues

Stainless steel is an iron-based alloy that contains nickel (Ni), chromium (Cr), and iron (Fe) and is characterized by high corrosion resistance. When exposed to oxygen or water, a chromium-rich oxide layer forms on the surface of stainless steel, preventing the material's leaching and corrosion. Additionally, nickel improves the re-passivation of the surface oxide on stainless steel, limiting the release of metals from the alloy, even in aggressive environments depending on pH and temperature (Taxell & Huuskonen, 2022). Stainless steel accumulation in city water could harm living organisms if they enter the food chain. Modern deinking plants typically recycle a significant amount of their process water, which could lead to the accumulation of stainless steel if it leaches from paper materials. There are various methods, such as membrane filtration, ion exchange, and adsorption, to eliminate stainless steel efficiently from the water (Kavčič, Karlovits & Zule, 2020).

4. CONCLUSIONS

The research demonstrated that paper with printed conductive inks can be successfully deinked, though the process's effectiveness can be influenced by both the substrate and ink composition. Additionally, the potential release of stainless steel particles in municipal water systems during deinking should be taken into account to avoid environmental issues. It is evident that the presence of fillers and coatings on the paper impacts the removal of stainless steel particles from the fibre structure. The samples were screen-printed with stainless steel based natural ink and dried in the oven to evaporate the solvent and increase the penetration of the ink. Then, they were deinked using the procedure given in the Ingede method to recycle the conductive metals in the printed ink. The results show that the deinking process was efficient with the ink containing stainless steel particles printed on a PE-coated paper substrate. More than 90% of stainless steel particles were removed with the deinking process due to poor adhesion to paper fibres. Although the stainless steel content in the printed sample was higher than the deinked residues, it can be explained by the adhesion of conductive stainless steel particles to the materials used to collect them due to static electricity.

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THE UTILISABILITY OF HORNBEAM WOOD SAWDUST WITH CALCITE FILLER IN POLYESTER-BASED COMPOSITE MATERIALS

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Abstract: *Fillers are used extensively in all types of polymers such as thermoplastics, elastomers and thermosets. It is considered impossible to develop many polymers without fillers. The primary purpose of using fillers in polymer materials is to reduce cost, but as polymers have become cheaper and more commoditized today, the main purpose of using fillers is no longer to reduce cost. A wide variety of fillers are available, and with their careful selection, composite materials with improved properties for functional use can be produced. The main reasons for using particulate fillers today vary by polymer type but include improved processing, increased hardness, thermal distortion temperature and creep resistance, better wear and tear resistance, and flame retardancy.*
In this study, it was aimed to use organic-based hornbeam wood sawdust together with inorganic-based calcite filler. Thus, it is aimed to obtain an environmentally friendly green material. General purpose polyester resin was chosen as the matrix material for the composite due to its extensive use in industry. Hornbeam wood sawdust and calcite were used as fillers, mixed with polyester resin in certain proportions. Composite samples were obtained by open mould casting method. The filler rate was determined as 20% limit value, taking into account literature studies. Izod impact tests, tensile tests, and hardness tests of the composite samples were performed and SEM images of the broken surfaces were examined. Since the composite samples contained organic fillers, water absorption tests were also performed. As a result of the study, it was evaluated that the use of hornbeam wood sawdust and calcite together increased the impact and tensile strength, and therefore hornbeam wood sawdust could be used as a filler together with calcite in sectors such as paint and plastic.

Key words: Calcite, green composite, hornbeam wood sawdust, thermosetting polyester

1. INTRODUCTION

Composite materials consist of at least two materials: matrix and reinforcement/filler. The use of reinforcement is mostly used to increase strength. Fillers are powdered substances with low aspect ratio particles, usually micron in size, that are generally added to polymers to reduce cost, improve processing, and/or modify one or more properties.
Particle-based fillers are used in many different sectors and fields such as vehicle tires, printed circuit boards, construction, transportation and cable. It is estimated that 25-30 million tons of particle fillers are used in the polymer industry worldwide. The main purpose of use of fillers is to reduce cost. The main fillers used for polymer-based composites are natural carbonates (calcium carbonates), carbon blacks, kaolin, talc, aluminium hydroxide, precipitated silica and wood sawdust.
In polymeric materials, there is no ideal polymer or filler. Therefore, the choice of fillers is made to maximize certain properties and reduce the loss of other properties and blend the materials. The main purpose when choosing particle-based fillers is to expect high performance and low cost from the material. It has been reported that there are at least 30 properties that can be changed in the structure of the polymer by adding fillers. So you might be adding a filler to increase hardness, but it's clear that many of the other properties would likely be changed in a negative way, even though that wasn't the intent.
The cost of fillers varies greatly, from raw clays and carbonates to special synthetic types. This difference can be up to 100 times. There are large price differences even for a type of filler such as calcium carbonate, depending on factors such as colour, purity, particle size and shape, and surface treatment. For very low-cost fillers, transportation costs have now become important. With the increase in globalization, uniformity of filling qualities around the world has now become an important issue. Additionally, factors other than raw material costs should also be taken into account when evaluating whether cost savings can be achieved. One of the most important of these is the additional transaction costs incurred.

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When considering potential cost savings from the use of fillers, it should always be borne in mind that they are often significantly denser than the parent polymer. While the densities of commonly used mineral fillers are in the range of 1.5–3.0 g/cm^3, the density of commercial plastics is in the range of 0.9–1.4 g/cm^3, which means that fillers generally have a density-increasing effect.

It is thought that green composites will make a significant contribution to the environmental problem in the 21st century, as they are a potential solution to the waste problems caused by traditional petroleum-derived polymers. Green composites, which are called environmentally friendly polymeric composite materials, offer techno-economic advantages in engineering applications and also have a very high pressure from the global market. For this reason, intensive studies have been carried out in the literature on green composites recently. In this study, hornbeam sawdust was used as a green composite component.

This tree species, which grows in many parts of the world, was chosen because it is common in our country, especially in the Black Sea region, and it is thought that the wastes from these tree species can be used other than incineration and will benefit the country's economy and energy recovery. The density of the hornbeam tree is 0.83 g/cm^3 and it is quite dense and hard compared to other trees. Due to this feature, it is used in shoe making, tools, firewood, flooring, coating, musical instruments, wheels, sports equipment, handles, spindles, cars, windmills, airplane bottoms, etc. It is used for.

In this study, hornbeam tree was chosen as the biomass source and waste hornbeam sawdust generated both from tree felling and furniture making was used as filler. Calcite, another mineral-based filler, is the most commonly used filler type in the industry. The amount of filler by weight was kept as the upper limit at 20%, the mechanical properties of the composite samples with different contents were examined and SEM analysis was performed on the fractured surfaces of the samples. Thus, it is thought that the wastes originating from this type of wood will be evaluated other than incineration and will benefit the country's economy and energy recovery, and will be used together with traditional mineral-based fillers in polymeric composites.

2. METHODS

2.1 Materials

In this study, the unsaturated polyester resin used as the matrix, general purpose unsaturated polyester resin. Methyl ethyl ketone peroxide (MEK-p) was used as a hardener. Hornbeam sawdust was obtained as coarse sawdust from local furniture manufacturing companies. Sawdust size is in the range of 1-200 microns, and larger and coarser particles are not used. Calcite (calcium carbonate) was obtained from Nidaş Mining and is 3 microns in size. In order to prepare test samples, open casting was made in a Teflon mould. The reason for using Teflon mould is that after the resin hardens, it is easily separated from the mould due to its hydrophobic surface feature.

2.2 Sample preparation

The curing process was carried out at room temperature and 1.5% by weight of 6% Cobalt naphthalate was added to the resin as an accelerator. The mixture was thoroughly mixed until it became homogeneous. Then, 1.5% MEK-p was added as hardener. Hardener was added to the filler added samples after the filler was added. The whole mixture was thoroughly mixed for 2-3 minutes until it became homogeneous. Addition ratios of fillers by weight are given in Table 1.

Table 1: Contents of composite samples (by weight, %)

Samples	Calcium Carbonate	Hornbeam sawdust	Polyester
Neat Polyester	0	0	100
5CC15HS	5	15	80
10CC10HS	10	10	80
15CC5HS	15	5	80
20CC	20	0	80
20HS	0	20	80

**Abbreviations: HS: Hornbeam sawdust; CC: calcium carbonate.*

2.3 Mechanical tests

The tensile test of the samples prepared according to the ISO 527 standard was carried out in the Zwick Z010 universal tensile device with a tensile speed of 5 mm/min. The impact strength of the unnotched samples prepared according to the ISO 180 standard was tested using a 5.4 J Izod hammer in the Zwick B5113.30 impact device. Hardness measurements were made in Zwick Shore D device, 15 sec. made with a waiting period. For scanning electron microscope (SEM) analysis, the samples were coated with a 10 Å thick gold/palladium alloy. The SEM test was performed with the Polaron SC branded device located in the Marmara University Faculty of Technology Laboratory.

3. RESULTS AND DISCUSSIONS

In this study, polyester resin, which is the most used in composites, was used as the matrix material, calcite filler, which is also the most preferred inorganic filler, and sawdust of the hornbeam tree, which is abundant in Turkey, was used as the organic filler. Green composite was made by using inorganic and organic filler together and their usability was evaluated. The total filler rate in the matrix was determined as 20% by weight.

In general, inorganic fillers increase the mechanical properties of polymeric composites with the filler content until the optimum value and then decrease. The mechanical properties of filler-based polymers are affected by the interfacial adhesion between the matrix and the filler. Factors such as the filler ratio and size used in the composite and the bond strength of the matrix layer between the fillers also affect the strength. The tensile strength values of the samples are given in Figure 1.

Among the samples, the highest tensile strength was found in the 20 CC coded sample (24,2 MPa), and the lowest tensile strength was determined in the 20 HS coded sample (16,8 MPa). The tensile strength decreased as the HS content increased in the samples. These results are similar to the literature. In addition, it has been stated in many studies that as the amount of organic filler in the matrix increases, the tendency to agglomerate causes the tensile strength to decrease. The tensile strength of neat polyester was determined as 23,1 MPa.

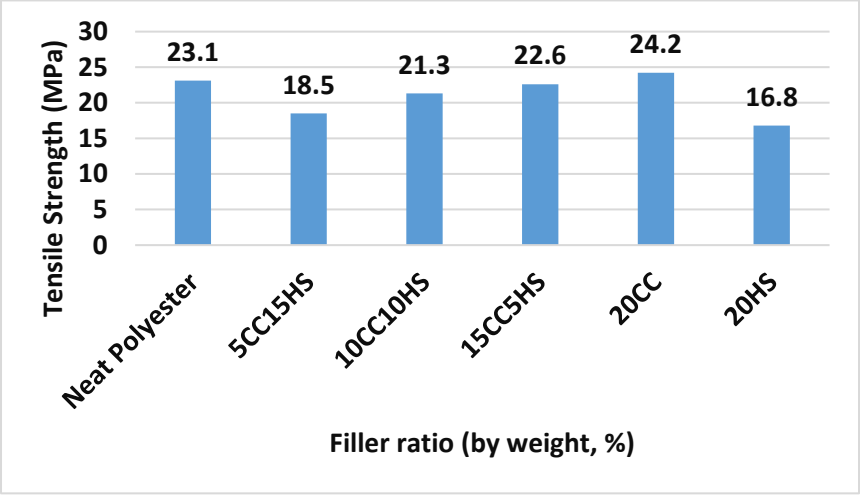


Figure 1: The tensile strength values of the samples depending on the filler ratio

Figure 2 shows the Izod impact strength properties of the samples depending on the filler ratio. The impact strength of composite samples may vary depending on many situations such as the properties of the filler material, the distribution and density of the filler, their interaction with the matrix material, composite production technique, and environmental factors affecting the filling material. Organic fillers can generally be in fibre or particulate form. Long fibres or larger particles generally provide better impact strength because they provide more opportunity to dissipate and absorb energy. However, this relationship is not always true and in some cases large filler sizes can cause undesirable results. Again, the homogeneous distribution of the filler material in the structure and its appropriate density also positively affects the impact resistance.

As expected in this study, a decrease in the impact resistance of the composite was observed with the increase in organic filler ratio, and a partial increase was observed with the increase in inorganic filler. The impact strength of the sample coded 15CC5HS increased compared to pure polyester. The highest impact strength was obtained in the 20% calcite filled sample. It can be said that the filler size in the samples, which was in the 1-200 micron size range, did not have a negative effect on the impact strength, because there was no obvious decrease with the addition of organic filler. Even though sawdust filler was used together with calcite, it showed lower impact strength than polyester after 5% filler rate. It is thought that the formation of weak interfacial bonding in the following ratios and the tendency to clump as the amount of filler increases reduce the impact strength.

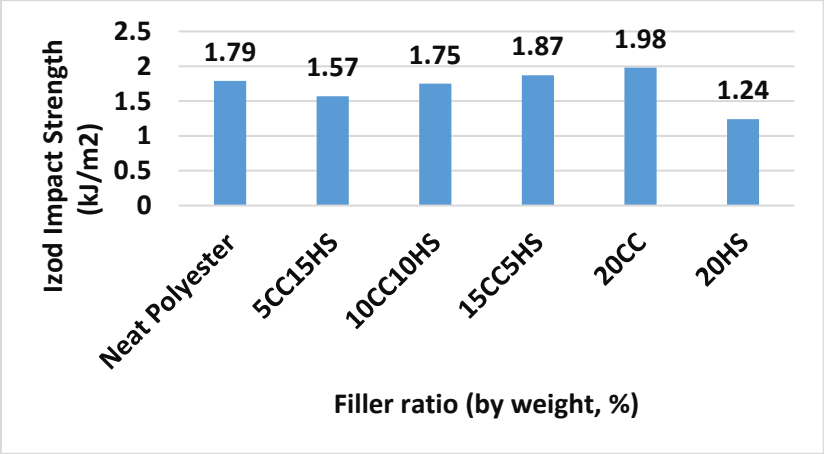


Figure 2: The Izod impact strength properties of the samples depending on the filler ratio

Figure 3 shows the hardness properties of the samples depending on the filler ratio. Inorganic fillers have a positive effect on hardness in composite materials. However, a complex relationship emerges between the size of the organic-based filler and the hardness properties it will provide to the structure. In general, fillers with large dimensions and high-density fillers can contribute to a higher level of hardness, but may vary depending on the filler type, distribution, and other factors. The process of combining organic fillers with the composite material can affect the hardness properties. The pressing processes used in the composite sample preparation stage can affect the homogeneity and therefore the hardness of the composite material. Or, in the open cast production method, the fillings may sink to the bottom due to the density difference. Again, with organic filler materials, moisture, temperature or chemical interactions can affect the properties of the filler material and therefore its hardness properties.

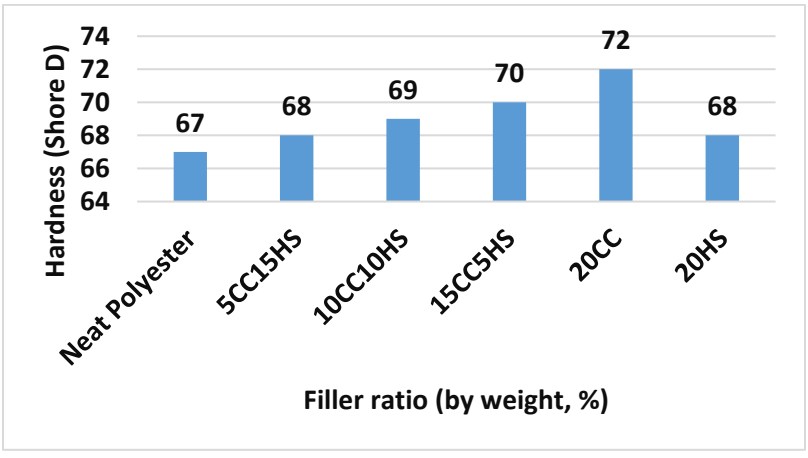


Figure 3: Hardness properties of the samples depending on the filler ratio

Figure 4 shows the density properties of the samples depending on the filler ratio. The density of polymeric composites varies depending on the density and amount of fillers. However, if the bonds between the filler

and matrix are strong, the density of the composite can often increase. Smaller particles are generally better dispersed and can form a tighter matrix, which can increase the density of the composite. If the filler particles are homogeneously distributed and have a uniform morphology, the density of the composite generally increases. As expected in this study, the use of inorganic filler amount increased the density, while increasing the amount of organic filler decreased the density.

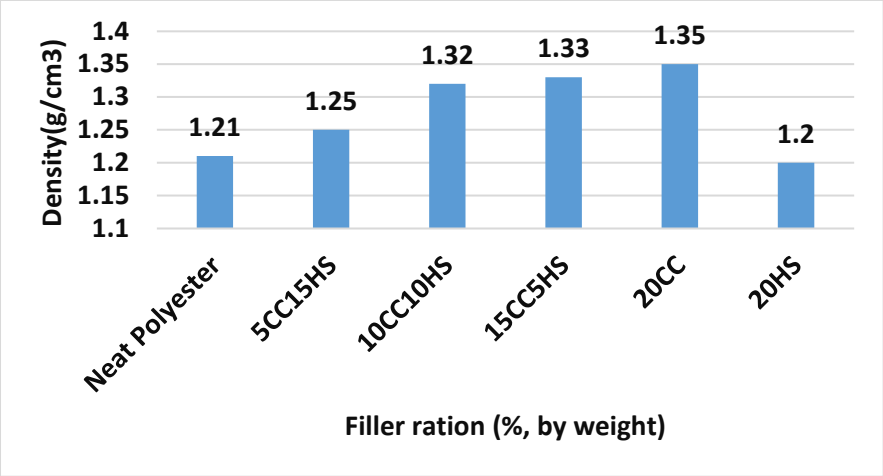


Figure 4: Density properties of the samples depending on the filler ratio

Figure 5 shows the water absorption properties of the samples depending on the filler ratio. Studies in the literature have reported that natural fibres, which are hydrophilic in nature, absorb high moisture and have a rapid water absorption rate. The hydroxyl groups and water molecules of cellulose form hydrogen bonds, increasing the water absorption capacity of the composite. It has been observed that sawdust-filled composites have a similar behaviour. The sample that absorbs the least water is neat polyester. Among the composite samples, the calcite-containing sample is the one that absorbs the least water.

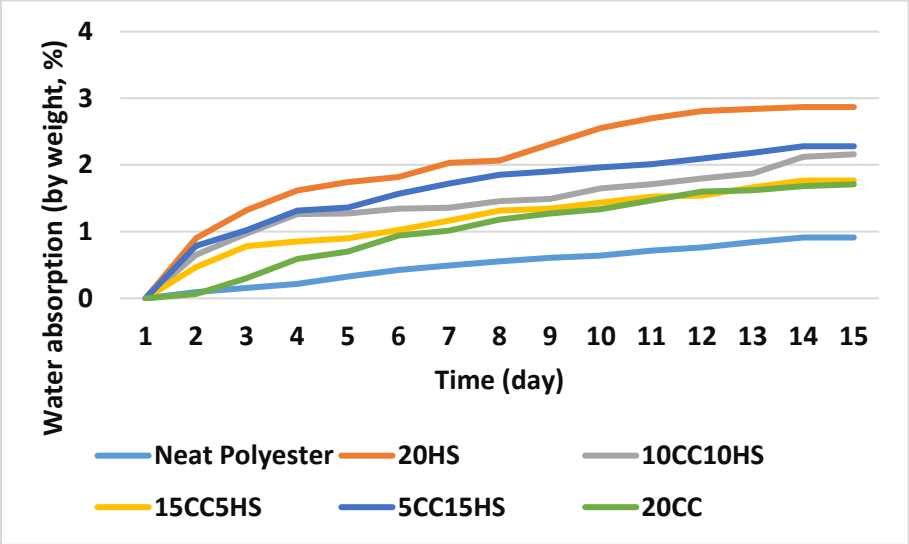


Figure 5: Water absorption properties of the samples depending on the filler ratio

SEM images of the samples are given in Figure 6. In Figure 6a, it is understood that pure polyester is broken by brittle fracture. Figure 6b image contains hornbeam sawdust and calcite filler. It can be said that hornbeam sawdust and calcite filler show a good combination in polyester resin. As can be seen from the images, it is understood that the ends of the sawdust are in the range of approximately 50-100 microns, and the remaining structure is embedded in polyester. It can be said that as the calcite ratio increases in the sample (6c) containing 20% calcite filler, agglomeration occurs. This can cause the formation of bubbles

and pores that can interfere with the mechanical properties of the composites. In the 6d image, hornbeam sawdust particles of certain sizes that have protruded from the matrix can be seen. As can be seen from the image, the sawdust particles, which have a cellulosic structure, adhered very well.

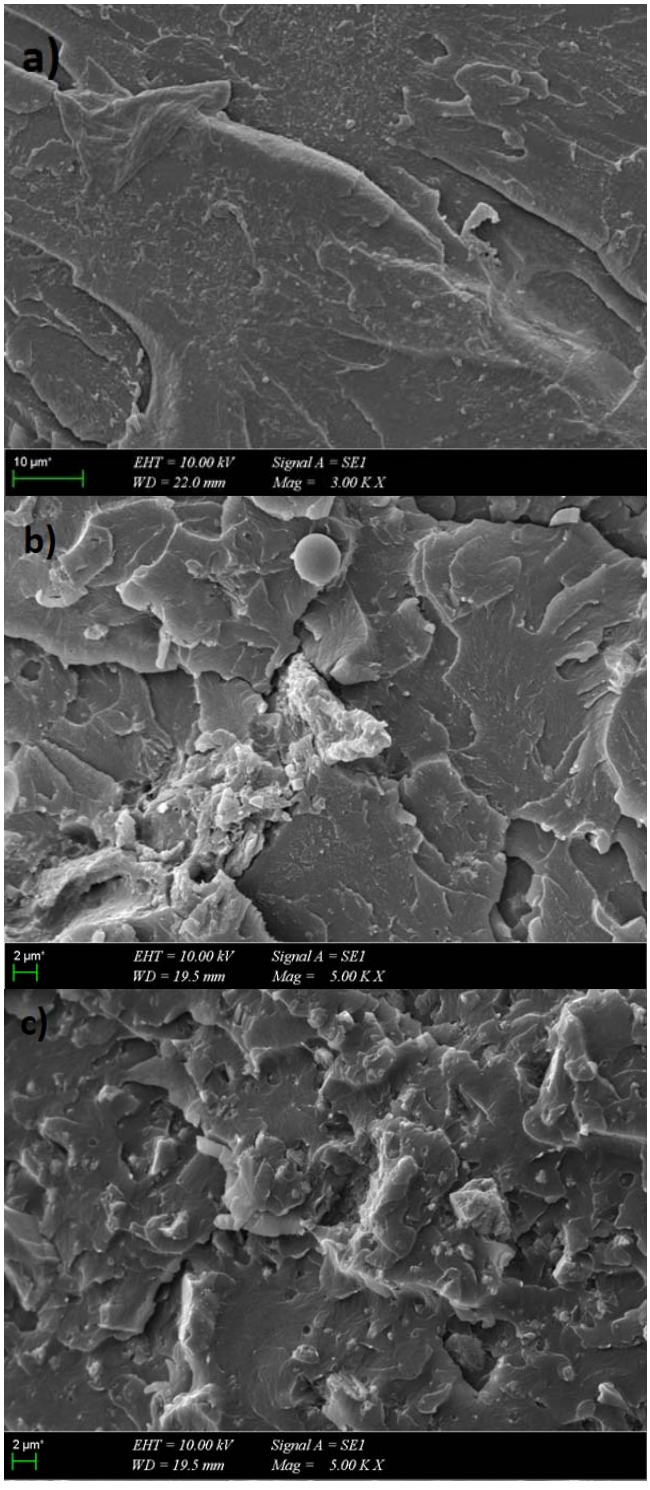


Figure 6 (part 1): SEM images of samples a) Neat polyester b) 10HS10CC c) 20CC d) 20HS

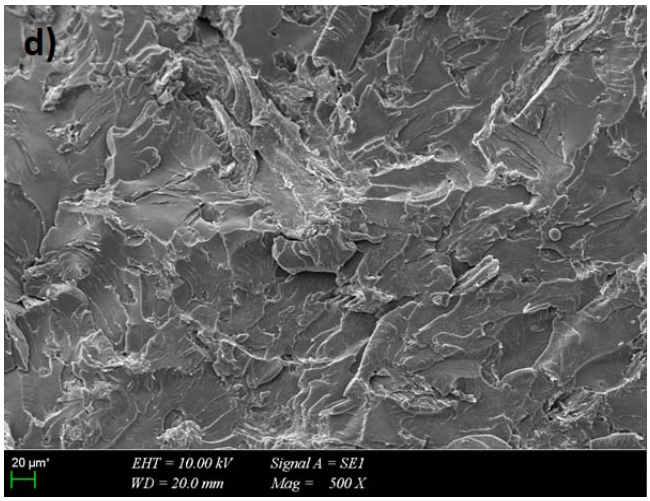


Figure 6 (part 2): SEM images of samples a) Neat polyester b) 10HS10CC c) 20CC d) 20HS

4. CONCLUSIONS

In this study, green composite was obtained by using natural filler and inorganic filler together. The use of natural fillers in green composites provides several advantages. These include reducing environmental impact, using renewable resources, increasing recycling opportunities and promoting biodegradability. Additionally, green composite materials are generally lower cost and energy efficient.
Natural fillers also reduce the cost of the material by reducing the amount of polymer in the composite. When the amount of filler material mixed into the polymer reaches a certain value, the mechanical properties of the polymer may weaken and its hardness may increase. For this reason, the fillers used in polymer-based composites have an upper limit. In this study, the upper limit was determined as 20%. Thus, it was determined that it would reduce the cost of matrix material by 20%.
When sawdust filler is used together with calcite, it has been evaluated that the ideal ratio is 5% HS and 15% CC, however, although 10% HS and 10% CC ratios partially reduce the mechanical properties, the decrease is tolerable.
As a result of the study, it was concluded that hornbeam sawdust together with calcite can be used as a filler in polyester-based composites. This approach can contribute to reducing environmental impact in industry and preserving natural resources. With the use of green composite materials, we can move towards the goal of leaving a cleaner and more sustainable world to future generations.

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TYPOGRAPHY



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ANALYSIS OF SLOVENIAN SONGBOOKS AND REDESIGN OF THE SCOUT SONGBOOK

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Abstract: *Many songbooks today are the work of a single author or contain a collection of songs by different artists, groups or singers from one or more genres. However, a scout songbook is always a collection of songs for singing, usually with additional sheet music or chord symbols. The need arose to create a new scout songbook that would improve on the existing songbook "Strune do lune" ("Strings to the Moon") in terms of content and design. The redesign of the existing songbook required an analysis of songbooks with a similar structure and, above all, a thorough analysis of the existing scout songbook from which we started. Therefore, in the experimental part, we analysed and thoroughly reviewed ten songbooks that are structurally similar to the original songbook. We analysed various criteria (format size and layout, fonts for the main text, titles and subtitles, size and spacing between text lines for the main text, x-height, special features in chorus notation, layout and categorisation of songs according to a theme, illustrations, cover design, binding method of the songbooks and certain special features such as split text verses on the other side of the page) that significantly influence the usability and visual appearance of the songbook. Based on detailed analyses and comparisons, we established sensible starting points for the design. Based on these starting points, we designed a new songbook entitled "Melodije do galaksije" ("Melodies to the Galaxy") and confirmed that analysing existing songbooks is crucial for the design of a new songbook.*

Keywords: songbook, analysis, redesign, layout design

1. INTRODUCTION

A songbook is a collection of songs that are intended to be sung and are usually accompanied by musical notation or chord symbols. Nowadays, there are numerous songbooks created by a single author or containing a compilation of works by various artists, groups, singers, etc., often covering one or more genres – from folk songs, contemporary melodies and popular music to hymnbooks for church singing and more. Songbooks in Slovenian first appeared during the Protestant Reformation in the second half of the 16th century. Primož Trubar and Jurij Dalmatin, two of the leading figures in the dissemination of Slovenian literature, were also responsible for the creation of the first songs in Slovenian. Church music became an essential part of Protestant rituals, which led to all Slovenian Protestant writers composing hymns until the 16th century. These were mainly translations from German or Latin (Možina, 2003; Levec, 1900; Dalmatin, 1584).

Until the 18th century, Slovenian songs served exclusively religious purposes, and since the church poets did not have a particularly well versed Slovenian language, the hymns they wrote generally had no artistic value. Their primary function was spiritual; they were intended to convey religious messages to the people through melodies. This changed during the reign of Maria Theresa and Emperor Joseph II, when Slovenian poetry, modelled on Austrian literary movements, began to flourish. One such follower of Viennese German poetry was the Augustinian monk Father Damascen Dev, who also ventured into secular literature and gave the Slovenes their first non-religious songs. During this period, Valentin Vodnik was the first to give Slovenian poetry lasting value, especially with his collection "*Pesme za pokušino*" ("*Songs to Taste*"), which was printed by Janez Krstnik Retzer in 1806. In the first half of the 19th century, France Prešeren raised Slovenian poetry to a European level and broadened the horizons of Slovenian poets (Možina, 2003; Levec, 1900; Kidrič, n.d.).

A fascinating and significant part of the literary heritage of the Slovene language is the tradition of handwritten songbooks, which, despite the prevalence of printed editions, survived well into the 20th century. The common people used them mainly for singing in church choirs, on pilgrimages and at folk devotions (Pisk, 2017).

ORCID numbers are provided at the end of the paper.

The scout songbook "*Strune do lune*" (*Strings to the Moon*") required a redesign in terms of content and graphics, which necessitated the creation of a new visual product. The first interaction between the user and the publication is created by the visual appearance, which emphasises the content and entices the reader to engage with it. Like any printed material, a songbook needs to be attractive and recognisable. We have designed a new songbook entitled "*Melodije do galaksije*" ("*Melodies to the Galaxy*"), which contains songs and their corresponding chords. When designing the songbook, it was important to place the chords correctly above the lyrics to make it easier to accompany them with an instrument (e.g. a guitar). As the content and text must be aesthetically arranged and logically structured – e.g. to ensure that a song is not continued the next page – we looked for the best possible solution. The aim was to create a coherent visual identity for the new Scout songbook and to design its layout to be both a design upgrade and a mirror image of the existing "*Strune do lune* songbook".

2. METHODS

The first decisive step was a detailed analysis of the songbook "*Strune do Lune*" and the examination of ten collected songbooks with a similar structure, meaning of the lyrics and accompanying chords. We analysed various criteria: Format size and layout, fonts for the main text, titles, size and spacing between text lines for the main text (for which we used a typometer), x-height, special features in the chorus notation, the layout and categorisation of the songs by theme, illustrations, cover design, binding methods of the songbooks and certain unique aspects such as split text verses that continue on the facing page. Some of the parameters have been presented in a table for better visualisation (*Tables 1 and 2*).
All songbooks are bound with soft covers, some stitched, others glued, and some with spiral binding. The songs are divided into a varying number of chapters. The illustrations are mostly in places where there would otherwise be large empty spaces, although "*Jubilate II*", "*Jubilate 3"*, "*Med nami je On!"* and "*Odrini na globoko"* only have illustrations at the beginning of the chapters. The covers are very different and usually reflect the content of the songbook. Some songbooks adhere to the principle of not splitting a song over several pages so that you do not have to turn the pages while playing.

Table 1: Analysis of various criteria of existing scout songbooks

Element	Od pomladi do jeseni (*From spring to fall*)	Od jeseni do pomladi (*From fall to spring*)	RBS RST skalar'ca	Rad bi svet naučil pesem (*I want to teach the world a poem*)	Le za Kristusa (*Only for Christ*)
Text block format (mm)	148 × 210	146 × 213	118 × 165	152 × 211	165 × 235
Layout size (mm)	124 × 172	120 × 180	92 × 148	136 × 193	142 × 210
Chapter title Font	Decorative Scripts	Decorative scripts	/	Sans Serif, bold	/
Song title font	Sans serif, bold	Sans serif, bold	Sans serif, bold	Decorative Scripts	Sans serif, bold
Subtitle font	Sans Serif	Sans Serif	Sans Serif	/	Sans serif, thin
Stanza font	Sans Serif	Sans Serif	Sans Serif	Sans Serif	Sans Serif
Stanza font size (pt)	9	9	9	9	9
Chorus font	Sans Serif, italic	Sans Serif, italic	Sans Serif, italic	Sans Serif, italic	Sans Serif, italic
Chord font	Sans Serif, bold	Sans Serif, bold	Sans Serif, bold	Sans Serif, bold	Sans Serif, bold

Table 2: Analysis of various criteria of existing scout songbooks

Element	Jubilate II	Jubilate 3	Med nami je On! (*He is among us!*)	Odrini na globoko (*Push it deep*)	Glasbena želja *(A musical wish)*
Text block format (mm)	98 × 157	102 × 159	115 × 169	148 × 210	212 × 209
Layout size (mm)	79 × 135	85 × 142	92 × 145	127 × 182	182 × 175
Chapter title Font	Sans serif	Sans serif	Decorative	Decorative	/
Song title font	Sans serif, bold	Sans serif, bold	Transitional Caslon Old Style, Bold	Sans serif, bold	Sans serif, bold
Subtitle font	Sans Serif, italic	Sans Serif, italic	Transitional Caslon Old Style	Sans Serif	Sans serif
Stanza font	Sans Serif	Sans Serif	Transitional Caslon Old Style	Sans Serif	Sans Serif
Stanza font size (pt)	11	11	12	9	9
Chorus font	Sans Serif, italic	Sans Serif, italic	Transitional Caslon Old Style, italic	Sans Serif, italic	Sans Serif, bold
Chord font	Sans Serif, bold	Sans Serif, bold	Sans Serif	Sans Serif, bold	Sans Serif, bold

2.1 Analysis of the "*Strune do lune"* songbook

After analysing ten songbooks, a detailed analysis of the songbook "*Strune do lune* was" was carried out according to the same criteria. The songbook "*Strune do lune"* has a portrait format of 148 × 210 mm, with the 224 pages giving the text block a thickness of about 15 mm. The songbook is softbound and stitched. The songs are divided into four chapters – "*Scout Songs"*, "*Christian Songs"*, "*Popular Songs*" and "*Folk Songs"*. The chapters are indicated at the top of each page with a larger, centred title and the chapter names are also indicated by a black rectangle in the outer right-hand margin. The text block is large in relation to the format and measures 123 × 194 mm. The margins are set at 15 mm from the inner edge, 8 mm from the upper edge, 10 mm from the outer edge and 8 mm from the lower edge. On some pages, the songs extend beyond the text block. The text block is divided into two columns with a space of at least 2 mm between them. The pagination is in the bottom right corner (Figure 1).

The font for the lyrics is the linear *Segoe UI*, size 9 pt. Its italic version is used for the choruses, while the bold version is used for the chords above the lyrics. The line spacing is 10 pt. The *Segoe UI* in its bold version is also used for the chapter titles, which are 36 pt in size. The song titles are set in *Penguin* font, size 14 pt, bold, while the author's name is displayed in *Courier New*, size 8 pt.



Figure 1: Beginning of a chapter in the songbook "Strune do lune"

The illustrations are stylistically varied and relate primarily to the content of the songs they accompany and are placed in places that would otherwise remain blank. The cover is in four colours: yellow, black, blue and green. The songbook belongs to the scouts who have blue and green on their scarf; therefore, this combination appears on the cover. The front cover is decorated with various elements, such as a dragon and a wolf, which, like the colours, represent the scouts. The guitar and strings on the cover as well as the musical staff and notes, allude to the nature of the songbook, while the depiction of the moon matches with the title. The title is written in *AR Berkley* font, size 72 pt. The chapters begin on the recto pages, immediately after the end of the previous chapter's songs, with no blank pages in between. Some songs continue on the next page, so the pages must be turned (Figure 2).



Figure 2: Image of the open cover of the songbook "Strune do lune"

2.2 Design of new songbook based on analyses

Both "*Strune do lune"* and the majority of the other songbooks analysed are in portrait format, so we decided to keep the same portrait format for the new songbook to ensure similarity and consistency. Next, we selected the main font for the song lyrics. In addition to the existing *Segoe UI*, we considered and compared six potential linear fonts: *Montserrat*, *Lato*, *Open Sans*, *Roboto*, *Source Sans Pro* and *Myriad Pro* (Figure 3).

Segoe UI	Šerif bo za domačo vajo spet kuhal žgance
Montserrat	Šerif bo za domačo vajo spet kuhal žgance
Lato	Šerif bo za domačo vajo spet kuhal žgance
Open Sans	Šerif bo za domačo vajo spet kuhal žgance
Roboto	Šerif bo za domačo vajo spet kuhal žgance
Source Sans Pro	Šerif bo za domačo vajo spet kuhal žgance
Myriad Pro	Šerif bo za domačo vajo spet kuhal žgance

Figure 3: Font comparison

We have opted for the Source Sans Pro font, which has a high x-height, which improves readability and which has narrower characters compared to the other fonts. This results in shorter lines or verses that are easier to fit into the narrow text block. The font size has been left at 9 pt, while the line spacing has been

increased from 10 pt to 11 pt. We have kept the italic version for the choruses to ensure adequate differentiation and the bold version for the chords as these need to be easily recognisable.
Once we had determined the font size and line spacing, we set up a baseline grid in Adobe InDesign, created several typical and less typical pages (especially songs with long verses) and used this as a basis for determining the size of the text blocks and their placement in the format. We made sure that no song was split across multiple pages so that you do not have to turn pages when playing or singing.
We have updated the font for the song titles, as the previous font *Penguin* seemed outdated. We opted for *Museo Sans*, an easy-to-read, reasonably geometric, strong font with low contrast. We used *Museo Sans 700* in 12 pt for the songs and *Museo Sans 900* in 38 pt for the chapter titles. The chapter titles were placed on the recto (left) pages, while the songs began on the verso (right) pages. We have retained the chapter indicator at the edge of the page but moved it to the outer edge of the sheet (Figure 4).



Figure 4: Beginning of a chapter in the new songbook

Most of the songbooks analysed use illustrations anywhere on the page to fill blank spaces between songs and enhance the page. We wanted to make sure that the illustrations in the new songbook were stylistically consistent and original, serving primarily to enhance the theme rather than simply fill space. We decided to present the illustrations in the style of an animated book, where the illustrations create an animation by quickly turning the pages (Figure 5).



Figure 5: Creating the illusion of movement with sequential illustrations

We have placed the illustrations on the right pages of the songbook, above the bottom right corner of the page. Because of this placement, we have adjusted the bottom margin of the recto pages and shortened it by two lines to create a little more space for the illustrations. All the songs were placed on page 203, which meant that we needed at least 102 different illustrations, one for each verso page. The concept design included moving illustrations to show the setting up of the camp and the end of the day with singing around the campfire (Figure 6).



Figure 6: Sketch of the set-up campsite

We determined the approximate number of frames needed to depict each activity and sketched the intermediate scenes. We then created vector illustrations using Adobe Illustrator. Due to the small size of the illustrations in the songbook, we simplified all the shapes and tried to depict the elements with as few strokes as possible (Figure 7).



Figure 7: Example of an illustration in the songbook on the right page

Once we had placed the illustrations, we determined the layout of the pagination, as we could not place it in the bottom outer corners as in the previous songbook. We placed the pagination on the right margin of the verso pages, below the rectangle for the chapter title.

For the newly designed songbook "*Melodije do galaksije*", we wanted to create a graphic link with the cover of "*Strune do lune*". The existing songbook has elements that extend beyond the edge of the cover, which we found to be an exciting basis for a visual link. On the front cover there is a musical staff with notes that extend beyond the right edge, and on the back cover a crescent moon continues on the spine and wraps around the front cover. We incorporated these elements into the new cover design and ensured that they continue seamlessly from one cover to the next when the songbooks are placed side by side (Figures 8 and 9).



Figure 8: Connection of the musical staff on the front covers of the old (left) and the new (right) cover



Figure 9: Connection of the musical staff on the front covers of the old (left) and the new (right) cover

We also wanted to maintain continuity in terms of colour, so we chose a dark blue background with a starry sky and a yellow moon and used green for the musical staff instead of the border. We matched the shade of green a little better to the colour of the scouts' neckerchiefs. The title of the songbook "*Strune do lune*" was realised in the *AR Berkley* font. We experimented with other fonts, but as none of them turned out to be particularly suitable, and to increase continuity between the songbooks, we decided to keep the *AR Berkley* font for the title. It was reproduced in the yellow of the moon, at 55 pt, in the lower third of the cover.

2.3 Print proof and corrections, printing and finishing

The print proof was intended for grammatical corrections and to analyse the user experience. With the help of guitarists and singers, we checked the suitability of the chords and their placement, the appropriateness of the font size, and corrected errors. In the printing house, we verified the accuracy of the colours, the placement of the illustrations and other elements. Finally, we printed the songbook digitally and bound it with a soft cover and a stitched spine.

3. RESULTS AND DISCUSSION

In our analysis, we have retained the design advantages of the earlier songbook while avoiding certain shortcomings. The *Source Sans Pro* font proved to be highly readable, clear and more suitable than the *Segoe UI* font, which had wider letterforms and consequently longer lines that were more difficult to fit into the margins. The *Museo Sans* font, which replaced the somewhat outdated Penguin font, also proved to be the better choice. Although the new fonts for the text and song titles disrupted consistency somewhat, we successfully updated the design and realised significant benefits (Table 3).

Table 3: Comparison of certain elements of the songbooks "Strune do lune" and "Melodije do galaksije"

Element	Strune do lune	Melodije do galaksije
Text block format (mm)	148 × 210	148 × 210
Size of layout grid (mm)	123 × 194	126 × 189
Line spacing (pt)	10	11
Chapter title Font	Segoe UI	Museo Sans, 900
Song title font	Penguin	Museo Sans, 700
Subtitle font	Courier new	Source Sans Pro, thin
Stanza font	Segoe UI	Source Sans Pro
Stanza font size (pt)	9	9
Chorus font	Segoe UI, Italic	Source Sans Pro, Italic
Chord font	Segoe UI, Bold	Source Sans Pro, Bold

The illustrations are stylistically consistent and show scouts and their setting up a campsite, which makes them thematically appealing. They often fill the space at the bottom right of the page, which is normally left blank. This placement makes them visually interesting and ensures a tidy appearance as they are always in the same place. Although the pagination used is not traditional for such songbooks, it is an appropriate solution given the placement of the illustrations. In addition, the page numbers harmonise well with the black rectangle containing the chapter title at the top. Users may need to get used to this layout the first time they use it.

We have designed a new cover while retaining the link to certain elements, colours and fonts of the previous edition (Figure 10).

The print proof was an important step before the final print, enabling us to recognise and correct errors.



Figure 10: Cover of the songbook "Melodije do galaksije"

4. CONCLUSIONS

The analysis of the existing songbook and the comparison with similar songbooks were decisive and served as the basis for the design of the new songbook. It has retained or improved the design advantages and avoided the shortcomings of its predecessor. The new songbook retains the green and blue colours on the cover, albeit in an updated look and includes unifying elements such as the musical staff and the moon. It retains the recognisable title of the songbook, but gets a new font for the lyrics that provides more space in the margins, an updated font for the song titles, stylistically consistent custom illustrations with an additional storyline and avoids splitting the songs across multiple pages, making it easier to use. The goal of making "*Melodije do galaksije"* a design upgrade and at the same time a sequel and a mirror image of its predecessor has been achieved.

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TEMPORAL TYPOGRAPHY: THE IMPACT OF ANIMATION SPEED AND INTERPOLATION ON INFORMATION TRANSMISSION EFFICIENCY

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Abstract: *This study investigates the influence of kinetic typography on information transmission efficiency within motion graphics. The focus is on the impact of two variables: word count displayed per minute and typography interpolation method.*
Type in motion plays a crucial role in conveying information and attracting viewers in new media. The speed at which text elements traverse the screen potentially impacts information perception and understanding. Similarly, the chosen interpolation method, determining transitions between states, affects readability, aesthetics, and overall message delivery.
To explore this impact, a combined quantitative and qualitative research approach was employed. Young viewers participated in the study to assess comprehension and information retention. Participants viewed motion graphic animations designed to isolate the two factors under investigation. An optimal speed range was identified, enabling comprehension at a pace that maintains viewer engagement while facilitating information retention. Additionally, the study found that the interpolation method significantly affects information transmission. Specific interpolation techniques enhanced readability, while others hindered it.

Key words: kinetic typography, interpolation, short-form video

1. INTRODUCTION

The continuous evolution of technology, combined with the high rate of production and wide availability of information, has fundamentally altered the way the public consumes media. As digital platforms proliferate and access to content becomes increasingly ubiquitous, video media has emerged as one of the dominant forms of communication and entertainment. High-speed internet, mobile devices, and social media have collectively contributed to this shift, enabling audiences to consume video content anytime and anywhere. A particularly significant trend within this space is the rise of short-form video content. Characterized by its brevity and engaging format, short-form videos typically range from a few seconds to around 90 seconds in length. Platforms like TikTok, Instagram Reels, and YouTube Shorts have capitalized on the audience's preference for fast-paced, visually stimulating content, propelling short-form videos into mainstream popularity. This makes short-form video a powerful tool in industries ranging from marketing to education. However, this shift in video media consumption habits poses a certain set of challenges for video content creators and advertisers. Beside the change in length, the change in orientation and dynamic environment of viewing video content on smartphones require a different approach in creating content. Since there are many situations in which the videos are viewed without sound (Wang et al., 2020), the video feed is often accompanied by sequenced or animated text.
In the context of using kinetic typography for promotional messages, text presented over time in a manner intended to convey or evoke a particular idea or emotion, combined with directing attention makes kinetic typography especially suitable for this purpose (Lee et al., 2002). Animation in general has shown to have a positive impact on the effectiveness and information retention of the ad content (Li & Bukovac, 1999).Advertisers have quickly adapted to this shift. Although generally the short-form video platforms allow in-feed video ad length up to 60 seconds, the recommendations are to keep the length of the ads significantly shorter. In the research of impact of 6,15 and 30 second in-feed video ad lengths to attention, emotional response, memory and attitude, Wang et al. determined that the 15 second video ad length provides the best compromise (Wang et al., 2020).
Within the broader domain of video media, motion graphics, and more specifically kinetic typography, have gained prominence. Kinetic typography refers to the animation of text in a way that enhances the communication of messages by combining dynamic movement with visual design (Lee & Park, 2023). The integration of motion and typography creates a visual experience that transcends static text, helping to emphasize important information, and boost viewer engagement. It is used in various contexts, including marketing, entertainment, education, and digital media (Schnotz & Rasch, 2005). Motion qualities, such as smoothness, acceleration, and transitions play a crucial role in how kinetic typography is perceived. Abrupt

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or disjointed movements can disrupt the viewer's experience, creating a sense of disconnection or cognitive overload. In contrast, fluid, well-timed motions can enhance readability and make the information easier to follow. Smooth transitions, achieved through techniques such as easing - gradually speeding up or slowing down the motion - help guide the viewer's eye across the screen and keep them engaged. All this is relevant to using kinetic typography in short-form video formats, where the speed and motion qualities of kinetic typography are critical factors that can influence how well the audience engages with the text. Finding the right balance is essential: text that moves too slowly might fail to maintain the viewer's interest (de Koning et al., 2011), while text that moves too quickly may overwhelm the viewer, affecting ability to comprehend and retain the presented information(Hasler et al., 2007). However, limited research has shown that high animation speeds in advertising can result in heightened viewer arousal (Sundar & Kalyanaraman, 2004), suggesting that faster-paced kinetic typography may grab attention more effectively. The objective of this study is to explore how different motion qualities—specifically text speed and keyframe interpolation—affect viewer engagement and content retention in kinetic typography, particularly within the fast-paced context of short-form video formats. By analysing the impact of both predefined and custom interpolation techniques, this research aims to provide insights into optimizing motion design for promotional media, where capturing attention and conveying information effectively in a limited time is crucial.

2. THEORETICAL BACKGROUND

Creating comprehensive motion graphics involves a combination of design principles, animation techniques, and the technical characteristics of the format for which the motion graphics are being developed. By taking these factors into account, motion graphics designers can optimise the effectiveness of information transmission, ensuring that the target audience comprehends the intended message. Some of the key elements for information transmission in motion graphics are:

a. Clear and concise messages: Animated graphics should prioritise clarity and brevity to ensure that the audience easily understands the information. This entails using succinct language, eliminating superfluous details, and structuring content in a logical and coherent manner.
b. Legible typography: Typography in motion graphics refers to the use of text and letterforms as design elements. It encompasses the selection of appropriate fonts, sizes, styles, and other typographic properties to effectively convey messages. Ensuring sufficient contrast between typography and background is also vital for enhancing legibility. While motion can amplify the expressive aspect of type, maintaining legibility and readability ensures its functional aspect (Bachfischer et al., 2006). Establishing a clear visual hierarchy directs the viewer's focus and aids in the immediate comprehension of the most important information. This can be achieved through variations in typography, colour, size, and placement of visual elements, thereby emphasising key points and ensuring a logical flow of information.
c. Animation: Animation techniques bring static elements to life, creating motion and visual interest. These techniques include determining keyframes, easing, timing, and sequencing to create smooth transitions, dynamic effects, and engaging visual narratives. By carefully controlling these temporal elements, designers can introduce subtle variations that infuse the motion with personality (Lasseter, 1987), making the animation not only visually appealing but also more engaging on an emotional level.
d. Timing and pacing: Timing and pacing are pivotal in motion graphics. The duration and rhythm of visual elements, transitions, and effects influence the viewer's perception, comprehension, and emotional response to animated content. Viewers should be provided with sufficient time to process information without being overwhelmed or losing focus. In the contemporary context, particular attention is given to the duration and pacing of motion graphics for several reasons. The primary limiting factors are the formats for which the motion graphics are produced. Different formats, media, or applications through which motion graphics are displayed impose specific temporal constraints on content duration. For instance, motion graphics displayed on Instagram as a profile story are limited to a duration of 15 seconds.
e. Interpolations: Interpolation is a fundamental technique in motion graphics that determines the transition between two states of an animated element, such as movement, size, colour, or opacity. It involves calculating and filling in unknown data between two known values. In animation, these values are most referred to as keyframes or key states.

The concept of controlling motion in computer software by manipulating speed curves has been present for a long time (Bartels & Hardtke, 198 C.E.). Keyframe-based motion graphic software tools, such as Adobe After Effects, Blender, and other animation software, rely on different types of keyframe interpolation to control how objects move between keyframes. These tools offer various interpolation methods, ranging from simple, predefined transitions to highly customizable curves that provide designers with precise control over motion. Each type of interpolation affects the fluidity, pacing, and realism of the animation, and understanding these options is crucial for optimizing kinetic typography and motion design.

1. Linear Interpolation: Linear interpolation maintains a constant speed between keyframes, resulting in uniform motion that can feel mechanical or rigid. While straightforward, it often lacks the natural flow required for engaging animations.
2. Easing Interpolations: Motion graphics tools provide predefined easing interpolations, such as ease-in, ease-out, and easy ease, to create smoother, more natural transitions between keyframes. These are simplified, preset versions of Bézier curves, designed to make motion feel more fluid by introducing gradual acceleration or deceleration. Ease-In slows at the beginning of the motion and accelerates toward the end. Ease-Out starts quickly and decelerates toward the end, providing a smoother stop. Easy Ease combines ease-in and ease-out, creating both a slow start and stop, offering a more natural motion effect.
3. Bézier Interpolation: For designers seeking full control, Bézier interpolation allows manual adjustment of the motion curve. By manipulating the Bézier handles, designers can gradually tune the acceleration, deceleration, and motion trajectory, creating more complex and dynamic animations. This type of interpolation is suitable for tailoring motion to specific creative needs.
4. Hold Interpolation: Hold interpolation offers no transition between keyframes, resulting in abrupt changes in motion or position. This method is often used for stylistic effects where immediate shifts are desired.

Predefined easing interpolations provide users with an easy way of achieving more natural motion compared to simple linear interpolations. In programming environments, these easing functions are often based on the notable work of Robert Penner, who formulated a set of mathematical easing equations (Penner, 2002). However, in keyframe-based animation production software, easing interpolations are usually implemented using Bézier curves, providing a limited number of presets. While these predefined options provide an easy way to create the impression of more natural movement compared to linear interpolation (Krasner, 2013), they may not always suit specific animation needs, especially when unique timing or pacing is required. Custom easing allows animators to have finer control over the speed curves, enabling them to create more fitting and dynamic motion.

3. METHODS

The study was conducted in two phases. The first phase focused on evaluating participants' retention of content and their preferences regarding different text sequence speeds in a kinetic typography motion graphic. The second phase involved a comparative analysis of motion graphics using predefined interpolation curves for easing versus custom speed curves applied to the animation. All participants in this study were aged between 18 and 30 years old, as this demographic represents the primary users of digital platforms where short-form video and motion graphics are most consumed (The State of Video for Tech 2024).

For the text presentation speed evaluation, a multivariate experimental design was employed to assess the effects of varying text speeds on content retention. A total of 60 participants took part in this evaluation. Participants were randomly assigned to one of four experimental groups, with each group viewing a kinetic typography video where the text was presented at one of four distinct speeds: 40, 60, 90, or 120 words per minute (Table 1). The stimuli were created using After Effects and consisted of a simple text sequence containing information about a design studio and its work. Given that animated motion graphics content is designed to not contain sentences or longer text paragraphs, the typography had to have a prominent and visually attractive appearance. According to all factors, the sans serif display fonts Now and sans serif fonts Helvetica were selected. Each word was presented individually on the screen, with every word having the same duration within the test sequence. Following the viewing, participants were administered a questionnaire designed to measure how effectively they retained the information conveyed during the video. The questionnaire comprised 9 questions that required participants to recall specific information from the text presented in the motion graphics. The answers to the questions were simple and more

complex from one term to a whole sentence that the respondents were asked to recall. Also, the questions asked the participants to memorize two types of data, words and numbers.

Table 1: Stimuli specifications and links to videos

animation	Words/min	Words altered every	format	Link to video
S40WPM	40	45 frames	30 frames/sec	https://youtu.be/0xGiwqwdQ4
S60WPM	60	30 frames	30 frames/sec	https://youtu.be/pK0rzEyFft0
S90WPM	90	20 frames	30 frames/sec	https://youtu.be/lRGGixLHQTQ
S120WPM	120	15 frames	30 frames/sec	https://youtu.be/fRiLajzXEH8

A separate evaluation was conducted to assess the subjective attractiveness of the four different speeds. A total of 40 participants viewed each of the four test samples and rated the attractiveness of each on a Likert scale from 1 (not attractive) to 5 (very attractive). The order in which the samples were viewed was randomized to minimize potential bias.

The second phase of the research was to investigate the influence of keyframe interpolation on the retention and subjective preferences. Tested were two samples with different approach to keyframe interpolation. Both kinetic typography motion graphics featured the same elements, general motion paths, number of scenes and transitions and the overall duration which was 18 seconds. However, in the first sample (I1) all movements and transitions were done by applying simple easing interpolations (easy ease in, easy ease out, easy ease). The movement of elements and transitions for the second sample (I2) were done by applying more elaborate Bézier curves for interpolations. The stimuli were created in Adobe After Effects. The topic of the text was promotional information about a concert.

For the retention test, a multivariate experimental design was employed. A total of 40 participants were randomly assigned to one of the two experimental groups. After viewing the assigned sample, the viewers had to answer 5 questions to test retention of the content presented through the kinetic typography.

4. RESULTS AND DISCUSSION

For the retention test across different sequence speeds, descriptive statistics, including the number and average of correct answers per participant group, were calculated. A Chi-square test was conducted to assess the association between video speed and response accuracy, determining whether significant differences in comprehension levels existed between different presentation speeds (Table 2).

Table 2: Answer counts per question for different sequence speeds

Video speed	Response Type	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	TOTAL
S40WPM	Correct	14	4	9	9	5	2	8	4	1	**56**
S40WPM	Partially Correct	0	5	0	0	0	4	0	2	1	**12**
S40WPM	Incorrect	1	6	6	6	10	9	7	9	13	**67**
S60WPM	Correct	13	7	10	10	4	2	11	4	0	**61**
S60WPM	Partially Correct	0	2	0	0	0	0	0	0	0	**2**
S60WPM	Incorrect	2	6	5	5	11	13	4	11	15	**72**
S90WPM	Correct	13	7	9	9	4	3	9	6	1	**61**
S90WPM	Partially Correct	0	3	0	0	0	0	0	2	2	**7**
S90WPM	Incorrect	2	5	5	6	11	12	6	7	13	**67**
S120WPM	Correct	12	4	8	8	4	2	6	5	0	**49**
S120WPM	Partially Correct	0	2	0	0	0	3	0	1	0	**6**
S120WPM	Incorrect	3	9	7	7	11	10	9	9	15	**80**

Regardless of sequence speed (Figure 1), most respondents correctly answered basic information questions, but struggled with harder ones (e.g., recalling the last three words in Q9). Performance across groups was comparable, with 120 WPM yielding the fewest correct answers, though the difference was not statistically significant ($p = 0{,}095$).

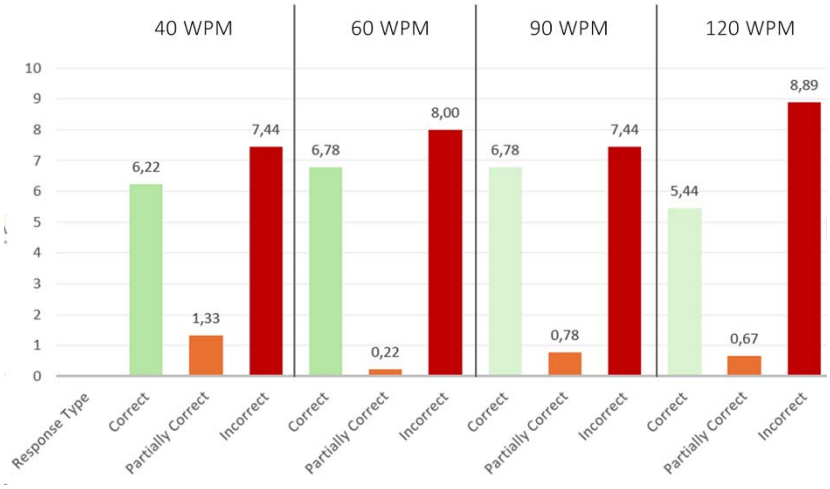


Figure 1: Average number of correct, partially correct, and incorrect answers per sequence speed

For subjective evaluations results (Figure 2), a Kruskal-Wallis test, followed by Mann-Whitney post-hoc analysis, showed a significant preference for faster sequence speeds, with 90 WPM rated most attractive. Significant differences ($p \leq 0{,}001$) were found between all pairs, except 60WPM -120WPM and 90WPM -120WPM.

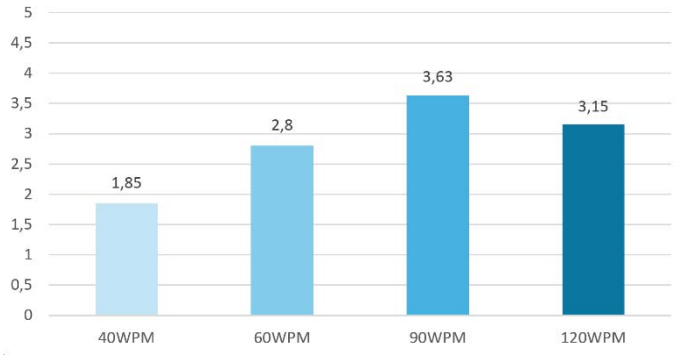


Figure 2: Average attractiveness scores for the sequence speed test samples

For the information retention evaluation related to different keyframe interpolations (Table 3), we employed the same statistical analysis as with the sequence speed test. The results showed comparable or improved retention across all questions, suggesting that the qualities of movement shaped by complex keyframe interpolations influence recall in viewers (Figure 3). The results were statistically significant ($p \leq 0.05$).

Table 3: Answer counts per question for different interpolation types

Sample	Response Type	Q1	Q2	Q3	Q4	Q5	TOTAL
I1	Correct	8	8	10	18	11	55
I1	Incorrect	12	12	10	2	9	45
I2	Correct	16	14	14	20	11	75
I2	Incorrect	4	6	6	0	9	25

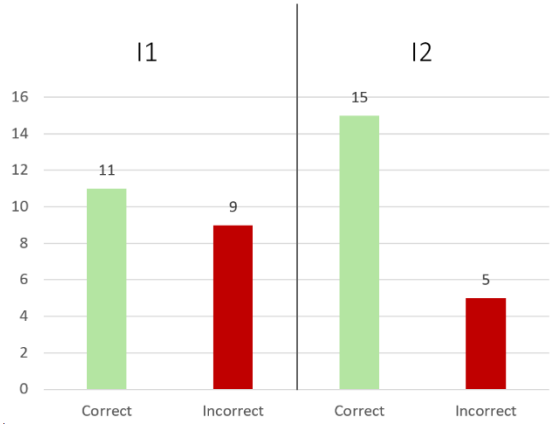


Figure 3: Average number of correct, and incorrect answers per sequence speed

5. CONCLUSION

Kinetic typography is one of the tools that content creators and advertisers can use to gather attention and effectively convey information in the era of short-format videos. However, crafting a quality kinetic typography is a complex endeavour and the designer should consider multiple factors that can have significant impact on the product. Speed and movement qualities are amongst those factors. While the results of our research don't feature statistically significant differences for the retention of information of the tested sequence speed, there is a clear subjective preference towards the faster sequence speeds, with 90 words per minute being scored as the most attractive one.

As for the keyframe interpolation, although predefined easing curves are readily available for use in keyframe-based animation software, the results show better information retention if more elaborate Bézier curves are used for keyframe interpolation. Such a result coincides with the practices and rules of movement in animation. It is more difficult for the human eye to understand simpler forms of interpolated movement because such movements are rarely encountered in nature. In addition, for simple forms of interpolation, sometimes it takes longer time for the change to fully occur, which disrupts the flow of the plot. To successfully animate changes in motion graphics, more complex interpolation methods give much more control in modifying the amount of change in a particular property in each time interval. Although such interpolations may seem quick and too complex, they effectively give the viewer more time to see the content moving in the time interval that is set for each change.

This study has limitations. The participants were exclusively between 18 and 30 years old, which may not fully reflect the preferences and retention patterns of other age groups. Additionally, a simple text sequence as stimuli may not capture the complexity of real-world kinetic typography applications, limiting the scope of the findings. Future research could broaden the participant demographic and explore the impact of keyframe interpolation on other types of video content, as this study primarily focused on promotional messages.

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INVESTIGATION OF THE INFLUENCE OF WATER TREATMENT IN BOOK CONSERVATION PROCESSES ON THE COLOUR CHARACTERISTICS OF PAPERS

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Abstract: *The conservation and restoration of books, documents and manuscripts is aimed at prolonging the life of our written cultural heritage, mainly written on paper, leather and parchment. The main aim of conservation is to preserve the integrity of the object and to prolong its life. In the present experiment, a study was conducted to evaluate the effect of water treatment in the conservation treatment of books on the colorimetric characteristics of paper. Unrestored books were selected from the archive of the Bulgarian National Library "St. St. Cyril and Methodius", and the study was conducted in the restoration center of the library. Water treatment of all pages of the book have been done and the colorimetric characteristics before and after water treatment have been measured with a spectrophotometer. Color difference - ΔE, lightness difference - ΔL and hue difference - Δh, between samples before and after water treatment have been calculated. From the obtained results, the effects and changes of the all investigated colorimetric parameters were determined. These results are important from a practical and scientific point of view. The results could be used as valuable information for restoration centers worldwide.*

Key words: Restoration, conservation, color characteristics, color difference, water treatment of papers

1. INTRODUCTION

Each paper, over time, changes its physical-mechanical and chemical properties, i.e. paper ages (Sonderegger et al., 2015). The durability of paper depends primarily on its composition, but also on the conditions of receipt and storage (Saoud et al., 2018). Book and paper conservation involves preserving and stabilizing the material as it is, while preserving as much of the original materials as possible. Conservation differs from restoration, which involves returning a book or manuscript to new condition using more invasive techniques and less preservation of original materials (Clarkson, 2015). Soaking paper in water removes water-soluble compounds originating from hydrolysis and oxidation of the paper, metabolism of microorganisms, atmospheric pollution, use, etc., since some of the removed compounds are acidic[3]. Deacidification is the main strategy for chemical stabilization of paper. It is considered the most important conservation intervention that relates to the long-term preservation of paper (Egorov & Slinkov, 2014; Baty et al., 2010).
Deacidification refers to chemical treatments meant to slow down the acid hydrolysis and embrittlement of books and paper documents that had been printed on acidic paper. From the early 1800s up to about 1990, papermakers used aluminum sulfate, an acidic compound, in most printing papers. Conservation and restoration of books, manuscripts and documents is an activity dedicated to prolonging the life of objects of historical and personal value, made mainly of paper, parchment and leather. The main aim of conservation is to prolong the life of the object as well as to preserve its integrity (Bansa, 2002; Ivanova, Spiridonov & Lasheva, 2022; Małachowska et al., 2021).

2. METHODS

For the present experiment, a book entitled ''Companion Talks on the Service of a Junior Officer'' dated 1898 with signature number 67.015 from the archives of the National Library of St. St. Cyril and Methodius (Figure 1). It is valuable and not restored. Twelve sheets of the book were selected. Two different fields were selected on each of pages without printing on them. Field 1 being the lightest area of the paper and Field 2 being the darkest area of the paper (zone with advanced oxidation). Colorimetric measurements were made in CIE* Lab and CIE Lch with a X-Rite spectrophotometer. The measurement conditions were standard illuminant CIE D50, 2ºstandard observer, measurement geometry 45/0, measurements without polarization filter. The individual sheets of the book were subjected to aqueous

ORCID numbers are provided at the end of the paper.

immersion with warm water, with 4 washes every 10 min. After 40 min, borax-phosphate buffer was added to deacidification the paper for another 10 min and the sheets were removed to filter paper until completely dry. The working solution of the buffer was 19.5 g. Borax and 13.5 g acid potassium phosphate in 2 liters of water (Figure 2). Measurements were taken before treatment and after water treatment. Color difference calculations (CIE ΔE*ab and CIE ΔE_{2000}) were performed. Mean values for L, C, h were also calculated. The effect of preservation treatment between pre-treatment and post-water treatment was investigated for lightness ΔL, saturation Δc, color tone Δh, color difference ΔE*ab and ΔE_{2000}.

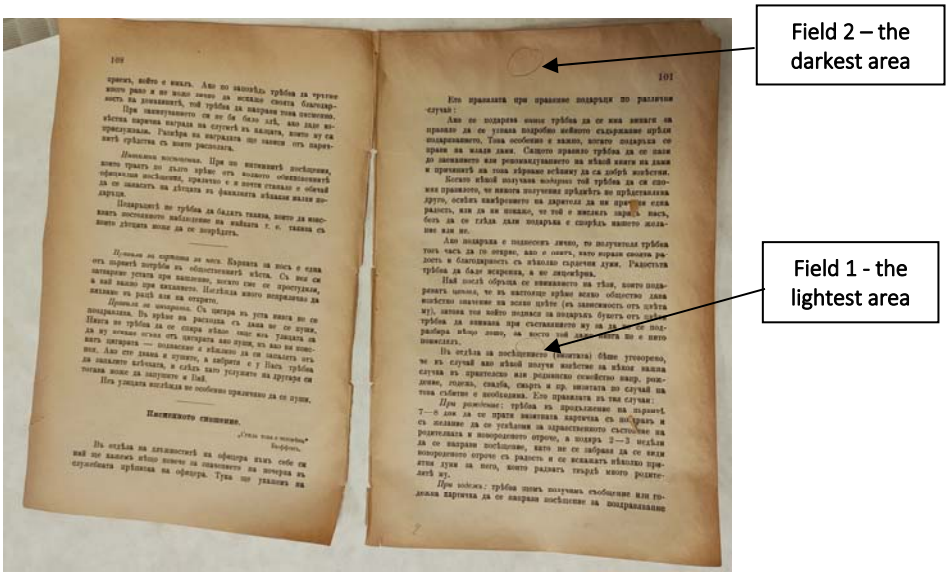


Figure 1: Sheet 1 and 2 of the book and selected fields



Figure 2: Water treatment of selected pages from the book.

3. RESULTS

Measured data from the color characteristics of documents provide information on the color change of paper manuscripts in the aging process during their storage and use. In previous research, it was found that the most suitable colorimetric systems for evaluating the aging of manuscripts are CIE L*c*h* and CIE L*a*b* and (Ivanova, Spiridonov & Boeva, 2024). Each of these color systems defines color using three color coordinates: CIE L* - lightness coordinate indicating the changes in the light tones of the paper to which the human eye is particularly sensitive (this characteristic is common and the same for the L*a* systems b* and L*c*h*); CIE a* – red-green color coordinate; CIE b* – yellow-blue color coordinate;

CIE c* – colorimetric coordinate responsible for saturation (in the present study defined as Δc – change in saturation); CIE h* – hue (in the present study defined as Δh – hue change of color tone). In order to better interpret the results regarding the analysis of the changes in the color parameters of the primary color coordinates, the saturation and the changes in the hue, both colorimetric systems – CIE* Lch and CIE* Lab – were used in the study.

3.1 Investigation of the effect of water treatments on the color characteristics of selected fields of the book pages, expressed by color difference (CIE ΔE*ab and CIE ΔE2000)

The processes of changing the color characteristics in the water treatment process in the conservation treatment were investigated and their quantification was done by determining the two most commonly used color difference formulas, CIE ΔE*ab and CIE ΔE_{2000}. CIE ΔE*ab is the classical method for determining color change, while CIE ΔE_{2000} is a method that is adapted to the specific characteristics of human perception (Kachin & Spiridonov, 2004). The CIE ΔE_{2000} color difference also gives more accurate results in white and neutral color shades, such as book paper. Figure 3 shows the influence of the color difference (CIE ΔE*ab) and (CIE ΔE2000) before and after water treatment of the twelve pages of the book for the advanced oxidation zone - Field 2 (darkest zone). Figure 4 shows the color differences in the lightest area of paper (Field 1) with less degree of oxidation.

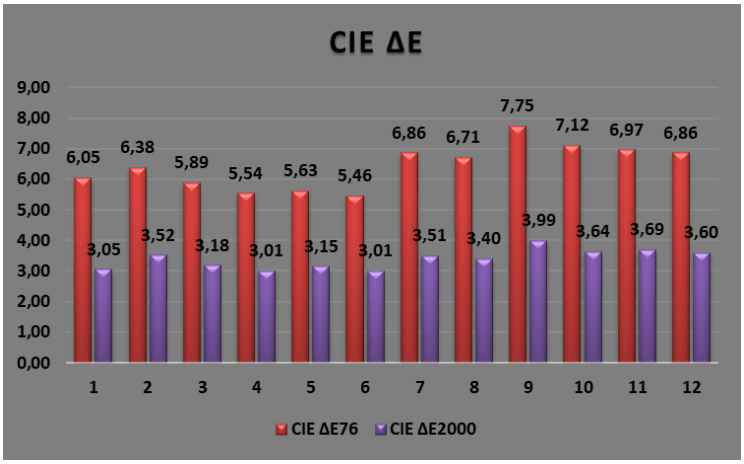


*Figure 3: Effect of color difference (CIE ΔE*ab) and (CIE ΔE*2000) before treatment and after water treatment of selected fields of paper sheets for the darkest area (advanced oxidation zones)*

It can be seen from the graphs that there is a highly noticeable color difference before treatment and after water treatment. The greatest change in color difference is observed in fields with advanced oxidation (the darkest area). In the lighter parts of the book's pages, there is a smaller difference, but noticeable.

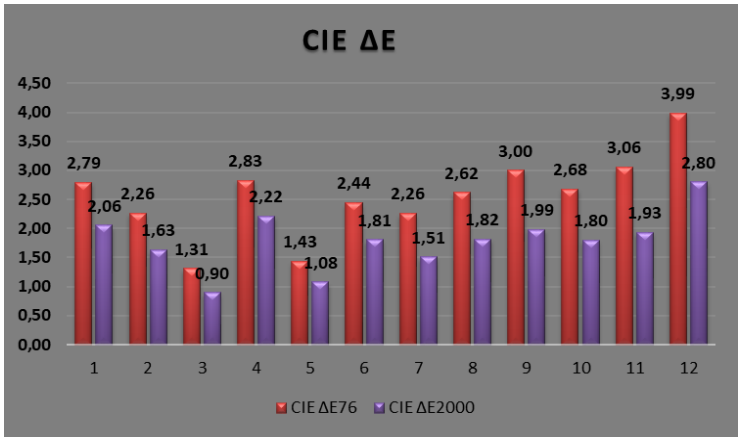


*Figure 4: Effect of color difference (CIE ΔE*ab) and (CIE ΔE*2000) before treatment and after water treatment of selected fields of paper sheets for the lightest area*

From the graph it can be seen that in the both color difference formulas - CIE ΔE^*_{2000}, which is high consistent with human perception, compared to classical formula - CIE ΔE^*_{76}. The biggest change is in the fields with advanced oxidation (Field 2) - ΔE^*_{2000} reaches up to 4 units, and ΔE^*_{76} reaches up to approx. 8 units. Less change is seen in the brightest area of Field 1 - ΔE^*_{2000} reaches up to 2,8 units, and ΔE^*_{76} reaches up to approx. 4 units.

3.2 Study of the influence of water treatment on colorimetric characteristics - lightness (CIE* L), saturation (CIE* C), color hue (CIE* H)

For a more detailed analysis of color changes expressed as ΔE, all three coordinates in CIE* Lch were examined separately each by other to determine the effect of water treatment in conservation process for each of coordinate changes. By this analysis, it will be determined the influence of changes in lightness, saturation and hue separately on the resulting color differences in the book conservation processes. Effect of water treatment on paper lightness (CIE*L) of selected fields of book sheets - before and after water treatment. Figure 5 shows the change in lightness (CIE*L) before and after water treatment of the twelve pages of the book for the lightest area – Field 1, and Figure 6 for the darkest and oxidized area of paper – Field 2.

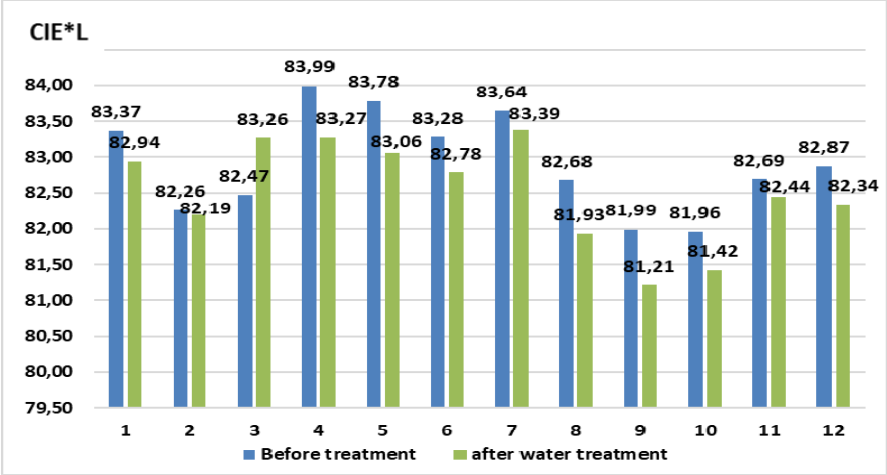


*Figure 5: Investigation of the change in lightness (CIE*L) of the papers under different treatments of selected similar fields 1 – lightest area of conservated paper*

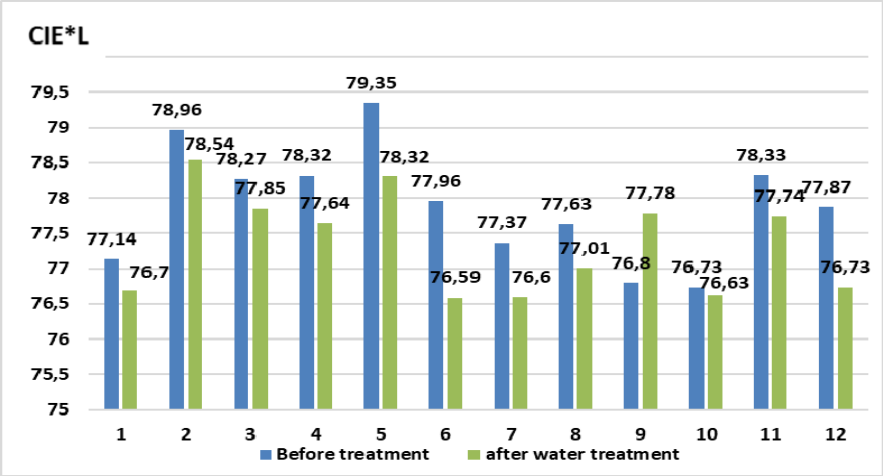


*Figure 6: Investigation of the change in lightness (CIE*L) of the papers under different treatments of selected similar fields 2-* darkest and oxidized area *of conservated papers*

From the graphs it can be seen that there is a slight change in the lightness of the paper for both areas which is almost imperceptible and is in range of 0,1 to 1 unit of CIE L. The water treatment in conservation processes very slightly decreases the lightness of paper. Effect of water treatment in book conservation treatment on paper saturation (CIE*C) of selected fields in the lightest area and the area with advanced oxidation (darkest area) – before and after water treatment. Figure 7 shows the change in paper saturation (CIE*C) of selected similar fields from the book pages in the darkest and more oxidized areas of paper, and Figure 8 in the lightest area of the paper.

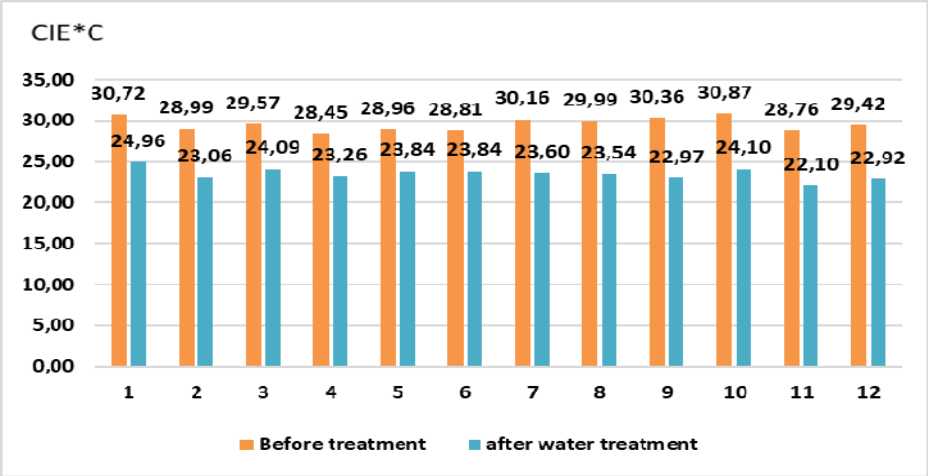


*Figure 7: Study of the change in saturation (CIE*C) of the book pages before and after water treatment for the darkest and more oxidized areas of paper*

Figure 7 shows that there is a significant change in the saturation of the paper (CIE*C) of the selected fields of the book pages in the area of advanced oxidation of the paper (darkest area) after water treatment. The water treatment reduces the saturation of oxidized paper by 6-7 units of CIE C. This change in the saturation values visually feels like a decrease in the intensity of the yellow-brown color of the oxidized paper after the water treatment process is done, which improves the good visual feeling when reading the book. Figure 8 shows a small change in saturation of light and non-oxidized area of paper. The obtained results show, that after the water treatment, the saturation of the darker and lighter areas of the paper become closer in value because the darker yellow spots on the paper fade and become closer in color to the lighter and less affected by oxidation sections of the paper.

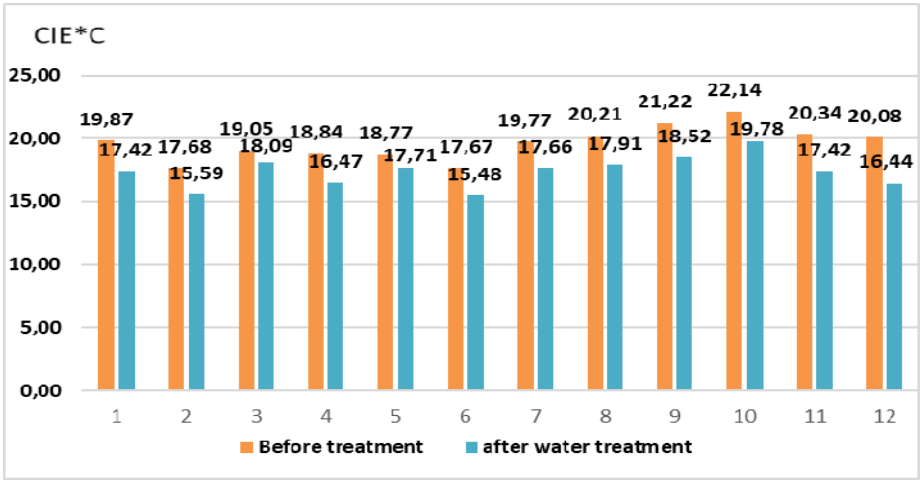


*Figure 8: Study of the change in saturation (CIE*C) of the book pages before treatment and after water treatment for the lightest area*

3.3 Study of the change in hue (CIE* h) before and after water treatment of book pages

Figure 9 shows the change in hue (CIE*h) before and after water treatment of selected fields of book pages in the more oxidated areas (darkest areas), and Figure 10 in the lightest area.

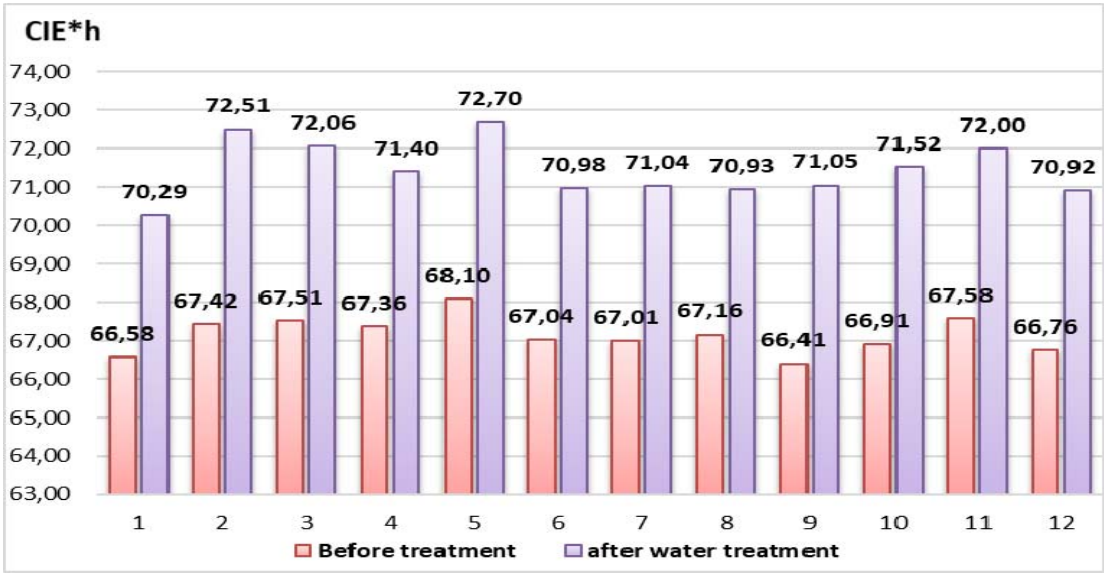


Figure 9: Change in hue (CIE h) before and after water treatment of the book pages for the darkest area*

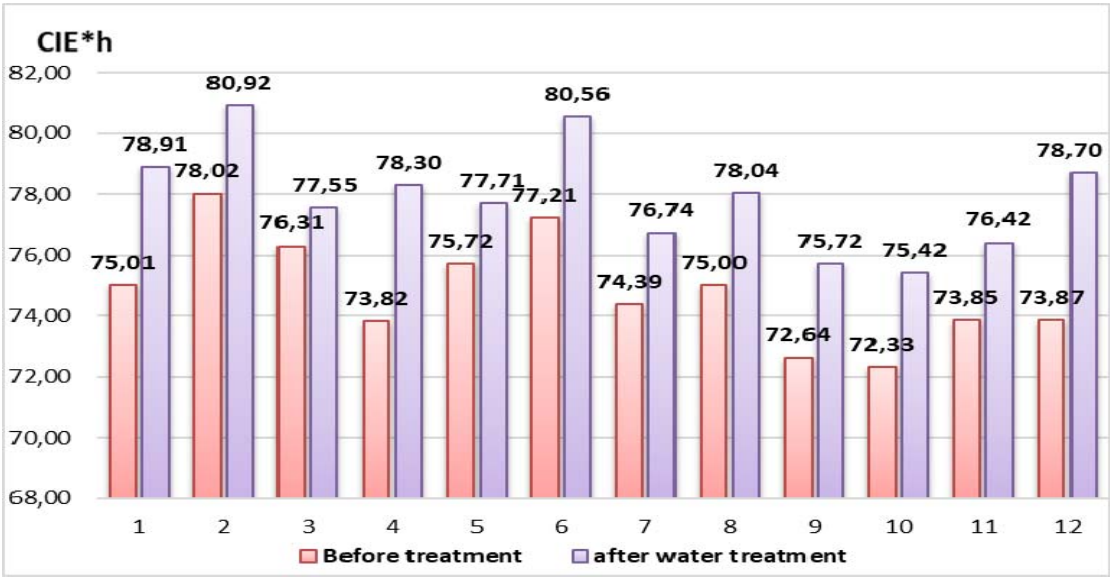


Figure 10: Change in hue (CIE h) before and after water treatment of book pages for the lightest area*

The hue changes after water treatment are bigger in the areas of advanced oxidation. The change in color hue as a result of the water treatment is approx. 3-4 units for the dark oxidized fields, and 1-3 units for the light parts of the paper. These changes in color tone are not visually significant because the color saturation is not high, especially for lighter fields of paper.

4. DISCUSSION

From an examination of the color difference (ΔE*ab and ΔE2000) of papers between original un-conservated book pages and after water treatment of selected different kind of investigated fields (light and oxidized-darker), it was found:

- The change in ΔE*ab (before and after water treatment) for the lightest selected area of the pages is between 1.31 and 3.06 and ΔE_{2000} is between 0.90 and 2.60 depending on the pages.
- The change in ΔE*ab (before treatment and after water treatment) for fields with advanced oxidation of the paper (darkest area) is between 5.44 and 7.75 and ΔE_{2000} is between 3.01 and 3.99 depending from the pages. Based on the study of the influence of water treatment on the colorimetric characteristics - lightness (CIE* L), saturation (CIE* C) and hue (CIE* h) it was found:
- The change in mean ΔL value (before and after water treatment) for the lightest selected area of the pages is between 0.07 and 0.78 and for the fields with advanced oxidation (the darkest area) is between 0.10 and 1 .37 depending on the pages of the book.
- The change in Δc (before and after water treatment) for fields with advanced oxidation of the paper (darkest region) is between 5.12 and 7.38 and for fields in the lightest region Δc is between 0.97 and 3.64 depending on the pages.
- The change in mean Δh value (before and after water treatment) for the lightest selected area of the pages is between 1.24 and 4.84 and for the fields with advanced oxidation (the darkest area is between 3.71 and 5 .08 depending on the pages of the book.

5. CONCLUSIONS

From the study made of the color characteristics of the book before and after water treatment of the paper, it was found that the conservation treatment gives a serious effect on the areas with advanced oxidation. The lightest areas of the papers (those least affected by the aging process) are very slightly affected by the conservation processes and practically change color characteristics in relatively small dimensions. From the calculation made of the color difference (ΔE*ab and ΔE2000) between before treatment and after water treatment of selected fields from the pages of the book, it was found that the highest values were obtained in the fields with advanced oxidation.

- The change in ΔE*ab (before and after water treatment) for the lightest selected area of the pages reached 3.06, and for fields with advanced oxidation of the paper (the darkest area) to 7.75, showing a highly noticeable difference.
- The change in ΔE2000 (before and after water treatment) for the lightest selected area of the pages reached 2.60, and for fields with advanced oxidation of the paper (the darkest area) to 3.99, indicating that there is a noticeable difference expressed by the more sophisticated color difference formula - ΔE2000. The biggest changes of the color characteristics - lightness (CIE* L), saturation (CIE* c), color tone (CIE*h), are in the fields with advanced oxidation. Based on the results obtained, it was found that the water treatment processes mostly affect the saturation (CIE* c), less affects on hue (CIE*h) and lesser extent the lightness (CIE* L) of paper.
- There is slight change in the lightness of the paper for both light and darker areas which is almost imperceptible and is in range of 0,1 to 1 unit of CIE L. The water treatment in conservation processes very slightly decreases the lightness of paper.
- There is a significant change in the saturation of the paper (CIE*C) of the selected fields of the book pages in the area of advanced oxidation of the paper (darkest area) after water treatment. The water treatment reduces the saturation of oxidized paper by 6-7 units of CIE C. This change in the saturation values visually feels like a decrease in the intensity of the yellow-brown color of the oxidized paper after the water treatment process is done, which improves the good visual feeling when reading the book. The obtained results show, that after the water treatment, the saturation of the darker and lighter areas of the paper become closer in value because the darker yellow spots on the paper fade and become closer in color to the lighter and less affected by oxidation sections of the paper.
- The change in color hue as a result of the water treatment is approx. 3-4 units for the dark oxidized fields, and 1-3 units for the light parts of the paper. These changes in color tone are not visually very significant because the color saturation is not too high, especially for lighter fields of

paper. From a scientific and applied point of view, the obtained results are important, as they provide valuable information on the effect of water treatment on the color characteristics of paper in the book conservation process. The study also proves that despite the advent of electronic media, paper remains the main material for storing and transmitting information. Therefore, in the future, care for the storage, conservation and restoration of written materials will remain the main priority of libraries, museums, archives, and private collections.

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BOOKBINDING OPERATIONAL PLANNING AND SCHEDULING OPTIMIZATION WITH DEEP LEARNING ALGORITHMS

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Abstract: *This work focuses on the scheduling optimization of the bookbinding process through the application of industrial engineering principles, complemented by artificial intelligence as a key factor in achieving operational efficiency. Flexibility and the need to adapt quickly to fluctuating market conditions in the publishing industry present challenges that require precise operational planning. This includes detailed planning of resources such as time, labour and machinery as well as the optimization of technical and technological processes. Each subprocess is meticulously documented in technological specifications, which precisely describe manufacturing process, product specifications and required quality controls.*
By analysing input and output parameters in four case studies, a mathematical model was developed to optimize the production process for soft book binding. The model is based on deep learning algorithms that analyse extensive data about the production process and enable an accurate prediction of the optimal production parameters based on current demand and production capacities. For this purpose, an artificial neural network was constructed, which is considered suitable due to its ability to learn complex patterns from data and generate predictions or recommendations based on a large amount of input data. The artificial neural network consists of input, hidden and output layers, each using an activation function that determines the activation of the neurons based on the input data.
When training the artificial neural network, the weighting factors between the neurons in the hidden layers are adjusted to minimize the errors between the actual and predicted results. This architecture enables the artificial neural network to learn complicated data patterns and use the derived model for predictions and optimization of the production process in bookbinding. In addition, the model's predictions facilitate continuous monitoring and analysis of product quality, identifying potential defects or problems before they impact production. By integrating this model, bookbinderies are able to continuously improve their production process and thereby achieve greater efficiency and competitiveness in the market.

Key words: bookbinding, process, optimization, deep learning, artificial neural networks

1. INTRODUCTION

In the context of modern publishing and book production, the optimization of softcover binding processes is proving to be a decisive factor in increasing efficiency and reducing costs. The increasing demand for flexibility in production, adaptability to smaller batch sizes and dynamic market conditions require advanced approaches to the management and organization of production lines (Gašparić, Petković & Pasanec Preprotić, 2018). Traditional methods in bookbinding, based on manual planning and resource allocation, face significant limitations in terms of speed of adaptation, ability to monitor fluctuating market conditions and optimization of resource utilization (Cetinjanin, 2020). These challenges, compounded by the need to reduce costs and improve quality, have led to the development of new technological solutions based on digitalization and artificial intelligence (AI), including the use of artificial neural networks (ANN) as tools to optimize key production processes (Bratić, Pasanec Preprotić & Jurečić, 2023).
Softcover binding is a specialized segment of bookbinding that involves multiple stages, including sheet cutting, folding, gathering, binding and trimming, with each stage varying depending on the type of production line and equipment available. There are significant differences in efficiency between multi-stage lines with more complex semi-finished product flows and more flexible, modern lines characterized by fast cycles and optimized line layouts. In this study, four different technological-organizational scenarios (SS_A, SS_B, SS_C, SS_D) are analysed, ranging from traditional to more advanced production models in bookbinding. Each scenario offers different settings in terms of operational organization, machine layout and employee utilization. The aim of the analysis is to evaluate the efficiency of each scenario based on key figures such as production cycle times, resource consumption and potential to reduce downtime and losses.
The application of ANN models in this context offers the potential for significant improvements through accurate resource management, improved prediction of potential bottlenecks and more effective adjustments to changes in capacity and demand (Huang et al., 2020). ANN models are particularly beneficial

ORCID numbers are provided at the end of the paper.

when analysing non-linear processes involving complex interactions between different variables, such as the number of sheets per book, cutting time, folding time, gathering time, binding time and trimming time. This adaptive optimization model analyses input data such as the number of sheets, the operating time for each task and the required number of employees and suggests optimal settings for production lines based on certain conditions.

By evaluating the results of the ANN model, it is also possible not only to predict optimal parameter values, but also to identify bottlenecks in the production process and strategies to minimize them (Qamar & Zardari, 2023; Aggarwal, 2018). For example, the ANN model can recommend an alternative machine layout or the use of additional labour to shorten the cycle time in multi-stage plants that suffer major losses when transporting semi-finished products (SS_A). In more flexible single-stage plants (SS_B), on the other hand, the focus may shift to optimizing machine utilization and shortening cycle times through improved operational planning.

This research not only examines the effectiveness of ANN models in predicting and optimizing key parameters of the production process, but also addresses how the implementation of such advanced technologies can contribute to the long-term sustainability and competitiveness of publishing companies (Pasanec Preprotić et al., 2022, 2023). By comparing different equipment layouts and production lines and analysing key operations such as cutting, folding, gathering, binding and trimming, this study lays a solid foundation for the implementation of advanced optimization methods in bookbinding industry.

2. FRAMEWORK FOR MODELLING

The production of books, whether soft or hardcover, requires sophisticated planning and optimization due to the complexity of the finishing processes such as folding, gathering, binding and trimming. These processes are of central importance for the overall efficiency of book production. However, traditional optimization approaches based on linear programming and manual methods often lack flexibility and effectiveness in a dynamic industrial environment that requires rapid adjustments to fluctuating market conditions (Pasanec Preprotić, Stančin & Petković, 2022).

The application of artificial intelligence, in particular artificial neural networks (ANN), opens up new possibilities for optimizing these processes (Brajković, Perinić & Ikonić, 2018). Although AI has not yet gained widespread acceptance in the publishing industry, initial studies indicate that the implementation of ANN and deep learning techniques can bring significant improvements in optimizing production phases, reducing operating costs and increasing production flexibility and efficiency.

The publishing industry involves multi-stage operations involving different machines. Traditional optimization models, such as heuristic approaches and linear models, often cannot fully adapt to the variability of operating conditions, including variations in labour and machine capacity. This inflexibility can lead to suboptimal resource utilization and increased costs (Dasović, Pasanec Preprotić & Petković, 2015). Advanced AI systems, especially ANN models, have the potential to significantly improve decision-making processes in publishing. These models facilitate the development of predictive models that accurately predict the optimal production parameters based on historical data, enabling the optimization of labour usage, machine capacity and cycle times.

In addition to optimization in publishing, AI is also successfully used in related finishing processes in the graphic arts industry, such as the optimization of flexographic printing and colour management. In these processes, technologies such as ANN are used to manage resources and optimize ink application, taking into account variables related to print quality, production speed and material costs.

The application of artificial intelligence in the optimization of book production and related finishing processes holds significant potential to increase efficiency, reduce costs and increase production flexibility. AI systems can analyse complex interactions between different production variables and suggest optimal configurations that adapt to changing production conditions. This adaptability enables faster, higher quality and more efficient production at lower costs, improving competitiveness and flexibility in today's demanding market landscape (Voulgaris & Bulut, 2018).

The production of softcover books, which was analysed on the basis of four case studies (SS_A, SS_B, SS_C and SS_D), includes processes such as cutting, folding, gathering, binding and trimming. These processes require the interaction of different types of machines: high-speed cutters, folding machines, gathering machines, rotary binders and three-knife trimmers. The efficiency and duration of each process depends on the spatial arrangement of the equipment, the number of employees and the specifics of the working environment.

Case study A illustrates a two-floor production plant that significantly limits the potential for continuous operation due to the need to transport semi-finished products between floors. This system is less efficient than a single-storey plant where all processes are on the same level, eliminating the time losses associated with transportation. In contrast to case studies B, C and D, which were conducted in single-level production environments, systems with flexible machine layouts allow for better resource utilization and higher productivity.
The efficiency of the production processes varies depending on the arrangement of the machines and their ability to process in parallel. For example, the use of two folding machines in case studies B and C enables a significant reduction in the time required to fold printed sheets, while case study A shows considerably longer times due to the suboptimal layout of the machines and the inability to use a three-knife trimmer. Of particular note is case study C, where the inline binding system offers even greater efficiency compared to the roto-binder used in the other case studies.
When analysing the time required to perform each technological operation, it became clear that the greatest losses occur in plants with poorly organized production flow charts. In this context, the parallel operation of machines with multiple functions, such as folding machines, contributes significantly to reducing the overall production time.

3. IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE IN THE OPTIMIZATION PROCESS

To further increase the efficiency of book production, a mathematical model was developed to optimize the production process by applying deep learning algorithms. This model is based on the analysis of input and output parameters derived from four case studies and uses an artificial neural network (ANN) that enables the prediction of optimal production parameters based on current demand and available capacity. The artificial neural network (ANN) is divided into three main layers: the input layer, the hidden layers and the output layer. The input layer of the model receives data on the most important parameters of the production process, including the number of printed sheets, available machines, labour resources and the duration of individual technological operations. The hidden layers apply complex activation functions that allow the network to recognize patterns in the data, while the output layer generates forecasts that are used to optimize key production parameters (Haykin, 2008).
During the training phase of the artificial neural network, the weighting factors between the neurons in the hidden layers are continuously adjusted to minimize the error between the actual and predicted results. This process allows the network to learn complicated patterns in the data and use the resulting model to make predictions and optimize the production process. Optimization includes predicting the most efficient machine scheduling, optimal workforce utilization and reducing production downtime, which ultimately leads to greater efficiency (Russel & Norvig, 2020; Ertel, 2017).
One of the key benefits of this model is its ability to continuously monitor production quality. The model analyses output parameters such as production duration, number of finished units and material consumption and suggests real-time adjustments based on this data to avoid potential errors or problems in the production process.

3.1 Definition of the input and output parameters

Input data for the model
To successfully optimize the softcover binding process, the ANN model uses the following key input parameters that define the capacity and operating cycle of each machine:

- N_S - number of sheets per book
- T_{cu} - time for cutting the sheets per unit (in seconds)
- t_s - time for folding the sheets per unit (in seconds)
- t_{co} - time for collating (in seconds)
- t_b - time for binding (in seconds)
- t_t - time for trimming (in seconds)
- R - labour force (number of employees)
- P - number of units to be produced (in pieces)

These parameters are crucial for optimization, and the ANN uses their combination to make predictions about optimal production configurations.

Output data from the model
The aim of the model is to predict the following output parameters:

- T_{opt} - optimal cycle time for each machine
- S_{opt} - optimal machine configuration
- W_{opt} - optimal work configuration for each segment of production
- Q_{opt} - maximum number of units produced within a given time frame

Based on the model, the system can generate optimal recommendations for resources and time intervals that minimize production time while maintaining product quality. The optimized production cycle function aims to minimize the total production cycle time T_{total}, which is defined as the sum of the time required for all production steps and can be expressed by Equation (1):

$$T_{total} = P \cdot (t_{co} + t_s + t_{cu} + t_b + t_t) \quad (1)$$

Where is:

- T_{total} - total time required for production
- P - number of units produced

Under real conditions, however, the model also takes into account the dynamics of personnel scheduling and machine utilization. By using an ANN, this model can be optimized to predict configurations that minimize the total time T_{total} while maximizing the number of units produced.

3.2 Architecture of the Artificial Neural Network (ANN)

The artificial neural network consists of three primary layers (Qamar & Zardari, 2023):
Input layer: contains neurons that receive input parameters such as the number of sheets, production times and available labour.

- Hidden layers: one or more hidden layers utilize activation functions to recognize patterns within the data. These layers allow the network to learn complex relationships between input parameters.
- Output layer: predicts the optimal production settings and provides output data, including optimal cycle times, machine configurations and the expected number of units produced.

3.3 Activation Functions

Activation functions such as ReLU (Rectified Linear Unit) are used so that the neural network can process non-linear relationships in the Equation (2):

$$f(x) = max\ (0, x) \quad (2)$$

The ReLU function is well suited due to its ability to quickly learn patterns from large amounts of numerical data. For the output layer, a sigmoid or softmax function is used to normalize the results.

3.4 Learning Algorithm

The ANN uses the backpropagation algorithm to learn from data. During network training, the weighting factors W_1 and W_2 are adjusted to minimize the error, i.e. to reduce the difference between the actual and predicted results (mean squared error) using the gradient descent algorithm. The error function E is used to measure this difference and can be expressed by Equation (3):

$$E = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \quad (3)$$

Where is:

- y_i - the actual output value
- $\hat{y}_i$ - the predicted output value
- n - the number of data samples

Since this refers to the mean squared error, the error or loss function to be optimized can also be written by Equation (4):

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2 \quad (4)$$

The mathematical model of the neural network is based on the approximation of a function that maps the input values *X* to the target values *y* and can be expressed by Equation (5):

$$y = f(W_2 \cdot f(W_1 \cdot X + b_1) + b_2 \quad (5)$$

Where is:

- *X* - input data (N_A, t_s, t_c, t_b, t_t, *R*, *P*)
- W_1,W_2 - weighting factors between the layers
- b_1, b_2 - biases
- *f* - activation function (ReLU)
- *y* - model output (predicted value for optimization)

Based on the ANN predictions, the optimization of bookbinding production can be expressed by an optimization function that minimizes the total production time T_{total}, which can be expressed mathematically by Equation (6):

$$MinT_{total} = P \cdot (\sum_{i=1}^{n} t_i \cdot x_i) \quad (6)$$

Where is:

- t_i - time for each machine *i*
- x_i - number of units processed by machine *i*
- *P* - number of units produced

Using this mathematical model and ANN optimization, a simulation of four scenarios is performed:

- Scenario A (SS_A): A multi-stage plant with material transportation problems between machines, resulting in longer cycle times.
- Scenario B (SS_B): A single-level plant with a flexible arrangement of machines and labour in which cycle speed is improved.
- Scenario C (SS_C): A seamless binding line where machine integration is most efficient and allows for shorter production cycles.
- Scenario D (SS_D): A standard line with a typical layout, but with optimized planning and manpower distribution.

4. GENERATING THE OPTIMIZATION CODE

To optimize the bookbinding production process using artificial neural networks (ANN), the Python programming language was used along with the following libraries: NumPy (for mathematical operations), TensorFlow (for building and training the model), Scikit-learn (for the machine learning functions and model evaluation), and Matplotlib (for the visualization of the data).
This code provides a basic implementation for optimizing the bookbinding production process using ANN. It can serve as a basis for more complex optimization models specifically tailored to the bookbinding industry. For further refinement, you can use more advanced architectures (such as RNNs or LSTMs for time-dependent data) and methods such as genetic algorithms or Bayesian optimization for parameter tuning.

4.1 Generating Simulated Data

The original data for four case studies is provided, including input parameters such as the number of sheets, cutting, folding, gathering, binding and trimming times, as well as the number of employees and order sizes. To enhance the data set for training the model, synthetic data is generated using a script that generates random values for these input parameters related to the bookbinding process (Figure 1).

```python
import numpy as np

# Original data
X = np.array([
    [54000, 15000, 8, 6, 1],  # Case Study A
    [54000, 15000, 8, 7, 1],  # Case Study B
    [54000, 15000, 9, 6, 1],  # Case Study C
    [54000, 15000, 9, 7, 1]   # Case Study D
])

y = np.array([37, 24, 18, 35])  # Total time to complete operations

# Generate synthetic data
def generate_synthetic_data(X, y, num_samples):
    np.random.seed(42)
    synthetic_X = []
    synthetic_y = []
    for _ in range(num_samples):
        sample = np.random.uniform(low=np.min(X, axis=0), high=np.max(X, axis=0))
        synthetic_X.append(sample)
        noise = np.random.normal(0, 1.5)  # Adding minor noise
        synthetic_y.append(np.dot(sample, np.array([0.0001, 0.0001, 0.5, 0.5, 0.5])) + noise)
    return np.array(synthetic_X), np.array(synthetic_y)

# Generate additional data
X_synthetic, y_synthetic = generate_synthetic_data(X, y, num_samples=100)

# Combine real and synthetic data
X_combined = np.vstack([X, X_synthetic])
y_combined = np.hstack([y, y_synthetic])
```

Figure 1: Code for generating simulated data

The original data is defined with the parameters of the production process and the actual execution times, while synthetic data is generated to expand the data set and improve the accuracy of the model during training.

4.2 Data Preparation and Splitting

The data is scaled and split into a training data set and a test data set so that the model can learn from part of the data and be tested on unseen data (Figure 2).

```python
from sklearn.preprocessing import StandardScaler
from sklearn.model_selection import train_test_split

# Scale the data
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X_combined)

# Split into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(X_scaled, y_combined, test_size=0.25, random_state=42)
```

Figure 2: Code for data preparation and splitting

The data is scaled to ensure that all input parameters are on the same scale and then split into training (75%) and test (25%) data to evaluate the performance of the model.

4.3 Building the Artificial Neural Network (ANN)

An artificial neural network (ANN) is created and trained to predict time based on input parameters. TensorFlow is used to define, compile and create a multi-layer neural network model. The model is then trained on the simulated data to improve its prediction accuracy (Figure 3).

```python
import tensorflow as tf

# Build the ANN model
inputs = tf.keras.Input(shape=(X_train.shape[1],))
x = tf.keras.layers.Dense(256, activation='relu')(inputs)
x = tf.keras.layers.Dense(128, activation='relu')(x)
x = tf.keras.layers.Dense(64, activation='relu')(x)
outputs = tf.keras.layers.Dense(1)(x)

model = tf.keras.Model(inputs=inputs, outputs=outputs)
model.compile(optimizer='adam', loss='mean_squared_error')

# Train the model
history = model.fit(X_train, y_train, epochs=300, batch_size=8, verbose=1, validation_split=0.2)
```

Figure 3: Code for constructing an ANN model

The model consists of an input layer and several hidden layers with 256, 128 and 64 neurons. The ReLU activation function is used for all layers except the output layer. The Adam optimizer and the Mean Squared Error (MSE) loss function are used to train the network. The model is trained for 300 epochs with the training data.

4.4 Model Evaluation, Simulation of Changes, and Optimization

Once the artificial neural network (ANN) has been successfully trained, it is applied to test data to predict results. In this phase, the Mean Squared Error (MSE) is calculated, which serves as a measure of the effectiveness of the model (Figure 4). MSE is defined as the average squared difference between the actual and predicted values and allows the accuracy of the model to be quantified. A lower MSE value indicates a better fit of the model, while a higher value may indicate problems with overfitting or insufficient learning. In this case, the calculated Mean Squared Error (MSE) after successful training of the artificial neural network (ANN) is 25.86, indicating that there is a significant difference between the actual and predicted values, indicating the need for further optimization to improve prediction accuracy.

```
from sklearn.metrics import mean_squared_error

# Predict and evaluate
y_pred = model.predict(X_test)
mse = mean_squared_error(y_test, y_pred)

print(f'Mean Squared Error: {mse}')
print("True values:", y_test)
print("Predicted values:", y_pred.flatten())
```

Figure 4: Code for predicting and evaluating an ANN model with Mean Squared Error

To further illustrate the accuracy of the model, the results are visualized on a graph that compares the actual values with the predicted values. This visualization allows for easy identification of discrepancies between expected and actual results and thus a quick assessment of the quality of the model. In cases where the MSE is too high, an analysis should be performed to determine which hyperparameters of the model such as the number of layers, the number of neurons in each layer or the chosen optimizer need to be adjusted. This will improve the model's ability to adapt to true data and predict optimal parameters in the context of bookbinding (Figure 5).

```
import matplotlib.pyplot as plt

# Visualize results
plt.figure(figsize=(10, 6))
plt.plot(range(len(y_test)), y_test, 'o-', label='Actual values')
plt.plot(range(len(y_pred)), y_pred.flatten(), 'x-', label='Predicted values')
plt.xlabel('Index')
plt.ylabel('Time (hours)')
plt.title('Actual vs Predicted Values')
plt.legend()
plt.grid(True)
plt.show()
```

Figure 5: Code for visualizing true and predicted values

After the model evaluation, the research continues with the simulation of different input values to analyse how these changes affect the predicted production time. In this simulation, random samples are generated within predefined ranges for the relevant production parameters (Figure 6). The model is then used to predict how these parameters will affect the total time required to complete the production process. This approach enables a better understanding of the dynamic relationships between input variables and output results, which can help optimize the entire process.

```python
# Simulating changes in input parameters
def simulate_changes():
    num_samples = 50
    param_ranges = {
        'cutting': (50000, 60000),
        'folding': (10000, 20000),
        'gathering': (5, 15),
        'binding': (4, 8),
        'trimming': (1, 2)
    }

    samples = []
    for _ in range(num_samples):
        sample = [np.random.uniform(*param_ranges['cutting']),
                  np.random.uniform(*param_ranges['folding']),
                  np.random.uniform(*param_ranges['gathering']),
                  np.random.uniform(*param_ranges['binding']),
                  np.random.uniform(*param_ranges['trimming'])]
        samples.append(sample)

    samples = np.array(samples)
    samples_scaled = scaler.transform(samples)

    predictions = model.predict(samples_scaled)
    return samples, predictions

samples, predictions = simulate_changes()
```

Figure 6: Code for simulating changes in input parameters

The simulation results are also visualized to easily interpret the effects of the different parameters on the predicted time. Each subplot in this visualization shows the relationship between an input parameter and the predicted time, allowing the identification of key factors that significantly affect production efficiency. This information is crucial for decision makers as it helps to direct resources to the most important aspects of the process.

In addition, the predicted results can be used to assess how effectively the model fits the true data. To further optimize the results, the objective function is used to calculate the predicted time for a given set of parameters. At this stage, the minimize function from the SciPy library plays an important role as it enables the identification of optimal parameter values that minimize the predicted time (Figure 7). This procedure leads to the identification of the optimal parameters and the corresponding minimized times, which can significantly increase efficiency and reduce production costs.

```python
from scipy.optimize import minimize

# Optimization using SciPy
def objective_function(params):
    params_scaled = scaler.transform([params])
    predicted_time = model.predict(params_scaled)
    return predicted_time[0][0]

# Initial parameter values (approximately)
initial_params = [54000, 15000, 8, 6, 1]

# Optimization
result = minimize(objective_function, initial_params, method='Nelder-Mead', options={'disp': True})

print("Optimal parameters:", result.x)
print("Minimized predicted time:", result.fun)
```

Figure 7: Code for predicting and assessing model performance

The simulation results are also visualized to easily interpret the effects of the different parameters on the predicted time (Figure 8). Each subplot in this visualization shows the relationship between an input parameter and the predicted time, allowing the identification of key factors that significantly affect production efficiency. This information is crucial for decision makers as it helps to direct resources to the most important aspects of the process.

```
# Visualizing changes
plt.figure(figsize=(12, 8))
plt.subplot(2, 3, 1)
plt.scatter(samples[:, 0], predictions, label='Predicted Time vs Cutting')
plt.xlabel('Cutting')
plt.ylabel('Predicted Time (hours)')
plt.title('Impact of Cutting')
plt.legend()
plt.grid(True)

plt.subplot(2, 3, 2)
plt.scatter(samples[:, 1], predictions, label='Predicted Time vs Folding')
plt.xlabel('Folding')
plt.ylabel('Predicted Time (hours)')
plt.title('Impact of Folding')
plt.legend()
plt.grid(True)

# (Continue for other parameters)
```

Figure 8: Code for visualizing changes

The graphical visualization on Figure 9 shows a comparison between the true and predicted values, allowing a clear assessment of the accuracy of the model by visually representing the differences between the expected results and the outputs of the model. The predicted results can be used to assess how effectively the model fits the true data and predicts the optimal parameters. If it turns out that the error is too high, it is recommended to adjust the hyperparameters of the network, including the number of layers, neurons and optimizer.

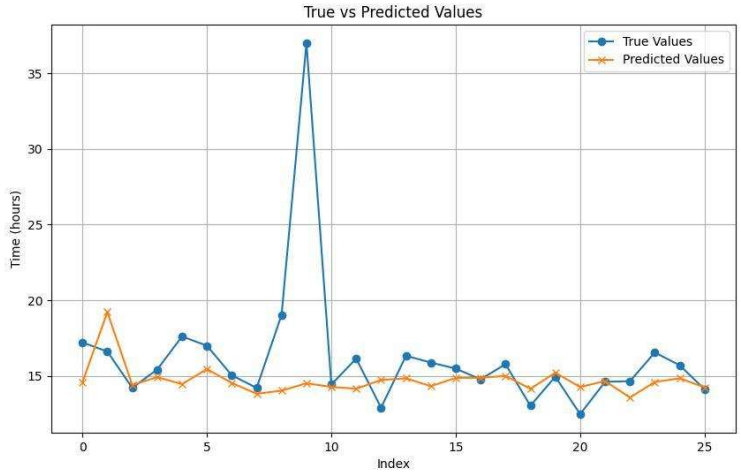


Figure 9: Comparison of true and predicted values

The graph shows comparisons between the true and predicted values of the time required for the production process, based on input parameters such as cutting time, folding time, totalizing time, binding time, trimming time, number of sheets, number of employees and number of orders. This analysis aims to evaluate the effectiveness of the artificial neural network (ANN) developed based on the given input variables.

The X-axis represents the indices of the samples created in the case analysis, while the Y-axis shows the time in hours, which is crucial for evaluating the efficiency of the production process. The blue line represents the actual values of the processing time, while the orange line illustrates the predicted values of the model.

The graph shows significant deviations between the actual and predicted values, especially for index 10, where the actual value was 37 hours while the predicted value was only 18 hours. This deviation may indicate unforeseen complications in the process, such as increased resource requirements or changes in the production flow that were not accounted for in the model, such as suboptimal binding times or longer summation times.

When developing the model, it is important to consider the input parameters and their impact on the predicted time. The binding and folding times showed a significant impact on the total processing time,

which means that further analysis should focus on more accurate measurement and optimization of these parameters. If the model does not account for variations in these key factors, major deviations in predictions may occur. Therefore, it is recommended to perform additional iterations of the model to adjust the hyperparameters (e.g. the number of layers, the number of neurons or the choice of optimizer) that could improve the prediction accuracy.

When analysing the production process data, the plot of true and predicted values is an important visualization that provides insight into the accuracy of the artificial neural network (ANN) model relative to the true data. When discussing the overlap of points in this graph, it is important to consider several aspects. The overlap of points indicates situations where the actual and predicted values are in the same or very similar positions in the graph, suggesting a high accuracy of the predictions. For example, if the points representing the actual and predicted values at indices 0, 1 and 2 are almost identical, this means that the model has successfully predicted the processing times for these samples. This may mean that the input parameters used in this part of the model were selected correctly or that the production conditions were stable and consistent.

In places where the points do not overlap or are clearly separated, such as at index 10, where the actual value differs significantly from the predicted value, this may indicate that unexpected problems or processing time deviations have occurred that were not accounted for in the model. For example, longer binding times or delays in summation may have significantly affected the overall time. In cases where the points are far apart, additional data may need to be collected to allow for better modelling. It is possible that the model does not account for all relevant input variables or interactions between them that affect the final result. If there is a major overlap between the actual and predicted values, one can rely on the model's ability to predict future outcomes given similar input data. If there is no overlap, this can help identify areas that require further investigation or model adjustments. This includes reviewing the input variables used, considering new features or redefining existing features.

When analysing the performance of production lines, it is important to consider the specific characteristics of each of the four case studies: SS_A, SS_B, SS_C, and SS_D. These studies illustrate different aspects of the production process and analysing them helps us understand how input parameters and operational specifics affect the actual and predicted values of processing time.

The SS_A line represents a more complex operation involving a multi-level drive, which results in an increase in the time required to transport the semi-finished products. It is expected that this increase in complexity will lead to higher actual production time values as additional losses, e.g. related to transportation, will affect the overall efficiency of the process. The graph clearly shows a pronounced peak around index 9, which represents the moment when the actual values of processing time are significantly higher than the predicted ones. This deviation shows that the model has difficulty predicting the time for more complex processes such as SS_A. The inadequately predicted time can be attributed to the fact that the model does not recognize all the factors that contribute to increased processing time, such as a higher number of sheets, additional time for folding, binding and trimming. This finding emphasizes the need to improve the model to account for all relevant aspects of complex production lines.

The SS_B line is characterized by faster production cycles and a flexible schedule, which should lead to reduced processing times and less performance variation. The graph shows that the predicted values for SS_B generally match the actual values. This high degree of agreement indicates that the model effectively predicts processing times for standardized operations. Minimal deviations between the predicted and actual times indicate that the input parameters, such as the folding time (t_s) and the summation time (t_c), are optimally set for this type of operation. This analysis confirms that the model can work successfully with simpler and standardized processes and provides useful information for further planning and optimization.

Since the SS_C line is the fastest and most efficient line, it is expected to have the shortest processing time. The model is expected to predict relatively consistent and low values for this line, which is optimized for maximum efficiency. The graph clearly shows that the predicted values are very close to the actual values, indicating that the model is effectively tracking the operations on this line. This agreement can be attributed to optimized input parameters such as a low binding time (t_b) and trimming time (t_t). This example shows that the model is able to accurately estimate the processing time in situations where the processes are standardized and efficient and illustrates the importance of selecting and configuring the input parameters correctly.

The SS_D line represents a standard process, but with an optimized schedule that should result in moderate processing times. The model also shows a close match between predicted and actual values in this line. This close agreement indicates that the optimized schedules have contributed to the predicted times matching the actual times. As there are no significant deviations, it can be concluded that the input

parameters for SS_D are optimally set, which confirms the effectiveness of the model in predicting processing times for standard processes.
Input parameters such as the number of sheets per book (*NS*), the folding time (t_s), the summing time (*tc*), the binding time (t_b), the trimming time (t_t), the labour input (*R*) and the production units (*P*) play a crucial role in determining the total production time and significantly affect the prediction accuracy of the model. In the SS_A line, the high number of bends and the increased times for folding and binding explain the significant deviations between the actual and predicted times. For example, the increased binding time can significantly affect the overall processing time, especially in the context of a multi-story operation where transportation losses are high. This analysis emphasizes the need for further investigation and optimization of certain parameters to reduce variation and increase efficiency. The SS_C line, which uses seamless binding, demonstrates how optimized processes can lead to the lowest processing times. Low binding and trimming times contribute to the successful predictions of the model and underline the importance of correct input parameter settings for standardized processes.
Based on the analysis of the graphical representation of the actual and predicted values, important insights can be gained on how the specific characteristics of each line affect the performance of the model. The model shows high accuracy in predicting processing times for standardized and optimized lines, such as SS_B, SS_C and SS_D, while larger deviations occur for more complex processes such as SS_A. These results provide valuable information for future process optimization.
The practical application of the results of this model can make an important contribution to production optimization. For example, flexible planning according to the "*just-in-time*" principle helps to reduce inventory and optimize resources. However, to achieve maximum efficiency, it is advisable to further refine the model to better adapt it to complex lines such as SS_A. This may mean generating more data for complex lines and taking into account additional factors that slow down production, such as transportation losses and specific challenges that occur in such environments.
This analysis not only provides useful insights for optimizing production lines, but also underlines the importance of continuous improvement and model adaptation to achieve the best results in modern production processes.

5. CONCLUSIONS

The use of artificial neural networks (ANN) brings significant improvements in the optimization of production processes, resulting in higher efficiency, lower costs and greater flexibility in adapting to market demand. Analysis of case studies has shown that ANNs can significantly reduce production time and improve machine scheduling, ensuring high product quality.
Based on the analysis of the results of processing time prediction in book production, the Mean Squared Error (MSE) is calculated to be 25.86, indicating a significant difference between the actual and predicted values. This high MSE indicates that the model did not learn sufficiently well, possibly due to the small size of the data set. To improve the accuracy of the model, it is recommended to increase the size of the dataset and fine-tune the hyperparameters such as the number of epochs and the stack size.
This deep learning-based model can be further adapted to the specific requirements of different production lines and enables continuous monitoring and optimization in real time. Further development may include advanced optimization methods and quality monitoring systems that improve the model's ability to adapt to changing production conditions. Overall, the application of artificial intelligence in bookbinding offers significant potential to increase efficiency, reduce costs and improve the quality of the end product, ensuring competitiveness in the market.
In addition, this model can serve as a basis for more complex optimization models specifically tailored to the bookbinding industry. More complex architectures such as RNN or LSTM networks for time-dependent data can be added and methods such as genetic algorithms or Bayesian optimization can be implemented for further parameter optimization.

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RESEARCH METHODS



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WOMEN IN PRINT: FIVE CENTURIES

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Abstract: *This article presents a literature review on women in the printing industry. It explores the diversity of publications on the subject through a systematic literature search based on Web of Science search. It seeks to identify the reasons why women have been marginalized as workers in jobs with higher prestige and pay. What reasons led to the pay gap compared to men. Who are the successful and talented women, whose work has been overshadowed over the centuries. How women have tried to challenge male domination, what women's movements exist today. The writing draws attention to gender inequality, sheds light on the causes of the current situation and provides good examples of how to break down gender stereotypes. In order to address the gender inequality that is still evident.*

Key words: gender inequality, equal pay, women workers, printing industry, literature review

1. INTRODUCTION AND BACKGROUND

As women, printers and managers, the authors have personal experience of the challenges of being a woman. The printing industry is a rather masculine industry and, unfortunately, the principle of equal treatment for women compared to men is often violated. There is still a perception that a man should be paid more because he is the breadwinner. This approach is not only outdated, but it also creates a gender gap and severely limits women's opportunities for advancement. Management positions are still mostly held by men, even though women are now more represented in higher education. This is confirmed by the results of a survey among Hungarian printing companies. A targeted questionnaire survey was carried out in 17 printing companies, covering 32% of all employees in the Hungarian printing industry. The data showed that although the proportion of women in the total population concerned is 43.8% and the proportion of women with higher education is also significant: 51.4%, despite these figures, women are represented in only 32.9% of senior management positions.

Table 1: Proportion of women in each job and skill level by industry sector in Hungary

	The proportion of women								
Sector	Of all employees	Of the top managers	Of the middle managers	Of the team leaders	Of employees	Of the high graduated employees	Of the middle graduated employees	Of the skilled workers	Of the employees without profession
Total Industry	43,8%	32,9%	34,4%	31,2%	46,4%	51,4%	40,2%	45,3%	43,9%
Large companies	43,7%	32,6%	37,1%	25,0%	46,8%	54,0%	39,1%	46,0%	37,6%
Small and middle size companies	44,0%	33,3%	30,2%	35,6%	45,6%	47,5%	41,1%	44,3%	54,2%

Women are increasingly graduating from higher education in the printing industry, and the proportion of female graduates working for printing companies is also increasing. According to the Hungarian DPR AAE 2023 database requested from the Department for Education, 60.4% of the graduated (between y. 2014-2021) workers in the printing industry are women. If we look not only at the printing industry but at the Hungarian population as a whole, we can also see the trend that has been observed for decades that

ORCID numbers are provided at the end of the paper.

women are graduating from higher education in higher proportions than men. In 2023, 34.7% of women in the total Hungarian population had higher education compared to 24.9% of men (www.ksh.hu, 2023). Furthermore, the average wage gap between men and women is not decreasing, neither between physical nor intellectual workers. It also varies significantly between 20 and 30% (www.ksh.hu, 2022).
In this article, the authors seek to present, through a literature review, some of the challenges faced by women printers, the historical background to the development of this inequality, and to draw attention to the many talented women of excellence who have contributed and continue to contribute to the achievements of the printing industry in the past. This article is part of a larger research project looking at the status and impact of women in the printing industry internationally.

2. METHOD

The literature review was carried out using the the Web of Science search using the keywords "wom* AND print*". The 355 results obtained were analysed one by one for relevance, and the references of the relevant articles were processed, finally 45 relevant publications remained which specially target women in the printing industry, most of them form the English-Speaking Countries.

3. RESULTS

Based on the available writings and works, we can see that researchers started to be concerned about the situation of women and equal opportunities in the printing industry in the 1980s. Several historical reviews have examined what led to the printing industry becoming a masculinised industry. They have consciously sought to identify women in the industry who, despite their achievements and accomplishments, have remained in the background.
The following topics emerged from the literature review.

3.1. Women workers in the printing industry vs. a feminist approach

The question arises of whether to talk about women and their role in the printing industry solely in terms of the positions they hold, or to take a much broader, feminist approach to women as creators and their inspirational and society-shaping power (Werner, 2020). Women themselves often deny being feminists, because there are many negative preconceptions and ideas attached to the term, while many do not actually know what it really means (Hoskin et al., 2017). But it is important to define it for the purposes of the topic, as it will be a recurring concept. Two widely known definitions are available in the literature: Bell Hooks (2014) sees feminism as a struggle against the ideology of domination, in order to prioritise human self-improvement over economic power interests. While in Mies's (1991) approach, feminism also seeks to study and combat the oppression and exploitation of women. The first approach is concerned with broader, more general human rights. In this article we will take Hooks's approach.

3.2 Special women in the industry before the industrial revolution

There have been numerous publications on the extraordinary and successful women who ran printing manufactories before the Industrial Revolution, after losing their entrepreneur husband or father, and thus inherited the family business, feeling responsible for running it to support the family. The history of such successful women had been a concern of professionals in the field of women printers since the first half of the 1900s, and they were motivated to compile bibliographies of the leading women in the field of book production and publishing, such bibliographies were compiled by Stowel (1979) in the field of American book production. Another example from the US is Walker's (1987) collection of outstanding women entrepreneurs, featuring more than a dozen brave women who have successfully led their printing businesses. Beech (1989), in an article published in a history journal, lists a number of successful Parisian women who, through their husbands or fathers, ran a printing business. The key to their success was a significant role played by a successfully transferred network of relationships, while the life cycle of the business showed a different dynamic for women, as a remarriage could mean that the business continued to be run in the name of the new husband. Charlotte Guillard's gripping story of a prominent Parisian Renaissance lady moved Goldstein (2017), but similar events and personalities in England have been explored by Jeffery (2020) and by Limbach (2022) from the German-speaking region. Before the Industrial

Revolution, the opportunities and fate of women, regardless of country or even continent, were similar.

3.3 The role of trade unions in the development of gender inequality

With the industrial revolution, after the spectacular mechanisation of the industry, women were still mainly engaged in a kind of manual labour, as folders and sewers, i.e. in the lower prestige and lower paid tasks of the bookkeeping process (Hunt, 1983; Coultrap-McQuin, 1996). The reasons leading to this situation have been investigated by several researchers, such as Burr (1993), Frances (1991), Thomson (1994). Summarising their results, it can be concluded that the activities of male-dominated unions have contributed significantly to the development of inequality. As an example, Christina Ann Burr (1993) of the History Department at the University of Windsor examined the use of exclusionary strategies towards women in the operation and negotiation of printing unions between 1850 and 1914, which may have contributed to the development of a particular division of labour between men and women that was to be perpetuated over time. By analysing historical documents, Burr has shown that men have acquired better paid positions at the expense of women, using the institution of the trade union to do so, so that gender interests have prevailed over class interests in the functioning of the organisation. Adding that employers were also unwilling to pay female workers the same wages as male skilled workers. Surviving historical evidence in America also shows that when employers would have hired women for a more prestigious job, male employees refused to take the job (Thomson, 1994). This is how, for example, although the proportion of women in the American printing industry increased significantly after the Industrial Revolution, from 40.8% to 55.8%, the proportion of women in higher paid, more prestigious printing positions was less than 1% (Thomson, 1994).

A similar historical period has been explored by Ava Baron (1989), who in her work has explored how employers in America 'used' female and child labour to weaken the working power and authority of men, such as in the 1835 printers' strike. Naturally, men felt badly about the presence of women and children in the workplace, as they felt their livelihoods and family support were threatened and they were seen as the enemy.

Surprisingly, the situation in union bargaining has not changed much since the early 1900s, as Burr (1993) has studied. Dawson (2014) examined the situation in the 2000s in his research. The results show that issues of equal opportunities and equal pay for women in trade unions were not adequately integrated into union bargaining until 2010. Even when the issue was put on the agenda, the process of negotiations virtually ensured that the issue remained invisible.

3.4 Women's wider impact on the industry (creators, inspirators)

The question arises whether to talk about women and their role in the printing industry solely in terms of the positions they hold. Or should we take a much broader, feminist approach to women as creators and their inspirational influence and society-shaping power. This latter approach is highlighted by Sarah Werner in her 2020 article. In the history of the printing industry, we should not simply talk about the history of women, but about a feminist history of printing. In other words, how different it is from the history of women and printing. In her article, she presents historical examples of how women have also contributed to the creative process.

Significant works of art and innovations in approach throughout history have often not been given sufficient prominence in their own time. It also happened that outstanding works were published under the names of women's husbands, because it was a better 'sell'. In recent years, many researchers, historians and editors have tried to bring these forgotten works and exceptional women to the attention of the general public. Many publications and articles have been published on the subject. In their book Aims and Objectives (2020), Michelle Levy and Sharren Kandice compile bibliographical data on unpublicised or under-publicised women authors, editors, translators and publishing collaborators who are part of the creative process. Edited in 2021, Briar Levit's book presents the biographies of women, hitherto less well known, from the Harlem Renaissance onwards, who made their living in graphic design, producing outstanding works and shaping public taste. In their book Natural Enemies of Books - A Messy History of Women in Printing and Typography (2020), Fanni Maryam and her feminist co-authors, with its sophisticated graphics and typography, introduce the reader to women printers, illustrators, writers, typographers and typesetters who, through their own narratives, highlight the inequalities of the printing

industry. The major works of art, the innovations in approach that have emerged throughout history, have often not been given the spotlight they deserved in their time.

3.5 Past and present women's movements in the industry

Attempts to break male dominance had already been made in modern England. As the dominant trade unions saw women printers as a threat to the wages of the 'breadwinners', women responded by forming their own printers' organisation. The Women's Printing Society, founded in 1876, employed both working and middle-class women as printers. In sharing the profits of the business, the interests of both investors and employees were taken into account, and they proved to be very successful (Tusan, 2004). It could be said that the full social sensitivity of women was also present here, because they did not focus exclusively on the interests of certain interest groups. The organization published its own weekly periodical called "Women's Penny Paper", where women could make their voices heard (Alexiou, 2022). The publication was designed and produced by women and addressed women in a unique way, thus showing and drawing attention to women's talents. But a similar women's movement emerged in 19th century America. A Boston weekly newspaper called 'The Olive Branch' employed only women in publishing and printing. Rebelling against the prejudices of the time that sought to force women into the 'kitchen' (Roman, 2022), this publishing platform allowed women to express their own creative voices in this era. Within the so-called "Second Wave" feminist movement of the second half of the 20th century, changes were also initiated in the printing industry, which was set up to liberate women so that they would not be devalued workers. In the 1980s, great number of offset printing companies founded and run by women were established in England, but unfortunately, they did not survive long because they were undercapitalised. For those who took part in the movement, it was a life-changing initiative. It is important to note that the common operating model of the feminist presses was a collectivist-democratic form. In general, everyone was involved in all work tasks, with less specialisation than in male-led enterprises, because this was seen as consistent with the radical democratic and feminist ideal (Baines, 2022).

Even today, the women's printing movement is primarily located in Anglo-Saxon Western cultures. They are dedicated to promoting equal opportunities and advancement for women. To give a few examples, the Women in Print Alliance Association, founded in the USA, has a mission to advocate for women through community building, communication, networking and mobilisation in order to increase the recognition of women in the industry and sensitivity to discrimination. The Girls Who Print (GWP) online movement, also based in the US, is already represented in Africa and Europe. It started as a circle of friends, with women in the printing industry facing similar issues, but has grown to a community of 10,000 people. This number shows the importance of the topic. There are already a high number of female senior members who are setting an example for their young female colleagues and helping them to get ahead. Another example: one of the main aims of the Australian Women in Print movement is to build a community of women within the industry, not only to share information but also to help each other in their career development. The movement helps raise awareness of the importance and benefits of equal opportunities for women. It also provides mentoring opportunities for women to develop their skills and abilities.

4. CONCLUSIONS

Even before the industrial revolution, many women were involved in the printing process, running printing presses. These were mainly widows who inherited from their husbands or orphaned daughters. The question arises as to why women have been relegated to the periphery of the printing industry, and why they continue to occupy positions of lower prestige today. The article shows that with industrialisation and the emergence of trade unions, men pushed women out of higher paid positions through their stronger bargaining power and to protect their 'breadwinner' status. Steps were taken to break the dominance of men, forming unions and movements with women-only work in printing and publishing. In a broader feminist perspective, women in the printing industry are not only seen as workers, but also as creators, authors, editors, and publishers. These women, like those in manufacturing, have historically been marginalised and their work has not been recognised. In recent decades, many authors have sought to draw attention to these talented women.

It is welcome news that there is now a women's movement in the printing industry in several developed countries, with a mission to promote equal opportunities for women, break down prejudices and support women's advancement.
This article is part of a larger study of an PhD thesis, and the research will be continued.

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