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

University of Novi Sad
Faculty of Technical Sciences
DEPARTMENT OF GRAPHIC ENGINEERING AND DESIGN

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Foreword

Dear readers,

It is my great pleasure to introduce You the research papers of the Eleventh 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 gatered a great number of participants from many countries as it became a tradition over the past 20 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 22. The research achievements presented here are also valuable to the scientific and professional community and are highly appreciated.

Editor

INVITED LECTURES

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COMPUTATIONAL INTERIOR DESIGN BASED ON 2D PATTERNS

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University of Western Macedonia, Dept of Product and Systems Design Engineering,
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Abstract: *Modelling with 3D CAD (Computer Aided Design) tools has reached a point that its complexity is difficult to be controlled without the use of programming tools. Both general purpose CAD systems and specialized CAD pieces of software allow their programming with textual or visual interface. The designer is offered with a variety of tools in order to automate the design process and handle its geometrical complexity. The present paper deals with the use of CAD based visual programming for product designers, who want to use unusual geometries based on 2D patterns and present their work to the final user using high-end rendering images. The proposed designs can be customized to a great extend and contribute towards their increased added value. At the same time, a family of products can be presented, when the design parameters used get alternative values*

Key words: computational design, 2D patterns, interior design, CAD programming

1. INTRODUCTION

Product design as a key procedure in the development of new consumables. It applies a number of methodologies and tools in order to satisfy the customer demands. A great deal of methodologies has been developed and some are taking the conceptual design to the limits of art (Manavis et al., 2017). Except for the application of different methodological tools, modern CAD/CAM/CAE pieces of software become more popular, and the designers are willing to expand their knowledge and expertise in incorporating them in their day-to-day design process (Kyratsis et al., 2020).
Programming skills in the product design industry are becoming mainstream and the design related university curricula incorporate this trend more and more. This can influence the quality and speed of the design process, the creativity and optimization in a variety of aspects (Hirz et al., 2017; Song & Yang, 2021).

2. LITERATURE SURVEY

Product design provides a solid basis for a variety of aspects to be researched and developed. A number of points of view can be adopted and as a result to be further developed.
Efkolidis et al. (2020) incorporated computational design tools in order to develop jewellery design alternatives. The designs use additive manufacturing technology in order to receive 3D printing detailed models. Stereolithography (SLA) is the most well-suited technology for these prototypes and the dimensional accuracy received.
Gastro Pena et al. (2021) took advantage of the artificial intelligence aspect of computational design in order to present a review paper in searching the design space. The aim was to gather researchers that employ early enough artificial intelligence methodologies and tools in order to optimize the design of architectural forms.
Cheng et al. (2021) deals with 4D printed wearable systems based on the computational design approach. The proposed biomimetic design strategies are used in order to implement 4D-printed mechanisms for motion. They deal with adaptive creations of wearable systems that can greatly impact the design process.
Kyratsis (2020) and Kyratsis et al. (2018) provided a solid basis for establishing CAD-based product design and computational product design methodologies. Alternative shape development and automated design of pneumatic cylinder systems based on the appropriate international standard, offered added value in designing with time restrictions.
Sun et al. (2022) use computational aids and 3D tools in order to design ceramic products. A number of alternative ceramic designs are developed based on the initial prototype and redesign it. 3D printing technology is extensively used to help the implementation of the proposed methodology that results in the final design of a group of innovative ceramic toys based on the properties from Changsha Kiln.

Sun et al. (2021) presented FlexTruss application that enables parametrical design based on the assembly of modularized truss-shaped objects. Those objects can be manufactured using 3D printing devices and be assembled by threading. There is a significant part of the research that aims in enhancing the design capabilities in 3D space via human-computer interaction tools, so CAD based programming is implemented for this reason.
Saric et al. (2020) uses Computer Aided Design (CAD) under the intelligent and integrated system development. The outcome is an application that designs and develops bridge crane geometries while utilizes knowledge and expertise that are incorporated within the final application.
Manavis and Kyratsis (2021) and Manavis et al. (2020) proposed the use of advanced computational design tools for product shape generation, jewellery design and wearables development. They make use of a complete methodological proposal in order to apply the computational strategy in a variety of product design areas.
Tzotzis et al. (2021) automated the generation of the necessary G-code for a number of drilling operations from different directions on a CNC machining centre. A general purposes CAD system is used via its Application Programming Interface (API) and it is utilized for implementing a user-friendly piece of software that guide the G-code generation for machining purposes. The quality of the produced codes was checked, and their high quality was proved experimentally.
Garcia-Hernandez et al. (2016) developed a CAD-based application for designing noncircular gears manufactured by wire electro-discharged machining. The increased accuracy achieved offers a great deal of advantages in the design and manufacturing process.
The present paper uses computational design tools in order to take advantage of the ability to use 2D pattern mathematical equations and transfer them into the interior design industry. As a result, innovative ideas can be transformed to customized products that can be presented to the customers very early during the design cycle and thus increasing their satisfaction.

3. PROPOSED METHODOLOGY

The proposed ideas are part of a holistic design process that involves design methodologies and tools, together with CAD based programming principles. It deals with the customization of interior design products in order to produce decorative wall panels. The geometries are inspired from 2D motifs and geometries while modelled with computational design applications. The final geometries are not only presented to the customer but stress the idea of customizing them with a great deal of variations in a fully automated way. At the same time, advanced tools for rendering the proposed designs are used together with product visualization, using high quality graphics. Figure 1 presents the proposed framework that applies the holistic methodology in the computational interior product design era based on 2D pattern geometries. First the product category is selected, and interior design is highlighted, then the inspiration from 2D motifs provide a set of variations, with an aim to establish strong customization characteristics and finally the product development incorporates computational design 3D modelling and product visualization tools.

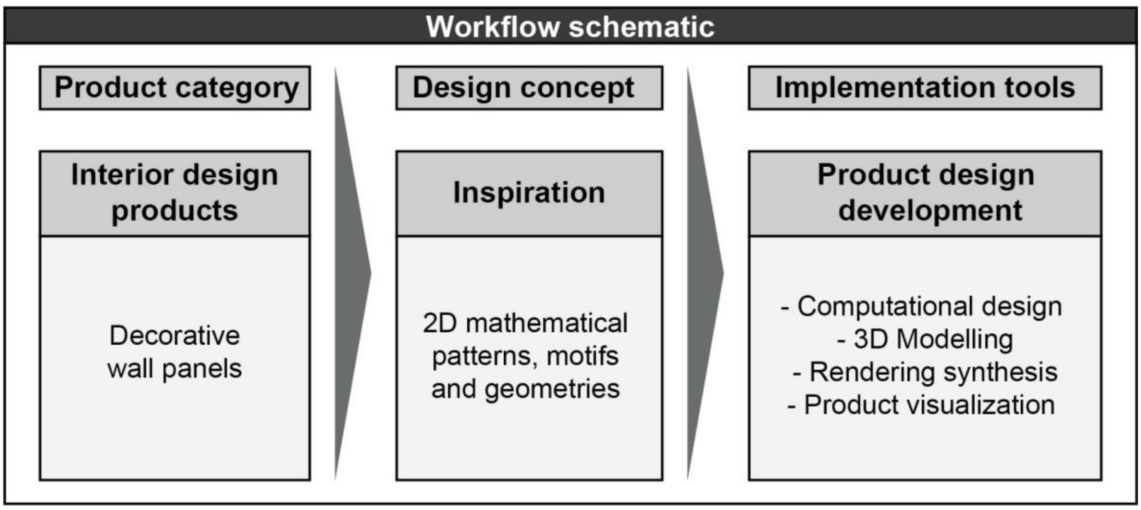

Figure 1: The holistic framework used in the computational interior design methodology

4. CASE STUDY DEVELOPED

The implementation of the proposed methodology offered a unique opportunity to develop interior design related products, decorative wall panels in this case. A number of methodological tools established the idea behind the developed case study (Figure 2). Mind-map was used in order to explore the different aspects of the design space and conclude innovative ideas. The use of computational design was at the heart of the problem while artistic impact and cultural influences led to using parametrically high end 2D & 3D tools in the design of geometrical shapes.

Mood board was used in order to explore the different patterns and establish a strong link of the design team with these patterns. It was the first step that helped the discovery of new directions towards geometrical complex geometries that played a key role later.

CAD-based sketching offered a number of impressive geometries to be modelled and presented in a way that combining different characteristics resulted in innovative patterns from the geometry point of view. Digitally delivered sketches helped the information transfer from one stage to the other without losing data in digitizing and reducing their quality.

Finally, the storyboard used created a road map that the design team could follow and produce actual unique designs to be implemented later on with advanced CAD and rendering systems. This stage was completed when new directions of the proposed designs were established. It is this stage that some designers say could be omitted, while it is the authors strongly belief that this is the stage that most of the unusual ideas find their way towards implementation. This is the basis for the presentation of the conceptual design results that later are implemented with advanced CAD systems.

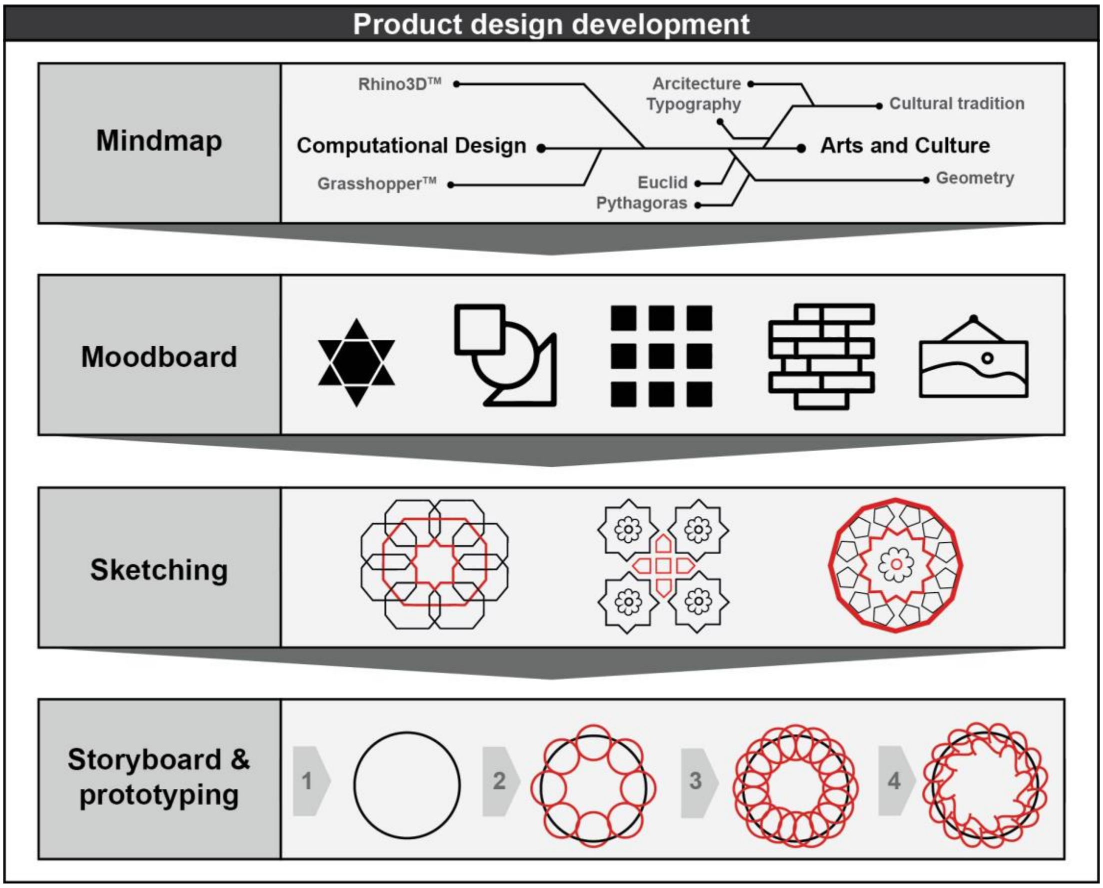

Figure 2: Customized ideas development using methodological tools

Grasshopper^{TM} was used as the tool to automate the design process and provide a solid basis for altering design parameters and receive customized final 3D models. Those models were built on the previously generated idea, to incorporate a number of 2D patterns and alter their geometrical characteristics with an aim to offer a great deal of different designs that could satisfy every customization preferred from the customers' point of view. Grasshopper^{TM} is part of Rhino3D^{TM} and can be used as a visual programming

language that can be learnt relatively in a short period and at the same time, to incorporate equations, parameters and geometrical constrains under the same roof.
The designer after establishing the computational design code, written with the CAD visual language, is able to change the parameters involved and present an infinite number of variations and alternative designs. Figure 3 depicts the code built with Grasshopper™ and some alternative designs that can be presented to the customers. While changing the parameters involved the customer can make his own selection directly and feels that he actively participates in the design process with the designers.

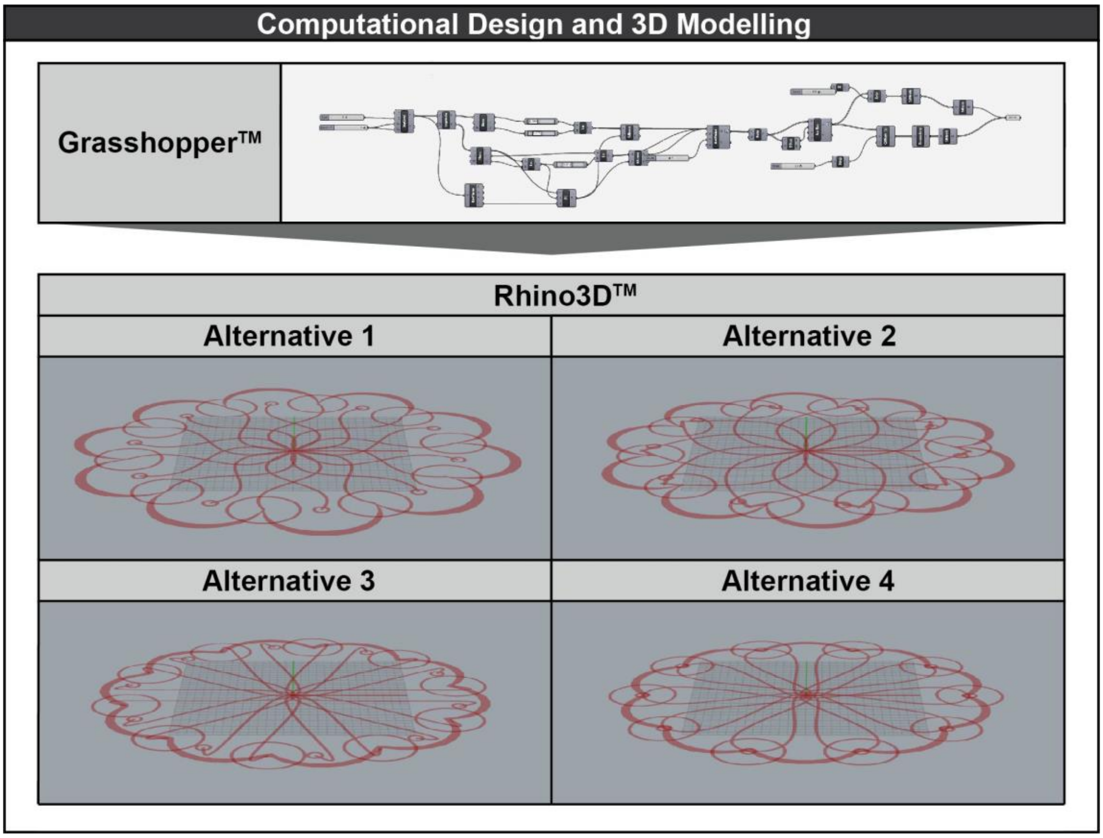

Figure 3: Implementation and alternative designs based on 2D patterns

Translating the selected design into vector-based geometry, a first set of alternative designs can be built with an aim later to strengthen those designs with the use of linear and circular motifs. Figure 4 reveals that the number of variations is extremely high, while the visual code built is able to change in real time the proposed design. These variations, that the decorative wall panels are based on, can be offered as design proposals and include the customers' wishes online.
The 2D proposals offer a useful tool for visualizing the final result but after that 3D models are created. Those 3D models together with the appropriate visual effects, led to creating a 3D render representation of the alternative motifs built within their use environment and ask from the customer to finally choose the best product that fits to its needs, the artistic and the cultural experiences (Figure 5).
At this final stage, the customer is able to actually see with the use of high-quality 3D models and graphical environments his proposal in an extremely realistic way, thus helping both the designer and the customer to agree on the final decorative wall panels design to be acquired very early in the design cycle.

5. CONCLUSIONS

The combined use of the proposed methodological framework, together with visually programming language that guide the CAD tools used is presented in the current research. The case study presented deals with high quality 3D representation of interior design products. The methodological tools are used at the beginning of the process in order to create unusual and innovative ideas, while transferring them to the computational design tools for automating their design process. The code produced offers the possibility to explore the design space together with the customer with an aim to satisfy his demands. Finally, a computational design tool is produced and transfers the initial design ideas into high quality 3D rendered products within a 3D graphical environment and the final output is high-end rendering images.

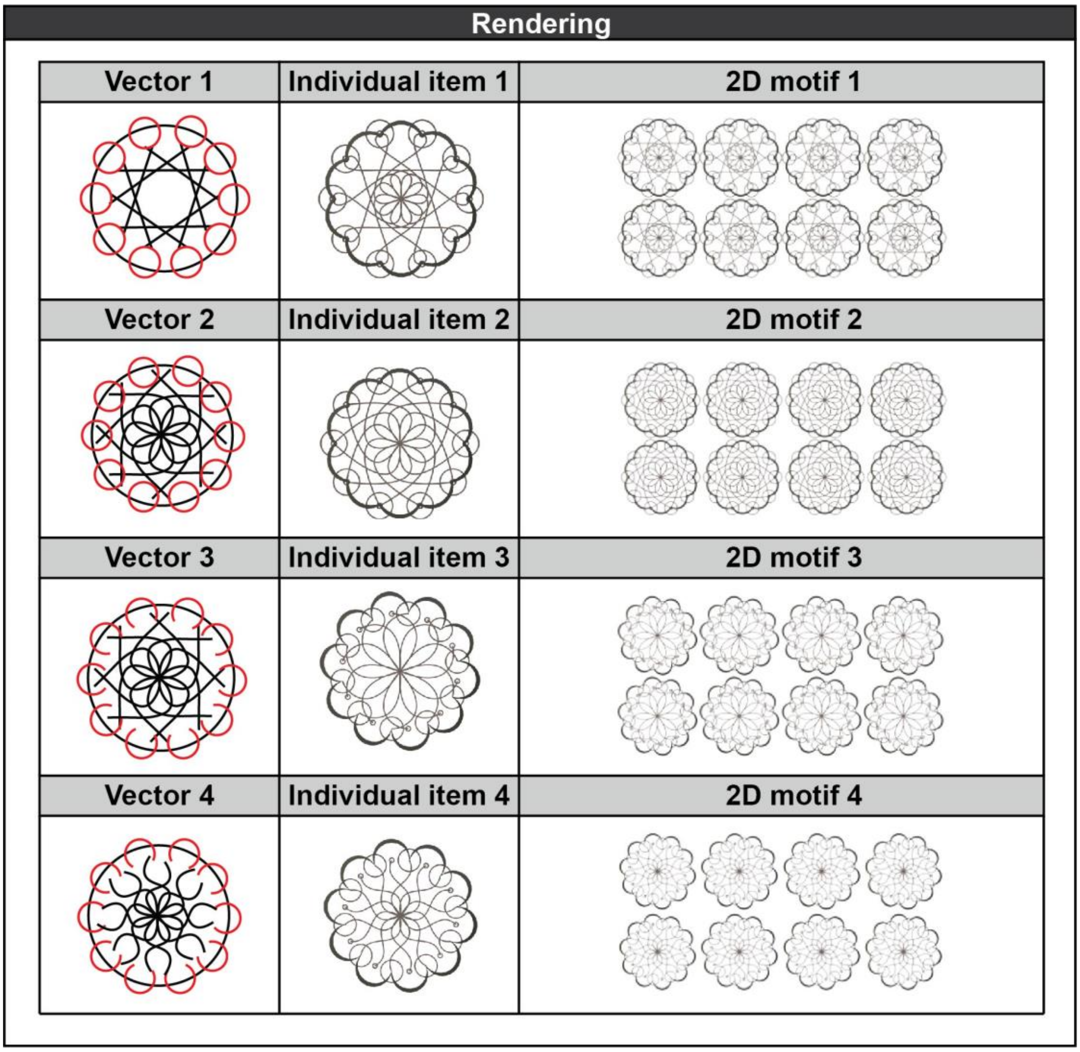

Figure 4: A series of alternative designs produced by computational design

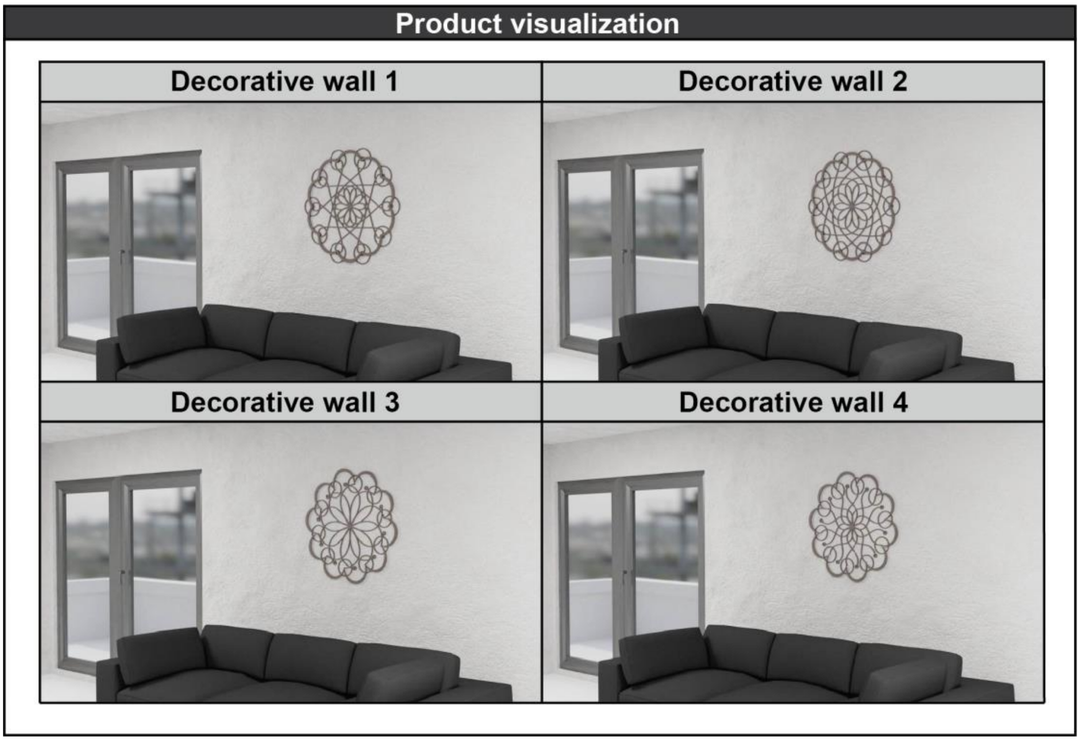

Figure 5: Rendered appearance of the proposed interior designs

The impact that the customized designs offer to the customer, when his involvements is so direct, is very high and provides the experience of co-designing the decorative wall panels and agree on their successful outcome. At the same time, it decreases drastically the ambiguity of delivering exactly what the customer has requested because the high-end environment with the wall panels offer a realistic representation of the final product inside the virtual environment.

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MULTISENSORY GRAPHIC PRESENTATION APPROACHES OF SCIENTIFIC DATA

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Abstract: *The use of digitization and virtual, multisensory presentation techniques in the study of natural and environmental processes, industry, technology, history, medicine, etc., the basis of which is scientific data, complements development and research areas, accelerates and facilitates computer-assisted insight and interpretation of results. By dealing with digital information, we not only deepen the research process, but also expand the possibilities of information presentation outside scientific research circles, in society, thus bringing basic knowledge closer to different target groups through interpretive approaches of human-oriented design. Multimedia, interactive, multisensory media, and extended realities are a bridge between the scientific result and the user experience. These media raise awareness and teach people to live with the nature, in the environment, to use the scientific context through the creative design and delivery of digital content. This paper presents some starting points and guidelines of preparing graphic content in a way that holistically and multisensory engages the participants of the experience. At the end some examples of the application of graphical multisensory presentations are shown: documentation, popularization of science at micro and macro levels, analysis and measurement, simulation and training, animation and interactivity, 3D modelling and reconstruction, stylisation and interpretation, argumentation of physical realities and extension into the new reality.*

Key words: digitization, graphic presentation, multisensory, scientific data, experiencing

1. INTRODUCTION

"*The faster the technology goes forward, the deeper we have to go inside what we really are as humans.*", said composer, inventor, futurist and author Perttu Pölönen and he added that there is "*a need rising to redefine expertise as knowledge transmission is becoming more cross-dimensional and future competencies more abstract*".

In recent years, we have made great strides in understanding nature, the universe, the human body, consciousness, neuroscience, human cognition and affectivity, etc. Moreover, the technology that supports scientific advances is developing at an extraordinary speed all over the globe. The basis and starting points of everything are data, in science, that is, scientific data. The fact that basic sciences, natural sciences, engineering as well as humanities and cultural studies research areas are not isolated is shown by the increase of inter- and transdisciplinarity. Inter- and transdisciplinary approaches connect different sectors both horizontally and vertically, involve researchers investigating a given topic from different point of views, and thereby enrich knowledge in such a way that new connections between fields emerge while inviting further directions of development. This connectivity requires science and research to think about new methodological approaches, experimental arrangements, and interpretations of results on the one hand, and to think about the possibility of disseminating the results to the public on the other.

This paper addresses the possibilities of preparing and interpreting data as results of scientific research for presentation purposes to a broad public with the aim of making scientific knowledge tangible and understandable. The paper discusses graphic multisensory presentations in such a way that they are accessible, educative, and appealing to users (experiencers), holistically engage users' senses, and awaken feelings.

2. MULTISENSORY EXPERIENCE AND SCIENTIFIC DATA

Sensory experience is any experience that involves the communication channels of the five senses of sight, smell, taste, hearing, and touch in recognition, recall, perception, understanding, and internalized experience. Although the senses are usually considered as systems localized only in single parts of the body, such as seeing with the eyes, tasting with the mouth (tongue, taste buds), hearing with the ears,

etc., we know that the experience of "seeing" is not isolated to the image we see, but to the whole context of conditions, circumstances of viewing a particular image, as well as to phenomenology (inner seeing, intuition), which is also the subject of current modern research (Radin, 2009; Frederich, 2021). The same applies to the other senses.
In creating an experience, the presentation approach of graphic and interactive content is the one that has the greatest impact on engaging the senses in a product, service, or media. Presentation level also called surface level is the top level among the levels of experience design with which users (participants) interact most directly, and which reflects the goal, purpose, structure of the whole product, service or medium. This level is closely interwoven and must be connected with the other levels of experience design, i.e., the strategy level, the scope level, the structure level and the skeleton level (Garrett, 2010).
In exploring the ways in which scientific data (quantitative, qualitative) can be brought to a level that is accessible to the general public (and target audiences), we think of the transfer between the form in which the data is initially accessible (numbers, descriptions, symbols) and the form of the presentation medium that engages users through a single sense or a combination of senses and their interaction. The experience will be more complete and engaging if the user engages multiple senses and the whole body in the experience than if the user uses individual sensory channels (sight, smell, hearing) separately (Figure 1). Which senses we include in the experience and how intensively and comprehensively we invite the user's body into the experience depends, of course, on the purpose and goals of the product (service, medium) and the needs of the user. In addition, empathy is crucial in the planning, design, and development of a product, where we empathically "put ourselves in the shoes" of the user so that the product, service or medium offers the user what is really important to them (Yantis & Abrams, 2016).

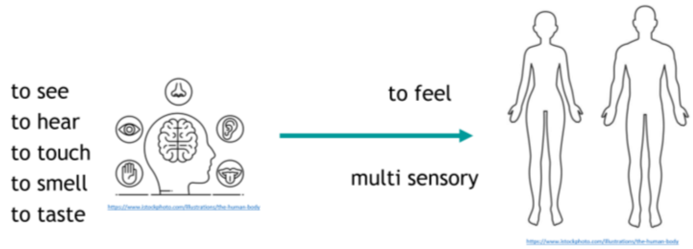

Figure 1: Schematic presentation of multisensory experience

Scientific data are the result of observations, calculations, and metric analyses. They represent in a particular way the information of scientific activities that investigate both intellectually and practically, through observation and experimentation the phenomena, structures, and behaviour of the physical and non-physical world. The data are usually taken from nature, the human body, the environment, society, history, etc., and must present and preserve the context of their meaning before being transposed and reinterpreted in the presentation mode. Graphic, digital and communication media are indispensable tools for presenting this information in scientific research (Shoshani & Rotem, 2009).
Regardless of the further use of scientific data, accuracy and precision are crucial starting point in data capture. For capture accuracy we select precise tools, capture techniques, which are placed in the methodological framework of the study. Figure 2 shows captures of bio-composite filaments for which computed tomography (CT), scanning electron microscope (SEM), optical microscopy, image analysis and image processing (2D and 3D) were used in order to analyse and produce final useful products (didactic tool).

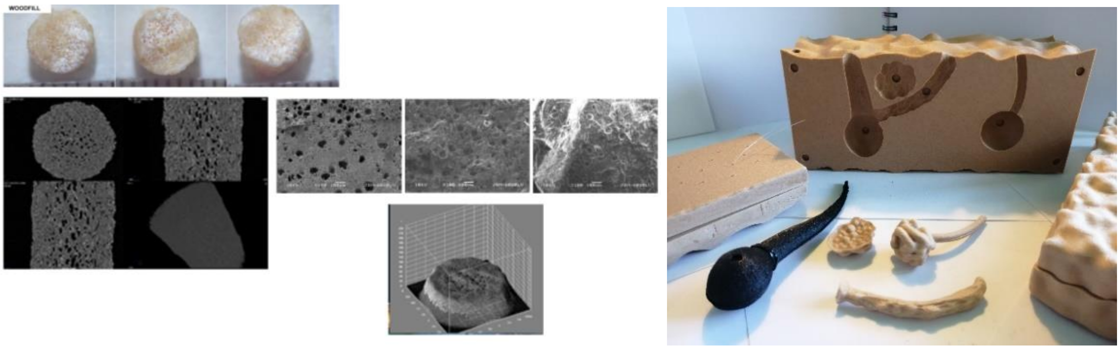

Figure 2: Images of bio-composite filaments (left) and final product (didactic tool, right), project: CEL.KROG, Discarded biomass potentials, Program "Exploitation of biomass potential for the development of advanced materials and bio-based products", researchers: Raša Urbas, Mirjam Leskovšek, Urška Stanković Elesini, Urška Vrabič Bordnjak, Diana Gregor Svetec, Helena Gabrijelčič Tomc, Deja Muck

2.1 Interpretation and stylisation

As in the analysis of scientific data for the purpose of summarizing findings and making syntheses, interpretation is an important process in translating scientific data into their more understandable representation. Interpretation for the purpose of scientific explanation involves the construction of scientific arguments that explain the data and make suggestions, while remaining reasonably faithful to the initial data as research findings. In interpretive approaches aimed at presenting the data to the general public, there is greater latitude in the presentation of the information, so that, depending on the audience and the design of the experience, it is simplified, generalized, highlighting what is necessary. Additionally, style of reinterpretation to the final presentation is also applied that includes the designer's (artist's) views on the subject (Figure 14). In this sense, interpretation involves knowledge of the needs of the users (participants) and a great deal of design, but also artistic approaches to the design of information and interaction (Knudson, 1995; Jameson & Baugher, 2022; Staiff, 2016).

3. FROM USER-CENTRED TO PLANET CENTRED DESIGN

The design approaches used may vary, but trends point to a simultaneous focus on the specific needs of a small group of participants (user-centred, participant-centred design) while incorporating the understanding and needs of humanity and the planet (human-centred, human-centred, and planet-centred design) presented in Figure 3 (Cennamo & Kalk, 2018; Stone et al., 2017). The applicability of approaches to multisensory graphical representation of scientific data is very broad and includes popular approaches in science, development and research, metrics, analytics, simulation, education, industry and engineering, natural sciences, medicine and healthcare, entertainment, art and design, rehabilitation, well-being, and social sciences (Eckert, 2019; Memarsadeghi et al., 2020; Bazarov et al., 2017; Lautenschlager & Rücklin, 2014).

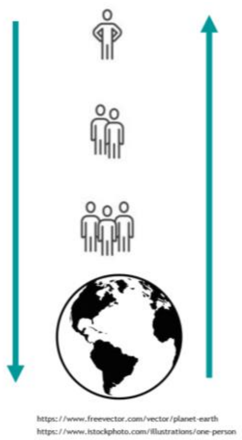

Figure 3: From user centred to planet centred design

3.1 Content creation and level of engagement with the experience

The design of information, content and interactivity for multisensory presentation approaches is based on strategies that, considering the objectives of the solutions and the needs of the user, identify, articulate and implement opportunities by first considering the functioning of all the senses of the human body (perception and cognitive and affective processes), and only then finding the best solution for the presentation (and interpretation) of data. In the presentation mode, the relationship between physical and digital communication media can be different, with the aim of stimulating the senses at different levels. Charging the experience and thus stimulating the visual, auditory, tactile (as well as gustatory) senses through interactions is based on the principles of accessibility, repeatability, accuracy, precision, enrichment, augmentation, non-invasiveness, simplification and, as mentioned earlier, interpretation with some degree of stylization (Looring, 2020).
The degree and intensity of entering and dwelling in the experience can vary from partial involvement in the experience, which includes seeing, hearing, touching, tasting, smelling (as an isolated sensation or as a combination of individual channels), present in the so-called use of the medium (the user), through participation in the interaction (to participate, participants) and engagement, where the involvement of persons is both on a sensory level as well as on a cognitive and affective level, up to full immersion in the experience, so that the participant has the feeling of being in a "new reality" offered by a particular presentation method. The latter are examples of extended reality and virtual reality in particular (Figure 4). The short- and long-term effects of immersion in digital worlds are still the subject of research, but we assume that the combination of physical and digital media in presentation methods contributes to a more complete and "healthier" experience for people on a mental, emotional, and physical level (Stanković Elesini et al., 2021).

Figure 4: The possibilities of involving the user in the experience, from using the medium to complete immersion in a new reality

4. PRINCIPLES OF CREATING MULTISENSORY PRESENTATIONS

Multisensory presentations are a bridge between science and the participant/user experience. With creative design of multisensory content and its delivery, we can benefit nature, technologies, environment, society, etc. In our opinion the paradigm of design the experience that consider the participants senses more holistically include:

- planning alchemy of action of senses, so that the image, sound, touch, movement, etc. are interconnected in the experience,
- the design of information and communication media should consider visual, auditory, tactile language and kinaesthetic language, …
- the paradigm of "user that uses the product/media/service" is a "passive" form of interaction, instead the presence of the participant in the experience can be implemented in experience design,
- multisensory medium space is dynamic, and it is telling stories,
- storytelling is an excellent principle, to introduce into the presentation media, but let us also consider the principle of creating a story from the participant, which allows for greater intimacy between the product, the media, and the participant experience,
- let the participant conduct the experience instead of the experience offered as part of the product (creating participant's own reality of the product/media/service experience),
- in every step of consuming the product/media/service we invite the participant in (multisensory) interaction (directing the experience),
- the importance of subjectivity of participant's experience is emphasized.

The following are some examples of the use of graphical representations involving different sensory channels, the starting point of which was scientific data. All products were created under the authorship of students of the Department of Information and Graphic Arts Technology, 1st and 2nd level study programme of Graphic and Media Technology and Graphic and Interactive Communication. The starting points of all presentations were scientific and/or technical records, captures, documentations, discussions, results, which in the further work steps included the study, the planning of the graphic language, the determination of the presentation content, the planning and design of interactions and the investigation of the possibility to achieve a multisensory experience, the design of information, the experience design and the integration of interactive graphic content in presentation platforms (3D players, web, social networks, mobile technologies, presentations in galleries, extended digital environments in museums, teaching and didactic tools in schools). Applications include documentation; popularisation of science at micro and macro levels; analysis and measurement; simulation and training; animated presentation and interaction; 3D modelling and reconstruction; interpretation and stylisation; augmentation of physical realities, and extension into the new reality (virtual reality).

4.1 Documentation

Documentation means the collection, study, categorization, and analysis of data about a particular phenomenon for the purpose of further use. Figure 5 shows the results of documentation of data about wooden statues (inventory of data about the statue, damages, recording by drone and cameras, photogrammetry) exhibited as Forma Viva in Kostanjevica na Krki (Slovenia). The work was carried out by students of graphic design and restoration under the guidance of mentors from the Department of textiles, graphic arts and design (NTF, UL) and the Academies of fine arts in Ljubljana, Tallinn and Zagreb, and took place within the two-year Erasmus+ project coordinated by the Božidar Jakac Gallery (Učakar et al., 2022).

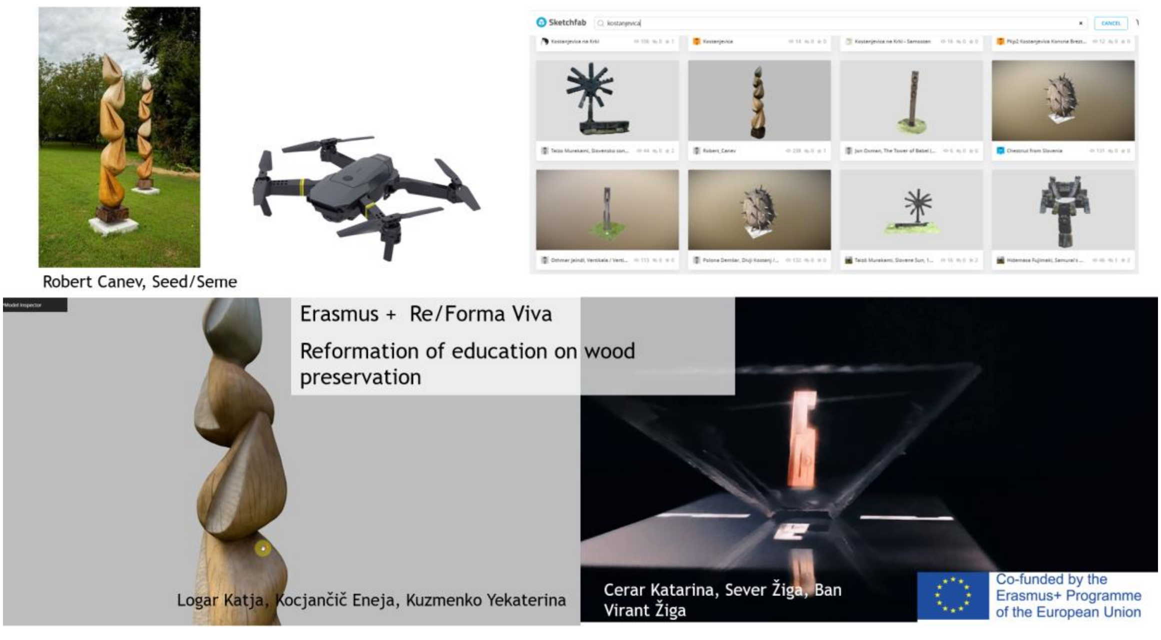

Figure 5: The results of documentation of data about wooden statues Forma Viva (Kostanjevica na Krki, Slovenia); authors: students of Chair of information and graphic arts design; mentors: Tanja Nuša Kočevar, Deja Muck, Andrej Učakar, Helena Gabrijelčič Tomc

4.2 At micro -level

Representations of science at the micro level include microscopic images and numerical and pictorial data of a microscopic nature. As shown in Figure 6 for the field of biology and the effect of a virus on a bacterium, the designer interpreted scientific findings (description of the infection, microscopic images of the course of the virus attack, microscopic images of the appearance of bacteria and viruses) through a computer-generated simulation of motion (animation), morphology, behavior, materials, textures, and final visualization.

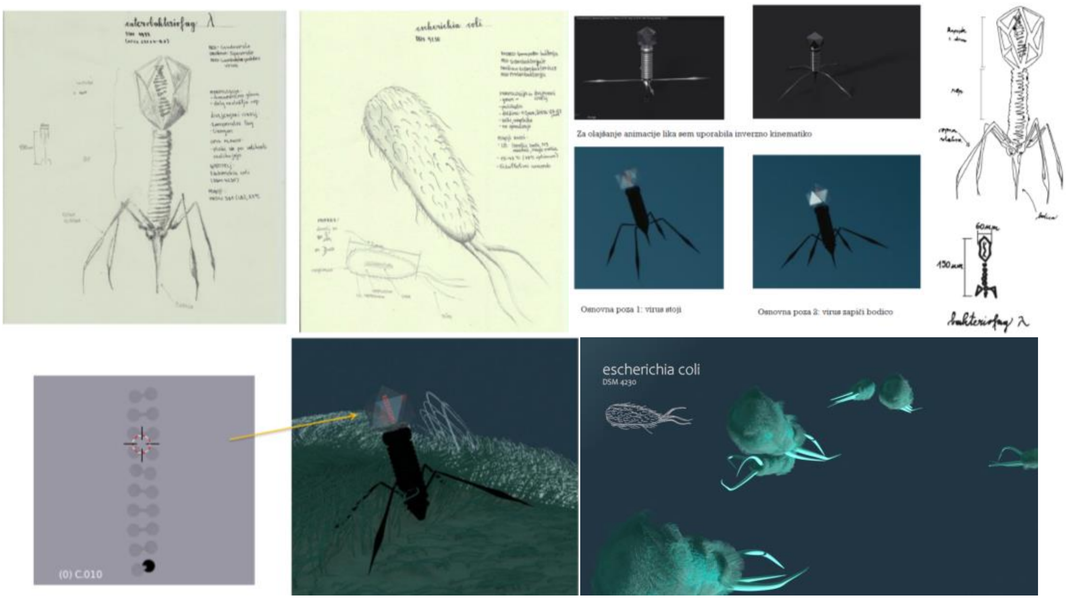

Figure 6: Presentation of the attack of virus on bacteria; author Polona Smolnikar, mentors: Tanja Nuša Kočevar, Andrej Iskra, Helena Gabrijelčič Tomc

4.3 Going on the scale of solar system

Not only at the micro level, digitally supported approaches also enable, on the basis of scientific data (distances between planets, perimeters and diameters of planets, surface morphology, textural and relief phenomena), an insight into phenomena that otherwise could not be observed from a human perspective. Figure 7 shows an interactive and educational walk through the system of the nearest planets to Earth.

Figure 7: Our solar sistem in visualisations presented as an interactive web site, author: Gal Černilogar, mentors: Tanja Nuša Kočevar, Andrej Iskra, Helena Gabrijelčič Tomc

4.4 Measuring and analysis

Photorealistic graphic visualizations are an excellent presentation medium of measurement and analysis results, allowing us to present to the public something that would otherwise be overlooked. Figure 8 shows a photorealistic visualization of a human face after it has been captured by a 3D scan and analysed in detail by 3D metrics (dimensions of eyes, nose, mouth, distance between facial elements) (Jančič, 2015).

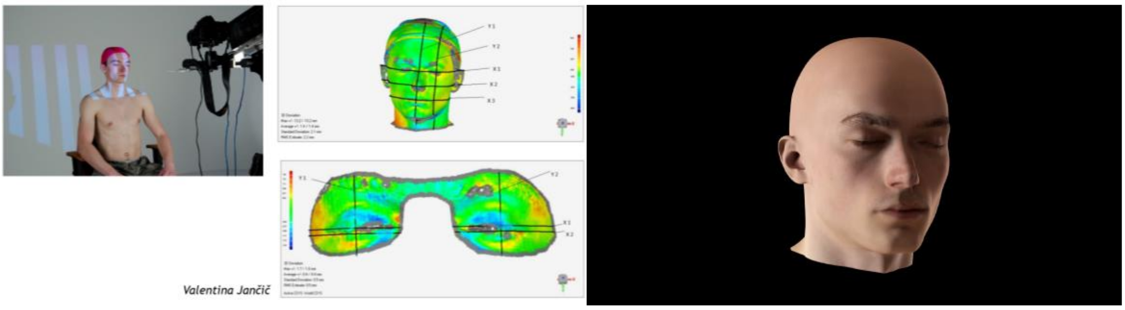

FIgure 8: Photorealistic visualisation of human head after detailed 3D metrical and analitical examination; author: Valentina Jančič, mentor: Helena Gabrijelčič Tomc

4.5 Simulation and training

Virtual reality solutions are about full immersion in the experience, making it a multisensory experience in the truest sense of the word. Figure 9 shows waste separation training, which was created with the help of documentation on the chemical and structural composition of each type of waste. The virtual simulation allows users to learn about waste types and the importance of separating waste. Moreover, educational virtual reality solution involves the user in the game by collecting points for cleaning up the environment (Štrumbelj, 2021).

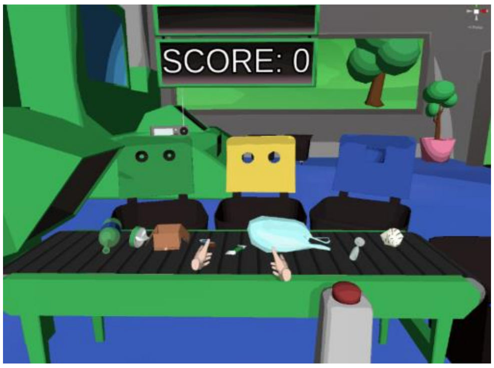

Figure 9: Waste separation simulation and training; author: Gašper Štrumbelj, mentors: Deja Muck, Helena Gabrijelčič Tomc

4.6 Invitation to multisensory interact

Full immersion and a multisensory experience are enabled not only through fully digital solutions, but also through an effective combination of physical and digital media. Such an example is the multisensory learning tool about human skin (Figure 10), where the learner gains knowledge about the elements of the skin and how it works through tactile experience, observation of the skin's parts and the application of augmented reality (Smaraglia & Sulič, 2021). The research starting points were microscopic images of the skin and its structures, descriptions of the functioning of the skin, which were interpreted for the target group of pupils in the first triad of elementary school.

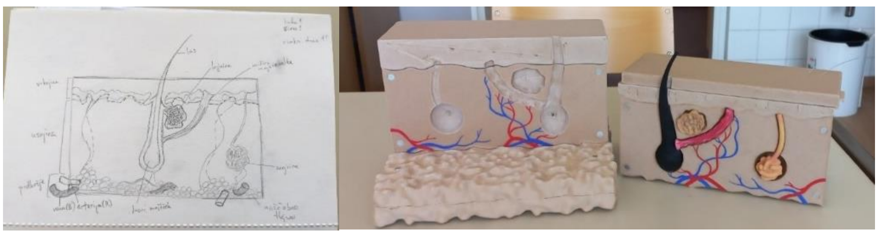

Figure 10 (part 1): Multisensory didactic tool for elementary school; authors: Matic Strgar, Sinja Stres, Simeon Perić, Jure Sulič, Celeste Sanja Smaraglia, mentors: Urša Stanković Elesini, Helena Gabrijelčič Tomc, Tanja Hrkač

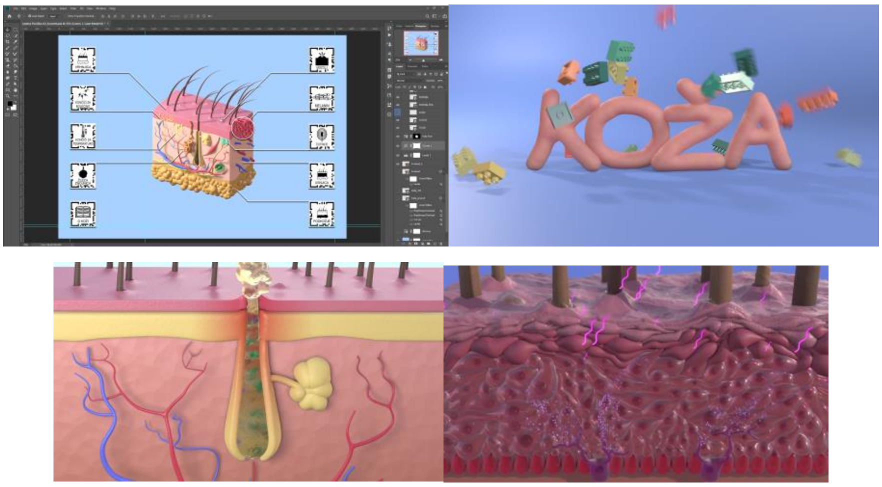

Figure 10 (part 2): Multisensory didactic tool for elementary school; authors: Matic Strgar, Sinja Stres, Simeon Perić, Jure Sulič, Celeste Sanja Smaraglia, mentors: Urša Stanković Elesini, Helena Gabrijelčič Tomc, Tanja Hrkač

4.7 Animated presentation

Animated presentations are probably one of the most commonly used multimedia content for showing technical procedures, scientific phenomena, etc. Their effect on better understanding and higher learning outcomes is proven in several researches (Mayer, 2001; Rias & Zaman, 2010; Principles of Multimedia, 2016; Hari Narayanan & Hegarti, 2016). Each scientific and technical field must be treated individually when transferred in audio-visual and interactive media. Figure 11 shows an example of a virtual classroom of a printing lab and an interactive pdf learning material where printing processes and parts of the printing equipment were exactly reproduced from the technical documentation of the machines (Perovšek et al., 2018).

Figure 11: Virtual classroom of a printing lab with 3D educative animation; author Simona Perovšek, mentor: Helena Gabrijelčič Tomc

4.8 Modelling and reconstruction

In addition to 3D scanning and photogrammetry, modelling and reconstruction are used to recreate digital elements. They are used when 3D scanning, or photogrammetry are not possible or to complement them. The results of 3D modelling and reconstruction are generally more time consuming, but usually contain less detail. Figure 12 shows an example of the 3D reconstruction of the ancient city of

Petoviona (today's city of Ptuj in Slovenia), where the only possibility of recreation was modelling based on scientific hypotheses about the possible state of the city (floor plans, archaeological research, actual buildings do not exist) (Sotlar, 2021). 3D reconstruction of the ancient city is implemented in virtual tour (Burger, 2021) that allows the participant to experience the exhibition with greater engagement.

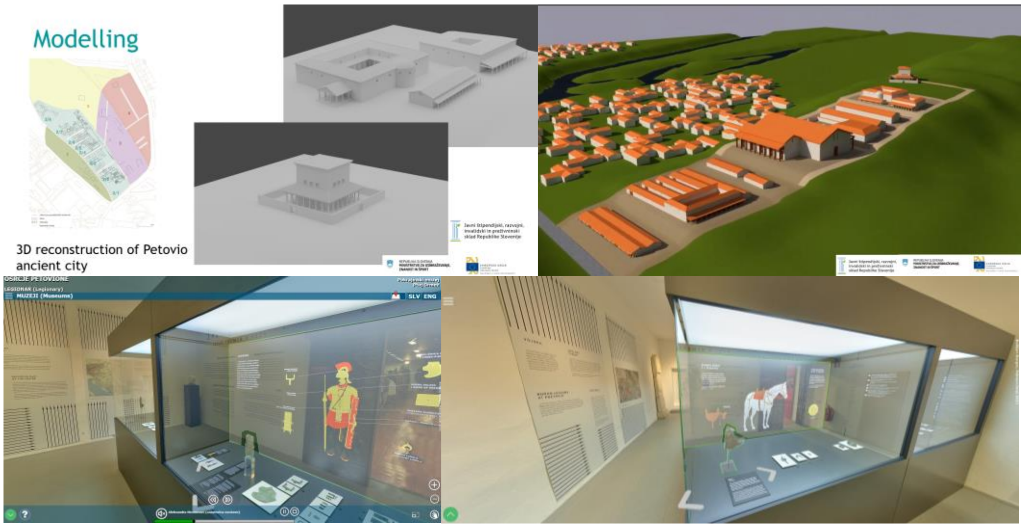

Figure 12: Modelling and visualisation of ancient city Poetovio with the virtual tour through exhibition, author Jerneja Sotlar, mentors: Helena Gabrijelčič Tomc, Tanja Nuša Kočevar, Aleksandra Nestorović

Figure 13 presents a 3D reconstruction of a sacral building that was never realized according to the plans of the famous Slovenian architect Jože Plečnik. The monument was dedicated to the Czech military leader Jan Žižka. The 3D printed model was created while taking into account the features of hand drawings, architectural plans and a photo of a 3D wooden model of poor quality (the wooden model has been lost). Here, it was necessary to introduce a lot of knowledge of the architect's style, references from scientific sources into the process in order to achieve a certain adequacy of the printed model. The 3D printed model is exhibited in the Plečnik House in Ljubljana (Škerjanc, 2019).

Figure 13: 3D printed model of reconstructed sacral monument dedicated to the Czech military leader Jan Žižka, authors: Anja Škerjanc, Helena Gabrijelčič Tomc, Matej Pivar, Tanja Nuša Kočevar

4.9 Interpretation and stylisation

Every operation of creating a presentation medium of scientific knowledge of greater clarity involves at least some simplifications, interpretations, and stylizations. The latter depend on the purpose of the presentation and the target audience. Interpretations and stylizations are judiciously planned design (including also artistic) interventions that, considering the meaning of the starting points of scientific results and the essence of the source information, introduce design elements and techniques in the final product with the goal of facilitating understanding of the meaning. Figure 14 shows an example of interpreting the incorporation of wooden cultural heritage data (wooden statues) into 3D animations and useful jewellery (Učakar et al., 2022).

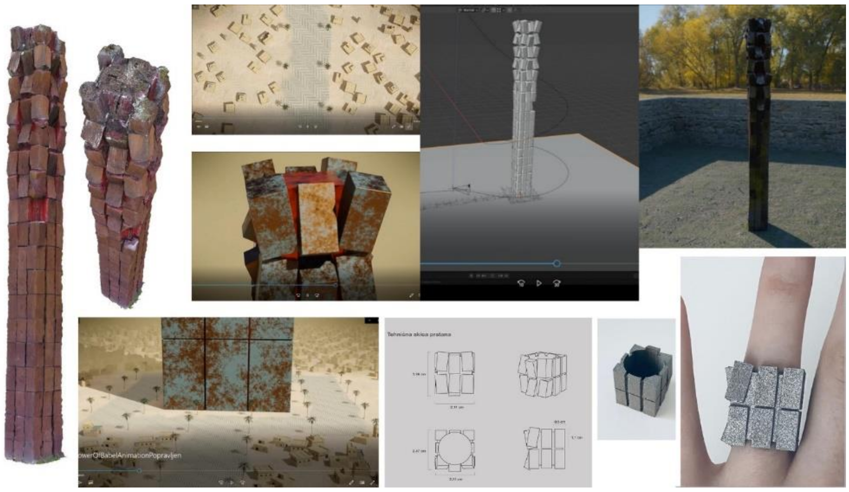

Figure 14: Interpretative approaches and stylisation of the digital data about wooden sculptures in 3D animation and jewellery; authors: Jernej Kalin, Kaja Bakan, mentors: Tanja Nuša Kočevar, Karin, Košak, Helena Gabrijelčič Tomc, Andrej Učakar, Andrej Iskra, Deja Muck

4.10 Augmentation of the physical realities and extension into the new reality

As mentioned earlier, extended reality technologies (XR) have emerged as one of the most promising ways to create a multisensory experience. Whether combining physical and digital reality (augmented reality, AR) or creating fully digital realities (virtual reality, VR), the participant is fully engaged in the experience, so that cognitive, affective, and kinaesthetic processes are guided by the content of the presentation medium. There is still some research to be done in this area to optimize the experience and the general use of these technologies (headsets, cybersickness), however we can say with certainty that these are technologies that open up new insights into science, technology, nature, people, etc. Figure 15 shows a virtual walk through a culturally significant and protected building Montanistika (in Ljubljana), whose floors and walls contain priceless geological heritage. In addition, the image also shows a mobile augmented reality project with educational cards, where the bodies of selected animals and their movements were captured, stylized and visualized for the purpose of educating about animal movements and behaviour (Vrhovnik et al., 2020; Bergant, 2022).

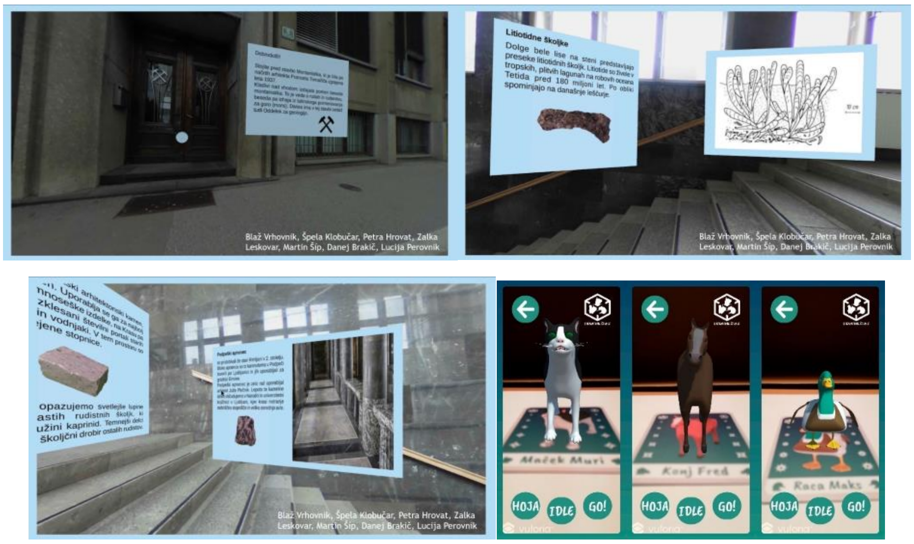

Figure 15: A virtual walk through the building Montanistika and a mobile augmented reality with the presentation of animal movements, author Marko Bergant, mentor: Helena Gabrijelčič Tomc

5. CONCLUSION

Although multisensory graphic presentations are not new, with the advancement of scientific data and their presentation new insights into the involving of somatic, perceptive, cognitive and affective processes in the experience keep inviting us to redefine the design of these communication media. The presentation layer is the surface level of interactive media, which we use to stimulate sight, hearing, smell, and taste to draw and hold the user into the experience. In an age of information overload, incorporating ethics and empathy is the key. To ensure that science and scientific data remain accessible to more than just researchers and consumers of scientific publications, their dissemination through media channels that are accessible to a broader audience is crucial. Perfecting graphic expression, incorporating the possibility of actively shaping a story on the part of the user, and understanding the dynamics of a multisensory medium are just some of the principles that go into planning, designing, and producing engaging multisensory graphic presentations.

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COATINGS IN GRAPHIC INDUSTRY

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Abstract: *Contrary to the negative predictions, the graphic arts industry keeps continuing its growth. The modern world is transferring information through digital platforms leading to decrease of the serial publications on paper (newspaper, magazines etc). But on the other hand, packaging industry is increasing its revenue by high numbers. In the same way as for the whole industry, many predicted that paper use will also decrease, as for a long period of time (still partly present) paper was thought of as being killer of trees. Today, along with new findings, paper is becoming more popular with EU Commission banning single use plastics. Paper as a substrate is becoming popular in packaging industry, mainly due to being suitable for both organic and material recycling.*
However, due to lack of some functional properties, materials are often coated. Coating as a process includes covering of a surface by another substance. The coatings processes are present in various industries and are intended to enhance properties of the base materials. In the graphic industry the coating process is often called varnishing, due to the resins used as a coating material. Varnishing is used to improve rub resistance and provide varnished material with special effects (combination of gloss and matte surfaces). Applicability and functionality of the coatings is achieved using various materials, among which are nano-engineered materials. Results of various researchers show benefits of introducing nanocomposites in the packaging industry by improving prints' resistance to degradation by UV irradiation, improving barrier to water vapour and enabling packaging surface to inhibit microbes' growth.
To conclude, coatings development and application plays a significant role in the material development, as it can provide common materials with improved properties, as well as enhanced aesthetics. At the same time, application of coatings could present some obstacles in both materials and organic recycling, and for that reason development of coatings should include evaluation of recyclability of the coated product as well as the characterization of coating's functionality.

Key words: packaging, coatings, varnishing, nanocomposites

1. PACKAGING

The contemporary world is more focused on a quick and widespread information transfer by means of digital media, which led to decrease in the graphic industry focused on the material information transfer (newspaper, magazines etc.). Nevertheless, the printing industry has continuous growth of revenues (LeBlanc, 2019). This growth is mainly related to the packaging sector. Packaging plays different roles, from protecting the product to conveying information to users and facilitating the use of the basic product (Kirwan, 2007). An increased awareness of human impact on the environment is pressuring the use of environmentally friendly materials in terms of their biodegradability and recyclability. In addition to user awareness, the European Union recognized the importance of transforming industries and has set regulations and development guidelines (EU Commission, 2018; *European Partnership under Horizon Europe Processes4Planet*, 2020). These regulations highlighted that although various materials are used for packaging purposes, paper and paper-based materials are highly involved due to good printability, possibility of biodegradation and recyclability (Rastogi & Samyn, 2015). The predictions for paper and paperboard products were very optimistic (*Global Paper and Paperboard Container and Packaging Market to Grow by $ 102.51 Billion During 2020-2024*, n.d.), but due to the obstacles in the global economy (COVID-19 pandemic, war in the Ukraine), these estimations lowered the numbers but are still not in recession (Globenewswire, n.d.; MarketWatch, n.d.).
The packaging is often classified as primary, secondary and tertiary. The primary packaging is in direct contact with the goods and can sometimes have printed outsides (e.g. various chocolates). Secondary packaging in majority of the cases comes in contact with customer, while tertiary packaging is used for storage and transport. Examples of packaging types in the pharmaceutical industry can be seen in Figure 1.

Figure 1: Example of packaging types according to its use (Types of Pharmaceutical Packaging – HVAX | The Pharma-Engineering Blog, n.d.)

Roles and desired properties of the packaging vary depending on its type. Primary packaging is intended to enable protection of the goods from mechanical and, more importantly, chemical threats. Secondary packaging provides mechanical protection and more importantly communicates with the costumer affecting it's purchase desision (Hurley et al., 2013), which is also important for branding (Grundey, 2010). Tertiary packaging is intended to provide a protection during transport and storage. In order to enhance some properties of the packaging materials, the substrates are often coated with other substances.

2. COATINGS

Coating is a widely used term, described by Cambridge dictionary as "a layer of a particular substance that covers a surface" (*COATING | Meaning, Definition in Cambridge English Dictionary*, n.d.). This can be applied to vast variety of industrial applications. The coatings are almost always used to provide or increase some kind of functionality of the basic material, for example; coating of the metal to enables anticorrosive behaviour (Li et al., 2018; Wang et al., 2019; Zhang et al., 2019), applying coating onto wood can increase its resistance to irradiation and humidity or as a flame retardant (Chen et al., 2022; Nair et al., 2018; Teaca et al., 2019), etc., fabrics enhanced by its waterproofness (Bramhecha & Sheikh, 2021; Luftinor et al., 2022; Pongsathit et al., 2019), etc.

In graphic industry coating process is usually related to application of the overprint coating or a primer to the printing substrate. Printing on a paper substrate often presents a challenge due to paper's porosity. The porous surface enables absorption of the small particles into the paper and diminishes their functionality, for example. conductive ink (Agianniotis, n.d.). Therefore, primers are applied to provide a paper substrate surface properties with good printability, i.e. primer is a coating which is applied onto the paper surface planned to be printed on (Havenko et al., 2020; Khadzhynova, 2020; Mendez-Rossal & Wallner, 2019; Morić et al., 2019).

On the other hand, basic roles of overprint coatings are to provide surfaces with some aesthetics due to the high gloss or matte finish and enhanced rub resistance. Although there are many overprint varnishes/coating present on the market, they are usually divided into three groups depending on the composition and/or application method (Hook, 2018). In offset printing, varnish is applied the same way as is the ink. In that case the applying is performed inline and can be spot printed or on the whole surface. For the aqueous or water-based coating the presses often have a special printing unit which is designed for coating. These are often used to cover the whole image. Both varnish and water-based coatings are curing without additional drying equipment. On the other hand, UV coating is cured by UV radiation. The UV coating is often being printed off-line, due to the fact that majority of the printing presses are not equipped with UV drier. Additionally, there is a strong movement towards UV LED technology due to the lower costs, environmental friendliness and shorter starting time (UV lamp need to heat up before curing process can start) (Milmo, 2020). Nevertheless, UV coating technology can provide higher gloss values and better rub resistance. On the other hand, although coating is intended to be transparent and should not change colour of the prints, previous research have confirmed colour changes (Hoffstadt, 2004; Simonot & Elias, 2004).

The research of MEGA research group also provided an insight into the colour change due to application of the commercial coatings (Figure 2) (Cigula, Hudika, & Donevski, 2021).

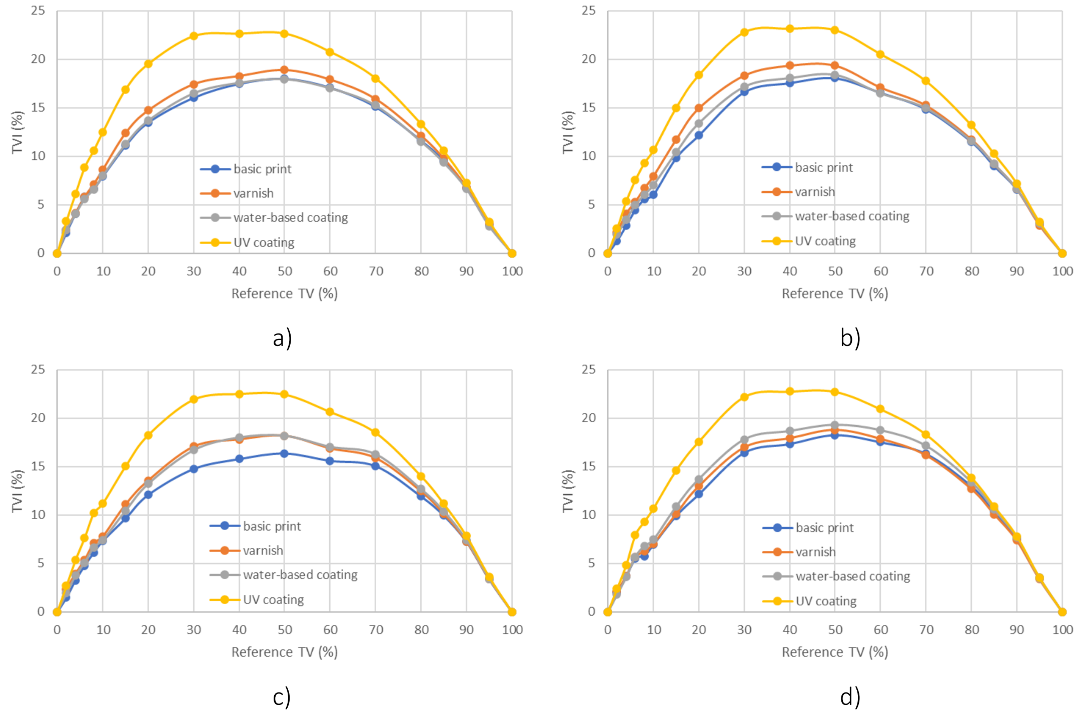


Figure 2: Tone value increase (TVI) of coated prints a) black, b) cyan, c) magenta, d) yellow

As it can be seen Figure 2, the water-based varnish has less influence on the tone values of all applied coating (with the exception of influence on magenta). On the other hand, applying UV varnish will result in significant change of the tone value and darker appearance of the print. Please note that in this research, UV varnish was applied off-line with the screen printing unit, i.e. it had thicker layer than the others.

Beside mentioned, development of nanotechnology have introduced nanomaterials to the coating industry as well. The nanocomposites include some nanosized compound which is incorporated into the polymer matrix and give added functionality to the basic coating. There are numerous papers related to this thematic, for example corrosion protection (Deyab et al., 2021; Kasar et al., 2020; Peng et al., 2020), UV protection (Nuraje et al., 2013; Zeljko et al., 2021), creating superhydrophobic surfaces (Ghashghaee et al., 2019; Ibrahim & Sultan, 2019; Sutar et al., 2020), antimicrobial behaviour (Kumaravel et al., 2021; Nakhaie et al., 2022).

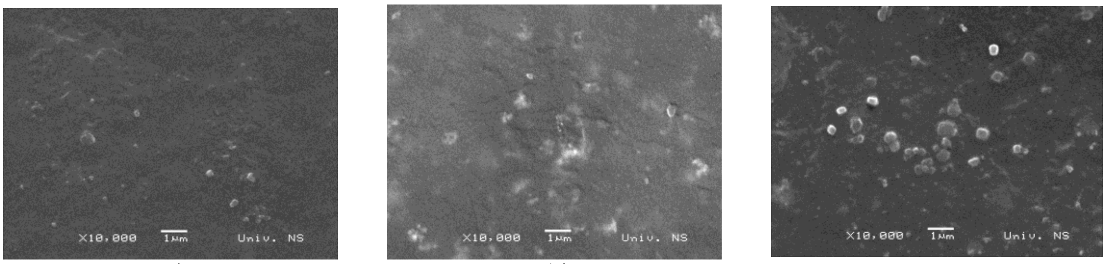
For that reason, the results section will present research covering the topic of nanocomposite coatings in the packaging industry.

3. RESULTS OF NANOCOMPOSITE AS OVERPRINT COATING

In the last few years, we have conducted research and development of new coatings, which would provide some additional features to the packaging material (paperboard, cardboard, labels). The results of those efforts are showed below, with references where the specific experimental details are shown in full.

For these coatings research team included nanoparticles of ZnO, TiO_2 or SiO_2 and mixed them into polycaprolactone (PCL) and polylactic acid (PLA). This proved to be challenging, as both of the biopolymers are soluble in organic solutions (ethyl-acetate and chloroform for PCL and PLA, respectively). For that reason, PLA was excluded from further research as it did not provide better functionality than PCL. All coatings were prepared by first dissolving biopolymer granules in a defined solvent (mixing in a closed glass container using magnetic stirrer). In the second step, defined mass of the nanoparticles was added and homogenized by ultrasonic homogenizer. Coatings were then applied with a laboratory coater in a defined wet layer thickness. After drying, the prepared print samples were analysed to reveal how the applied layer had influenced their properties.

This procedure enabled a satisfactory distribution of the nanoparticles within the nanocomposite, and consequently, on the applied layer on the paperboard prints Figure 3.



a) b) c

Figure 3: SEM images of coatings on printed coated paperboard: a) PCL-0, b) PCL + 0.5 % ZnO, c) PCL + 0.5 % TiO_2

The visible particles on the surface of the samples originated from Ca (Figure 4), which is commonly used as anti-set-off powder (preventing the prints to stick to each other during the printing process).

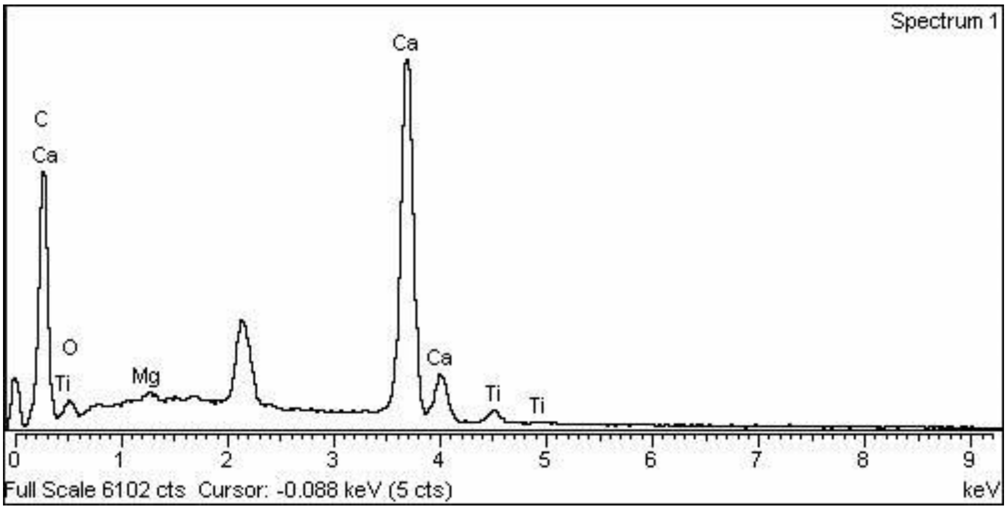


Figure 4: EDS spectra of the PCL-0.5%TiO_2 nanocomposite on coated paperboard print

Nevertheless, coatings have provided basic prints with better lightfastness and also improved barrier to water vapour, but had not influenced colour that well. Research have been undertaken on both coated and uncoated paperboard.

In Table 1 and Table 2 one can see the colour difference ΔE_{00} of nanocomposites including SiO_2, ZnO and TiO_2 (Cigula, Hudika, & Tomasegovic, 2021; Majetić, 2020). It can be noted that colour differences are visually unnoticeable. The results were obtained during previous research (Cigula, Hudika, & Tomasegovic, 2021; Majetić, 2020).

Black ink was influenced the most, which is expected as prints generally darken when coated, as previously shown in Figure 2.

Table 1: ΔE_{00} between uncoated print and samples with applied nanocomposite coating on a coated paperboard

	Cyan			Magenta			Yellow			Black		
	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2
PCL	0.19			0.48			0.25			1.43		
0.10%	0.35	0.63	0.95	1.18	1.12	0.54	0.38	1.08	0.40	2.34	1.10	1.39
0.25%		0.58	0.53		1.10	0.58		1.01	0.14		1.02	1.34
0.50%	0.85	0.63	0.38	1.26	1.40	0.50	0.57	1.04	0.63	2.68	0.48	2.58

Table 2: ΔE_{00} between uncoated print and samples with applied nanocomposite coating on an uncoated paperboard

	Cyan			Magenta			Yellow			Black		
	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2	SiO_2	ZnO	TiO_2
PCL	0.19			0.48			0.25			1.43		
0.10%	0.33	1.09	0.43	0.26	0.64	1.02	0.21	0.88	0.24	1.61	0.86	1.87
0.25%		1.06	1.02		0.69	1.36		1.00	0.56		1.48	2.65
0.50%	0.16	0.94	0.60	0.50	0.62	1.58	0.33	0.96	0.50	1.52	0.92	1.99

An application of biocomposite coatings reduced water vapour transfer rate (initial paperboards without coatings were 0.52 g/m^2*day and 1.44 g/m^2*day for coated and uncoated paperboard respectively), although it was evident that addition of nanoparticles gave worse results that the neat PCL coating.

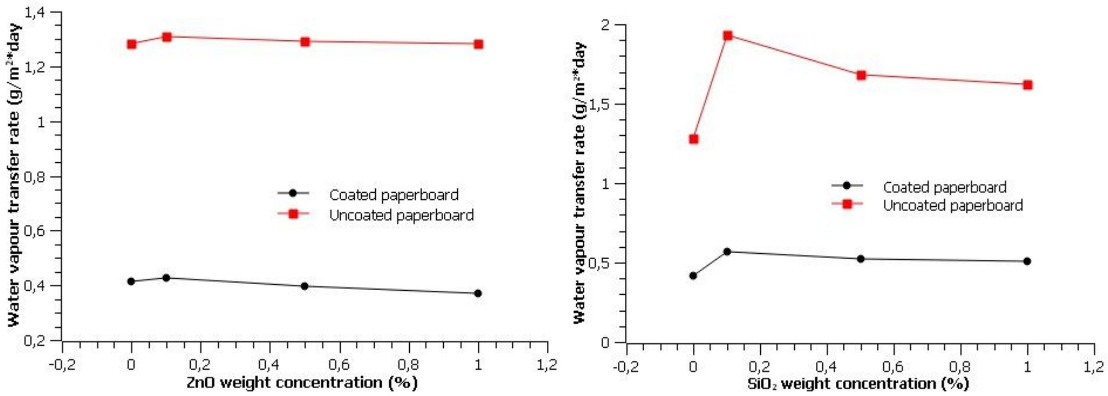


Figure 5: Water vapour transfer rate of SiO_2-PCL (right) and ZnO-PCL (left) nanocomposite

The second property investigated was the resilience of prints to the accelerated ageing by exposing the samples to the UV light source under controlled conditions (Cofomegra Xenon chamber 1500e, using indoor filter). The test was performed on coatings containing ZnO and TiO_2, as they were known UV absorbers (Ghamsari et al., 2016; Tsuzuki & Wang, 2010; Wang et al., 2009). Due to being most sensitive to UV radiation, the results shown include observing the chromatic change of yellow ink only. Further information is available in (Cigula, Hudika, & Tomasegovic, 2021).

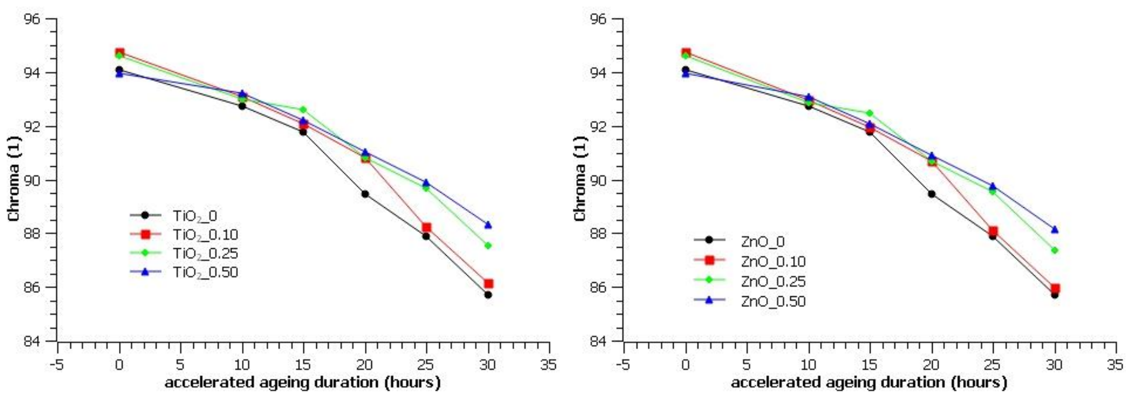


Figure 6: Yellow colour chroma change of prints on coated substrate due to accelerated ageing. Samples coated with PCL-TiO_2 (left) and PCL-ZnO (right)

It can be seen in Figure 4 that both nanoparticles had performed similar in the accelerated ageing tests and diminished chroma change. Additionally, it is visible that in the first 15 hours of accelerated ageing there is almost no change in chroma regardless to the nanocomposite composition i.e. weight ratio of the incorporated nanoparticles in coating

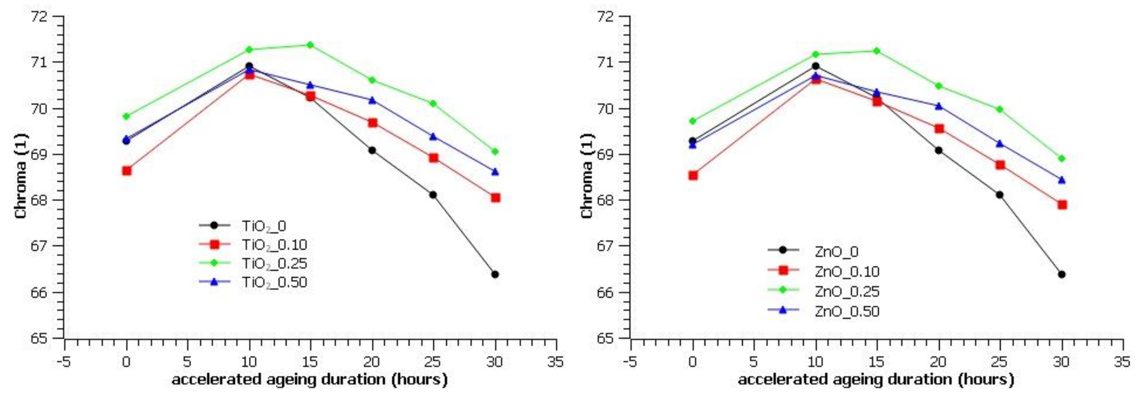


Figure 7: Yellow colour chroma change of prints on uncoated substrate due to accelerated ageing. Samples coated with PCL-TiO$_2$ (left) and PCL-ZnO (right)

Opposite to the prints on coated substrate, chroma of the samples on uncoated paperboard is significantly lower and the accelerated ageing has lower influence in general (probably due to the partial protection of printing ink by paper fibres). Influence of the nanoparticle's concentration is more visible on these samples. At the beginning of the accelerated ageing process, it is increase of the yellow chroma, most probably due to the yellowing of the paperboard and higher amount of the optical brighteners in the sample paperboard.

4. CONCLUSION

This paper was prepared to give some insight in the coatings in the graphic industry. Furthermore, some results of the research including biopolymer based nanocomposites and their influence on some aspects of the packaging material improvement. These results have proved that procedure for coatings' mixing and homogenization results with satisfactory distribution of nanoparticles. Application of biopolymer based nanocomposites had provided some improvements in the lightfastness of the samples without causing significant colour change.

To conclude, development of coatings and their application is widespread activity over numerous industries. It plays a significant role in the material development as it can provide basic material with enhances properties, but enhanced aesthetics as well. But with all benefits, application of coatings could provide some obstacles in materials and organic recycling due to the antimicrobial potential of some added particles and possibly, their retention in wastewater. For that reason, development of coatings should include determination of recyclability of the coated product as well as the characterization of coating's functionality.

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GRAPHIC MATERIALS AND PROCESSES EFFICIENCY

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DETERMINING POINT SPREAD FUNCTION OF PRESSURE SENSITIVE LABELS FACESTOCK

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Abstract: *Pressure sensitive labels (PSL) are a growing part of graphic industry. In the past, their design and application were rather limited to basic packaging and product information while currently labels are receiving more and more attention because they are customer's first contact with a product. PSL composition includes release liner, adhesive and facestock. Facestock can be considered as the most important part of the label since its properties determine the final label appearance. Nowadays, facestock material can be both paper and filmic. Therefore, it is necessary to perform a comprehensive characterization of pressure sensitive labels facestock in order to investigate the future impact of optical dot gain on the print. Point spread function is a measure of scattering and absorption of light in the given substrate. It carries information regarding paper composition and its future behaviour in term of optical dot gain. In the study, seven different facestock substrates were examined, two made from biogenic polyethylene, and five paper based PSL facestocks, three of which are made from 15% agro industrial waste by-products (barley, citrus and grape). Point spread function of the substrates were obtained by projecting collimated red laser light source on the facestock of pressure sensitive labels. Although the laser light used in this experiment was characterized by a narrow beam width of 0.5 mm and low divergence, <1 mrad, the beam was further converged and then passed through a space filter to ensure collimation of the laser beam which was then incident perpendicular to the set sample. Laser profile was firstly obtained by photodiode profiling. Based on the measured values of light intensity, the laser light profile was determined, as well as the average beam width that was needed for further image analysis. Image of the light scattering within the substrate was obtained perpendicular to the surface with Canon EOS 5DS camera. From the obtained image, laser profile was removed, and the resulting profile gives the point spread function of the substrate. The resulting images were processed with commercially available image analysis software (ImageJ). The mean background intensity subtracted from each individual pixel was determined to remove the background effect, and the distribution of the scattered light profile was achieved. The results showed that facestock composition has a high influence on PSF shape and width.*

Key words: PSF, optical dot gain, pressure sensitive label, facestock, light scattering

1. INTRODUCTION

Pressure sensitive labels had come a long way since their first appearance in the 1930's until today. Their early design was based on a paper facestock, adhesive coating and a liner that was coated with silicone (Irwin, 1973). Nowadays the basic construction of the PSL is the same but the materials in use vary. For example, facestock can be made not only from paper but various polymer film materials such as PE, PP, PET, PVC, Polyvinyl Fluoride and Polyimide. Also, the adhesives can vary from solvent based, water-based, hot melt, UV hot melt, silicone-based. Each combination of facestock and adhesive is appropriate for specific storage conditions (temperature, humidity, exposure to chemicals and UV radiation). Of course, the mechanical and optical characteristics of the facestock surface like smoothness, mechanical resistance gloss, transparency, colour affect the overall print quality and durability of the printed label.
Pressure sensitive label market is increasing rapidly in the last decade mainly because of the overall increase in distribution chain due to COVID. Consumer behaviour is changing, consequently the role of the labels too. Labels were initially used as an informative tool for product information, while nowadays their design significantly influences the buyer's decision about the product itself. Increasing the number of labels on the market also increases the amount of waste that needs to be disposed of. In this sense, it is necessary to include alternative materials to produce labels in order to use the various by-products that arise during the processing of different types of grain and fruits. This principle makes it possible to solve the problem of disposal of a large amount of organic waste through it's utilization in paper and packaging industry. Cacao (Nurika, 2019), barley (Vargas et al., 2015), wheat (Tutus & Cicekler, 2016), pulp from

banana pseudo stem (Melesse et al., 2022) , citrus (Tutus, Cicekler & Kucukbey, 2016) were all examined as a possible alternatives for paper production.

Characteristics of future print on PSL facestock made from such components is highly influenced by the characteristics of the PSL substrate itself. One of the ways of quantifying substrate is by determining it's point spread function (PSF). PSF is a probability density function that describes the probability that a photon that entered the substrate exits on the same surface at a distance from the entry point. It is a measure of scattering and absorption of light in the given substrate since it carries information regarding PSL facestock composition and its future behaviour in term of optical dot gain. Importance of knowing the substrates point spread function is discussed in numerous articles since it's shape and value is closely related to the optical dot gain.

Optical dot gain is caused by scattering of light within the paper (Rogers, 1998). Modrić et al. (2009) introduced the possibility of applying modified Monte Carlo model for characterizing optical dot gain by modelling light propagation within the paper based on its composition. Further research dealt with the Monte Carlo modelling of uncoated paper using randomly orientated microfacets. Modelling of the uncoated paper surface was based on paper surface reflectance data (Modrić, Maretić & Hladnik, 2012). The model was further improved in the case of coated papers by introducing photon behaviour at the interface between the coating and the rest of the paper (Modrić et al., 2013). During one of the steps, the photon can reach the border of the two media, such as in the predicted case the border between the coating and the rest of the paper, which is well defined. These layers can be considered as separate areas in which the optical properties differ significantly. This resulted with the determination of point spread function of paper substrate based on light-scattering simulation with the clear indication of Lorentzian function as the one that satisfactorily describes the shape of the PSF (Modrić, Maretić & Hladnik, 2014). Itrić et al. experimentally determined the PSF of the paper substrate and confirmed superiority of Lorentzian function for the description of the shape of the PSF, which was recently acknowledged by Rogers et al. (2019).

2. MATERIALS AND METHODS

2.1 Pressure sensitive labels facestock used in the study

For the purpose of analysing scattering of light within the PSL facestock comprised of different materials seven PSL of the same manufacturer were selected. In the selection of labels, care was taken to represent the most common paper-based labels, also included are those with a significant proportion of recycled fibres, as well as those based on synthetic polymers.

Two polymer bio based facestocks (polyethylene white-PEW and polyethylene clear-PEC) are primarily made from sugar cane ethanol. It's production is similar to one of conventional polyethylene and it is certified under the Bonsucro® layout and it is fully recyclable. It is characterized with a very high bio-based content (white minimum 80%, clear minimum 95%) (Avery Dennison Corporation, 2016; Avery Dennison Corporation, 2021). Chrome has a conventional filmic polymer facestock[2]. Three fibre based facestocks used in this research are produced with 15% agro-industrial byproducts, 40% post-consumer recycled paper and 45% virgin wood pulp. Regarding different types of agro-industrial byproducts, citrus leftovers from juice production, grape pomace from wine production, and barley residue from whiskey production were used (Avery Dennison Corporation, 2021). Remaining fibre based facestock of thermal top is white woodfree, top coated thermal paper (Avery Dennison Corporation, 2022).

Table 1 (part 1): Properties of the used PSL facestocks given by the manufacturer [2–8]

Sample name	Designation	Facestock	
		Basis weight ISO 536/g·m²	Caliper ISO 534/ µm
Fasson ® PE85 BIOB WHITE S692N-BG40WH FSC	PEW	82	82
Fasson ® PE85 BIOB CLEAR S692N-BG40WH FSC	PEC	78	82
Fasson ® THERMAL TOP K8 FSC R5100-BG40BR	TT	76	82
Fasson ® 772 BRUSHED CHROME S697-HF125	CH	70	51

Table 1 (part 2): Properties of the used PSL facestocks given by the manufacturer [2–8]

Fasson ® rCRUSH CITRUS FSC S2030-BG45WH FSC	C	100	130
Fasson ® rCRUSH BARLEY FSC S2030-BG45WH FSC	B	90	110
Fasson ® rCRUSH GRAPE FSC S2047N-BG45WH IMP FSC	G	90	114

2.2 Procedure of obtaining PSF

When determining the PSF, the linearity of the input-output system is assumed (Dainty & Shaw, 1974), whereby *f(x,y)* represents input, and *g(x,y)* output, while the operation of the system is represented by the operator S{ }, and it is valid then

g(x,y) =S{f(x,y)} $g(x, y) = S\{f(x, y)\}$ (1)

If the input information is described as

$$f(x,y) = \iint_{-\infty}^{+\infty} f(x',y')\,\delta(x-x')\delta(y-y')dx'dy' \quad (2)$$

$$f(x,y) = \iint_{-\infty}^{+\infty} f(x',y')\,\delta(x-x')\delta(y-y')dx'dy' f(x,y) = \iint_{-\infty}^{+\infty} f(x',y')\,\delta(x-x')\delta(y-y')dx'dy'$$

And the output is defined as

$$g(x,y) = S\{\iint_{-\infty}^{+\infty} f(x',y')\,\delta(x-x')\delta(y-y')dx'dy'\} \quad (3)$$

$$g(x,y) = S\{\iint_{-\infty}^{+\infty} f(x',y')\,\delta(x-x')\delta(y-y')dx'dy'\}$$

due to the linearity of the system it can be sown that

$$g(x,y) = \iint_{-\infty}^{+\infty} f(x',y')\,S\{\delta(x-x')\delta(y-y')dx'dy'\} \quad (4)$$

$$g(x,y) = \iint_{-\infty}^{+\infty} f(x',y')\,S\{\delta(x-x')\delta(y-y')dx'dy'\}$$

where the system response is the so-called point spread function (*PSF*).

$$H(x,x';y,y') = S\{\delta(x-x')\delta(y-y')\}H(x,x';y,y') = S\{\delta(x-x')\delta(y-y')\} \quad (5)$$

Method of determining PSF was developed in 2017. by Itrić et. al. (2017) and is presented in Fig. 1. The method itself comprises of laser profile energy distribution measurement followed by scattered light intensity of substrate. Laser used in the research was helium-neon red laser with the beam diameter of 0.5 mm, output wavelength of 632.8 nm and beam divergence ≤1 mrad. Spatial filter in the form of the 350 µm was placed in front of the laser on the optical bench in order to secure spatial coherence. Also, optical lens, 10 cm focal length, was added as a condenser. At the other edge of the optical bench, single photodiode was mounted for efficient laser profiling. Photodiode possesses it’s own transconductance amplifier in the desired spectral range and a high signal to noise ratio along with a slit diaphragm for high resolution light intensity measurements. Average laser profile was plotted in Origin 9 mathematical software. The exact width of the laser beam was determined so it can be subtracted in the following step.

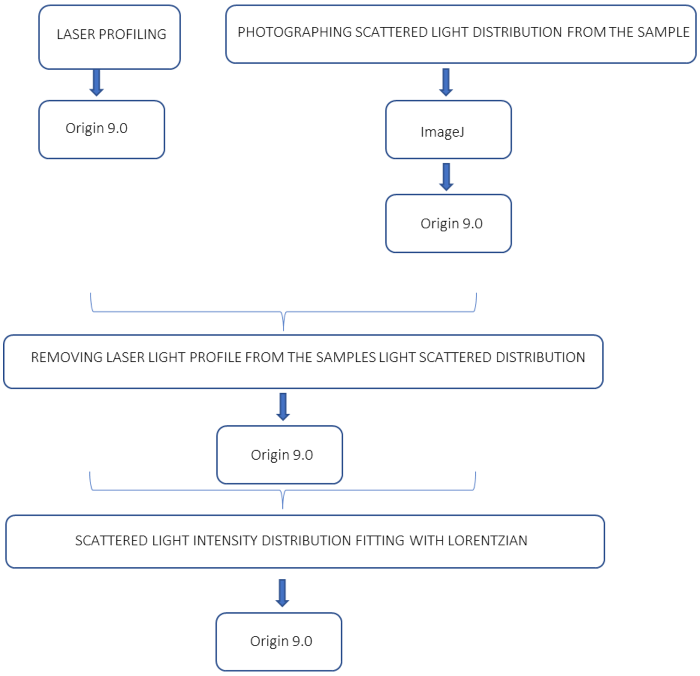

Figure 1: Procedure of generating PSF

Scattered light intensity of the laser on the facestock substrate was obtained by photographing the resulting interference of point light source with the substrate perpendicular to the substrate itself. Deviations of up to 2 degrees are possible. The Canon XC10 4K camera with 50 mm, 1/30 sec at f 5.6, ISO 400 was used for the imaging of the samples. ImageJ software was used for further image processing. Recordered image profiles of subsurface light scattering showed cylindrical symmetry which is why the mean value of the vertical and horizontal profiles was chosen for a reliable profile analysis. Final scattering distribution was obtained by removing the laser light profile. Resulting profile was normalized to unity and fitted with Lorentzian function in Origin 9 according to eq. 6.

$$y = y_0 + \frac{2A}{\pi} \cdot \frac{w}{4(x-x_c)^2+w^2} y = y_0 + \frac{2A}{\pi} \cdot \frac{w}{4(x-x_c)^2+w^2} \quad (6)$$

Lorentzian function is 4 parameter function, where y_0 stands for the offset of the function, x_c is the position of the centre, w is full width at half maximum (FWHM) and A is the area under the curve.

3. RESULTS AND DISCUSSION

Resulting experimental PSFs are presented in Figure 1. Every PSF was fitted with Lorentzian function in order to acquire numerical quantities that can be further used as a prediction parameters of optical dot gain. Upper two thirds of all experimentally acquired PSFs are uniform and symmetric while at the wings the influence of the noise arises resulting in irregularities and greater deviations from the proposed model function.

All of the fitted PSF show satisfactory correlation with the Lorentzian PSF, $R^2 > 0.96$ *(Table 2).* If higher level of smoothening was used the correlation would be even higher. It was estimated that this level of correlation is adequate to achieve the ideal ratio of level of smoothing and preservation of background information. The wings of the PEC point spread function are flatter compared to PEW facestock PSF (Figure 1 a-b).

Table 2: Correlation of Lorentzian PSF with the measured PSF

Designation	PEC	PEW	TT	CH	C	B	G
R^2	0.97365	0.98185	0.967	0.9839	0.985	0.98252	0.9712

By fitting the measured PEC PSF with Gaussian, 0.99 correlation was obtained. This is an indication of approximating clear filmic based PSF with the Gaussian function, while the paper based and filmic with the addition of white pigment is better described by Lorentzian. Obviously, the interaction of light with the clear bio based polymer results in different behaviour compared to paper substrates, in terms of the shape of the line spread function.

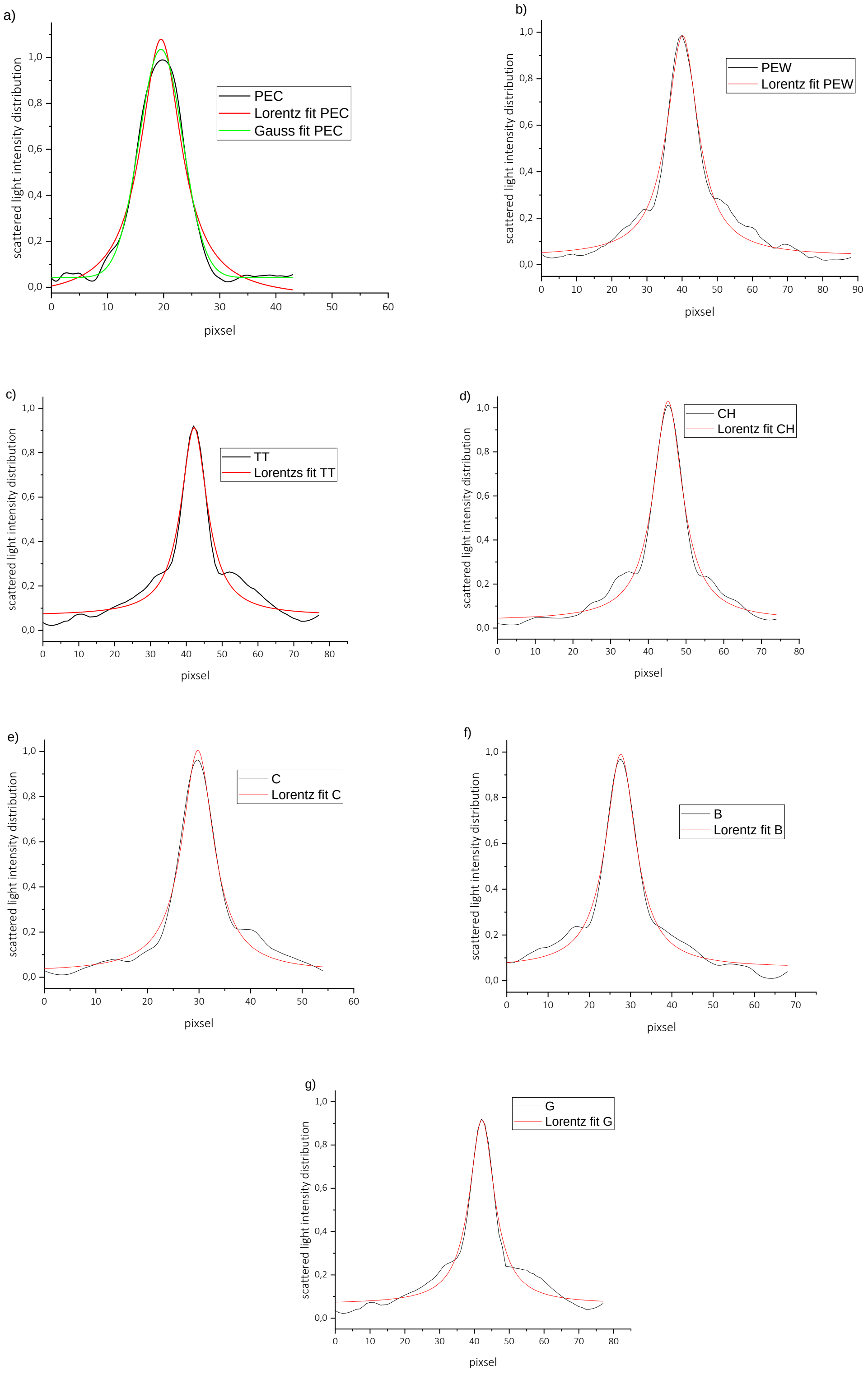

Figure 2: Measured and fitted PSL facestock point spread functions of a) polyethylene clear, b) polyethylene white, c) thermal top, d) chrome, e)citrus, e) barley, f) grape

Numerical parameters, w, A, y_0 and x_c of the fitted Lorentzian PSFs are given in Table 2.

Table 3: Values of the Lorentzian parameters used to fit PSL facestock point spread function Correlation of Lorentzian and Gaussian with the measured data

Designation	w	A	y_0	x_c
PEC	8.84216 ± 0,47652	15.67975 ± 0,82142	-0.04996 ± 0.01656	19.53018 ± 0.11683
PEW	10.73371 ± 0.32068	16.01006 ± 0.41002	0.03564 ± 0.00529	40.11795 ± 0.09205
TT	8.91329 ± 0.38728	11.84832 ± 0.43685	0.06575 ± 0.0066	42.1703 ± 0.11251
CH	9.4092 ± 0.28854	14.70078 ± 0.38865	0.03453 ± 0.00583	45.21705 ± 0.08253
C	7.52866 ± 0.26449	11.59962 ± 0.35843	0.02294 ± 0.00702	29.77081 ± 0.07364
B	8.90319 ± 0.29813	13.06042 ± 0.37943	0.05589 ± 0.0061	27.62036 ± 0.08456
G	8.77083 ± 0.35514	11.73341 ± 0.40198	0.06508 ± 0.00613	42.15353 ± 0.10352

Chemical composition obtained by FTIR in our previous research (Vukoje et al., 2021) confirmed the same composition of the PEW and PEC which is also stated in their product sheet (Avery Dennison Corporation, 2021). Nevertheless, their PSF differ. The scattering coefficient of polymer is ruled by the polymer matrix and different additives used for enhancing desirable polymer properties. Every additive has it's own refractive index. The higher the difference between refractive indices of the components the higher scattering of light occurs. Addition of white piment into the polyethylene base clearly caused the increase in light scattering, resulting in highest full width at half maximum.

From paper based PSL facestock, the one comprising of 15 % citrus byproducts from orange juice production shows the lowest value of FWHM indicating least scattering of the incident light. Due to the fact that all three paper based facestocks with 15% ratio of byproducts from citrus, grape and barley have the same amount of recycled and virgin fiber, the differences in the PSF width corresponds to the fibre characteristics of depeptinized micronized citrus mash, barley and grape pomace. Citrus pulp contains 128 g/kg of cellulose fibres, together with 183 g/kg hemicellulose. On the other hand, grape pomace has 540 g/kg of cellulose fibres and 208 g/kg of hemicellulose. The lignin content in grape pomace is higher than that in citrus pulp 197 g/kg compared to 22 g/kg (Mussatto, Dragone & Roberto, 2006) indicating the higher level of chemical bleaching that had to be applied. As for barley fibres, research by Mossatto et. al. (2006) showed that chemical composition of exhausted barley malt consists of 25.4 % cellulose and 11.9 % of lignin.

Thermal top PSL facestock shows the widest FWHM from all paper based facestocks which can be explained with the existence of coating. Namely, it is well known that the latteral light scattering is more pronounced within coated papers due to numerous interactions between the coating layer and the substrate. Filmic based facestock, CH, confirms higher level of scattering of light within the filmic PSL facestocks. Due to it's lower weight compared to PEW and PEC PSL facestock the scattering of light is lower and consequently the point spread function is narrower.

This data can be indicative for the evaluation of the future print characteristics. In the research that dealt with determining the quality of the printed monochrome line of 0.5 pt nominal width on PSL facestocks examined in this study, it was observed that dot gain, including both mechanical and optical dot gain was lower for paper based PSL facestocks (Itrić et al., 2022).

4. CONCLUSIONS

The demand for an attractive PSL design is more and more pronounced. Therefore, the need for the characterization of such substrates increases in order to obtain as many measurable values as possible that can give useful information and which can be used for future prediction of print quality. One of the values that affects this is optical dot gain. Optical dot gain or lateral scattering of light within the substrate can be characterized by point spread function.

Pressure sensitive labels consist of liner, adhesive and facestock. In the research we examined the possibility of applying previously developed method for determining point spread function of paper substrate based on laser-paper substrate interaction for determining point spread function of PSL facestock. The method is based on image analysis since the laser-substrate interaction is captured with

the camera and further processed in image processing software ImageJ followed by the mathematical fitting in Origin 9. Red laser was used to gain the highest levels of lateral light scattering within the samples due to it's wavelength. Both types of facestock material, paper and filmic, were represented. Paper facestock was represented by four label types, three of which are with a high percentage of agro-industrial byproducts, barley, citrus and grape, while the fourth is wood-free coated paper. Filmic PSL facestocks are represented with two bio based PSL facestocks, PEW and PEC, made from sugar cane and one conventional polymer The based, TT.
Results showed that measured PSFs of all PSL facestocks can be satisfactorily fitted by means of Lorentzian function. Also, paper based PSL facestock shows lower level of light scattering compared to filmic ones. It should be also noted that coated paper based PSL facestock, TT, has the widest PSF FWHM value. This is supported with the fact that coating increases the degree of reflections and scattering between the substrate and the coating layer.
The results showed that facestock composition has a high influence on PSF shape and width. The research confirmed that in terms of the shape and properties of the point spread function of the ecology friendly facestock made from a significant ratio of industrial by products is compatible to the commercial woodfree PSL facestock.

5. ACKNOWLEDGMENTS

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THERMAL STABILITY OF PACKAGING PAPERS TREATED OF SILVER WATER

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Abstract: *Paper aging depends on the type and chemical composition of the fiber raw materials, the chemical additives used, such as dyes, fillers, sizing additives, pH and others as storage conditions of the paper (relative humidity and temperature) and the degree of exposure of temperature, light and some microbiological factors. The durability of paper is its ability to retain certain physic-mechanical, optical and chemical properties unchanged over time. In this context and in line with the increased consumption of coated or treated printing and packaging papers, the aging resistance of treated or coated paper is of a great scientific, research and applied interest. This research work inherently involves preparation and properties evaluation of thermal stability of packaging papers treated of silver water. In order to examine this process for woodfree packaging paper, accelerated thermal aging for 72h at temperature of 105°C and dynamic thermogravimetric analysis (TGA) was carried out of a pulp sample and four paper samples (three of them treated with silver water – 1, 2 and 3 ml) together with the structural-dimensional and strength properties of the laboratory obtained paper samples. The degree of colour changes in the CIELab colour space have been studied, bearing in mind that the changes in colour characteristics define the stability over time and even more – the influence of the silver water treatment. As a result of the studies carried out it was found out that paper do not change significantly during 72h of accelerated thermal ageing, but it is not recommended to be used more than 2 ml of silver water, as silver ions probably catalyze the aging process and the paper darkens and turns yellow in a greater degree. The change of the weight of the paper samples as a function of temperature was monitored by TGA. When comparing the weight losses, it was found out that for the paper sample treated with 2 ml of silver water the temperature of complete burning of the sample increased by 2.28°C. In addition, the surface of the treated paper samples is more even compared to the untreated due to the callandering effect of the manufacturing process.*

Key words: ageing stability, thermal stability, packaging paper, silver water

1. INTRODUCTION

The bactericidal effects of silver (Ag) have been recognized many years ago. In ancient times, it was used in water and food containers to prevent putrefaction. Years ago in Mexico, water and milk were kept in silver containers. Silver was also mentioned in the Roman pharmacopoeia of 69 b.c. In 1884, silver nitrate drops were introduced as a prophylactic treatment for the eyes of new-born, and this became a common practice in many countries throughout the world. Silver ions have the highest level of antimicrobial activity of all the heavy metals. Generally speaking, the observed antimicrobial efficacy of silver and its associated ions is through the strong binding with disulfide (S–S) and sulfhydryl (–SH) groups found in the proteins of microbial cell walls. Through this binding, normal metabolic processes are disrupted, leading to cell death. The antimicrobial metals silver (Ag), copper (Cu), and zinc (Zn) have thus found their way into a number of applications (Silvestry-Rodriguez et al., 2007).
Enhanced manufacturing methods and technologies have led to more widespread employment of nanomaterials in newly developed and commercially available products. Silver could be incorporated to polymers (Gordon et al., 2010; Schierholz et al., 1999; Sun et al., 2004) for the production of consumer products such as washing machines, refrigerators and ice machines that have silver. Silver has been added to plastics to produce items such as public telephones and public toilets (in Japan), toys, and infant pacifiers (Xiao et al., 2017). Silver is added to inorganic composite with immobilized slow-release silver effect. Synthetic fabrics with silver are popular in items such as sportswear, sleeping bags, bedsheets, and dishcloths (Wang et al., 2007). These fabrics are believed to reduce the level of bacterial contamination and thus odor.

Some inorganic ceramics (e.g., zirconium phosphate, zeolite) are also combined with silver (Wang et al., 2021) thus are able to trap metal ions and may then be added to other materials (e.g., paints, plastics, waxes, polyesters) to confer antimicrobial properties (Asafa et al., 2021; Kurnyta et al., 2021; Ma et al., 2016).

Among these materials, silver nanoparticles are increasingly being used as a comprehensive antimicrobial agent in clothing, food storage containers, pharmaceuticals, cosmetics, electronics, and optical devices. The silver nanoparticles are readily released from these products during use, particularly washing and thus it is likely that these materials will eventually be introduced into the environment (Li & Lenhart, 2012). The toxicity of silver nanoparticles is primarily related to the released ionic silver produced as the silver nanoparticles oxidize and dissolve. The known toxicity of silver and silver nanoparticles necessitates their use and fate in the environment be closely scrutinized to avoid compromising environmental or human health (Gorka et al., 2015; Strużyńska, Dąbrowska-Bouta & Sulkowski 2022).

The application of nanotechnology shows significant advantages for improving the quality of packaging materials (Barage et al., 2022). Innovation related to the use of nanotechnology in food packaging and quality control is the focus in the modern food industry. The silver nanoparticles can be relatively uniformly distributed in a matrix of other materials such as pulp, plastics, and others and thus be more effective at killing bacteria and fungi, either in stock preparation proses (Kraśniewska, Galus & Gniewosz, 2020) or as a coating (Gottesman et al., 2011; Srichiangsa et al., 2022; Tsai et al., 2017; Wang et al., 2014). Packaging materials with nanoparticles of silver or coated silver containing coatings allow creating effective and safe antimicrobial packaging. Therefore, studies on the thermal stability of the silver water treated cellulose paper and packaging could possess the desired knowledge if the silver-water treatment catalyses the paper aging or makes it more stable. This research shows the preparation, characterisation, TGA and accelerated thermal ageing analysis of packaging papers treated with silver water. The purpose of the research conducted was also to improve the antibacterial activity of the produces papers, which was also achieved and results are in process of publication.

2. MATERIALS AND METHODS

The cellulose mixtures for paper samples were prepared from a bleached kraft woodfree pulp samples from softwood (delivered by SCA, Sweden) and hardwood tree species (delivered by Svilosa AD, Bulgaria) in ratio 80:20 percentage. The used kraft cellulose were refined by laboratory Valley beater method, acc. ISO 5264-1:1979. The celluloses were refined separately and the Schopper Riegler Value as degree SR (ISO 5267-1/AC:2004) of the obtained pulp mixture was 30 °SR.

The analyses have been conducted with one sample of only pulp, base paper and three paper samples treated with 1, 2 and 3 ml silver water. The wet-end chemical additives have been added to the obtained base paper, in the following sequence: alkylketendimer (AKD) sizing agent – 1 % of o.d.f (Kemira® Fennosize KD 157YC) and cationic retention additive – 0.025 % of o.d.f. (modified polyacrylamide with molecular weight 11.106 g/mol and charge density +1.05 from Ciba Specialty Chemicals-Ciba® Percol®Co (Basel, Switzerland)). The base paper has been sprayed with the exact amount of Arcol silver water with concentration of C = 10 mg/l = 0.00001 g/l delivered from Gal ET.

2.1 Microscopic analysis

The microscopic analysis of cellulose and paper materials, is a specific analysis generally used to determine the fiber composition of the paper and to study the structure and size of the source fibres. Small amount of test fibres (pre-milled mechanically) is placed in a porcelain pounder with a few drops of 1 % NaOH. This is followed by rinsing the sample several times with distilled water on a fine, metal mesh. Three samples of fibres have to be placed on a glass slide, well distributed. A drop of Herzberg's reagent (Cl-Zn-J) according to ISO 9184-3:1990 is dropped on each of the samples and again very carefully the fibres should be distributed. Finally, the samples are dried at about 60°C. After cooling down to room temperature, each sample is covered with a thin glass slide, so the fibre samples are evenly distributed, free of accumulations and air bubbles. Stained fibre samples were observed with microscope VisiScope® TL254T1 (VWR, Italy) at 100x magnification. Objective: 10x/0.25 E-PLAN, Eyepiece: WF10x/20mm.

2.2 The papermaking processes

The papermaking process was simulated by using laboratory paper-sheet machine. All samples were prepared on paper laboratory machine (Rapid-Kothen, Germany) acc. ISO 5269-2:2005, with a grammage of 50 g/m^2, with drying conditions of – 95°C and duration of 7 minutes. After the silver water treatment, paper samples have been again dried for 5 minutes at the same drying conditions.

2.3 Grammage, thickness, density, porosity, smoothness

Grammage of all samples was determined in accordance with the ISO 536 standard. Density and porosity were calculated form grammage and thickness, as described in the standard method ISO 534. Smoothness was determined by Bekk method according to standard ISO 5627/A1:2004.

2.4 Tensile strength, TEA Index, elongation and tear resistance

Tensile strength, TEA Index and elongation at break of papers were determined on a tensile testing machine Zwick/Roell according to ISO 1924-1/2:2000. The samples were analyzed in the standard atmosphere at 23°C of temperature and 50 % of relative humidity. The tested speed was 20 mm/min. Paper stripes of 18 cm in length and 1.5 cm in width were used and a minimum of ten probes for each sample was tested. During the sample stretching, several load and elongation data per second were recorded until the break of a sample occurred. After the measurement and determination of tensile strength, the tensile index was calculated. The tensile index is tensile strength divided by grammage, the unit being Nm/g.
Tear resistance is the force, required to tear the sample after a cut was already made. The test was performed with an Elmendorf tester and proceeded as described in standard ISO 1974:2012. For each paper sheet, two parallels were measured. All samples were tested at 23°C and 50 % RH. When tear resistance is normalized with respect to grammage, then the tear index can be calculated and the unit is mNm^2/g

2.5 TGA analysis

TGA analysis was performed on TGA analyzer TGA Q5000. Samples (see Table 1) 5 x 5 mm were cut into squares and put into the sample dish. The method was dynamic TGA, meaning that the temperature continued to increase over time as mass was recorded. The temperature measuring range was between 10°C and 600°C. Heating range was 10°C/min. On graphs two curves are presented, where the first one (green presents the curve of measurement) and the blue one present the 1st derivative of the curve, at which the start and end of the 2nd stage of the weight loss can be determined.

Table 1: Sample names and compositions

Sample	Composition	Mass of the measured sample, mg
0	Only pulp	2.7380
1	Base paper	2.3680
2	Base paper+1 ml Ag water	1.8150
3	Base paper+2 ml Ag water	2.4090
4	Base paper+3 ml Ag water	2.0180

2.6 Thermal aging of papers

The accelerated thermal ageing of the investigated paper samples was conducted according to ISO 5630-1:2014 in closed chamber at 105°C and air circulation for standard humidity of 50 % with duration of 72 hours, because from the literature review is known that 72 h of thermal ageing corresponds to 25 years of natural ageing of paper. The colour coordinates L*, a*, b* from the CIE Lab colour space were measured before and after the thermal ageing by Konica Minolta Spectrophotometer CM-3630 from Frank – PTI, according to ISO 5631-2:2008.

3. RESULTS AND DISCUSSION

Paper as an anisotropic material has multifunctional properties, which are a result of the diversity of its fibrous composition, the presence of wet-end chemical additives, the technology of its production and additional coating, callandering or other finishing and ennobling processes. These properties should correspond to the application, and their degree should be consistent to the specifics of the end use.

As a packaging material for household application, the obtained paper samples have to have excellent surface and optical properties, sufficient strength, optimal barrier properties with respect to water and grease well-balance with its lower basic weight. Therefore, as a raw material was used virgin bleached kraft cellulose from soft and hardwood tree species. In order to establish the exact type of wood, a microscopic analysis have been carried out through a microscopic analysis illustrated in Fig. 1. From the analysis it was found out that the cellulose fibres from softwood tree are of bleached kraft coniferous cellulose from pine wood and bleached kraft deciduous cellulose from beech and poplar wood.

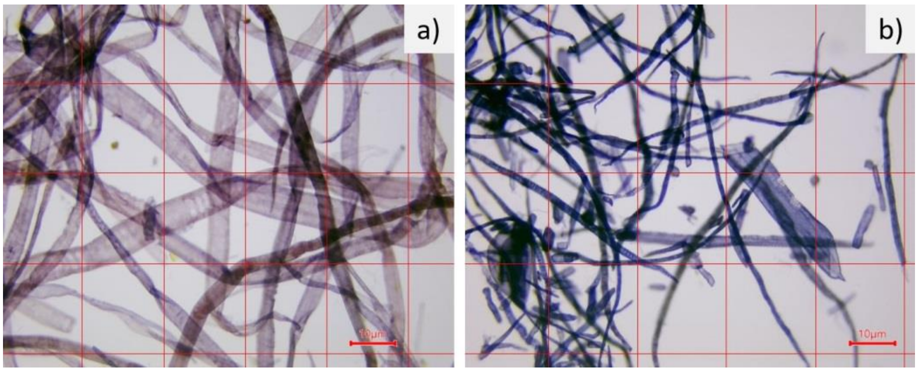

Figure 1: Microphotograph of a fibre raw material: a) bleached sulfate softwood from pine wood; b) bleached sulfate hardwood from beech wood

As the colour of the fibre staining, by the used Herzberg's reagent, determines the degree of delignification (bluish colour means lignin content up to 9 %, while yellowish over 9 %.) and furthermore the delignification determines the degree of inter-fibre bonds as strong hydrogen bonds in the obtained paper, we could assume that the strength properties of the examined paper samples could meet the requirements of the end users.

To determine the influence of chemical additives on the complex parameters of the papers, the correct and maximum detailed characterization of the paper structure is of essential importance. As an anisotropic material and on the basis of the used experimental methods determining the properties of the paper in different directions, the provenance of meaningful trends is a complex process, which starts with determining the basic weight, thickness, density, porosity and smoothness of the paper. The smoothness of the papers is of essential importance for the surface-coated papers. It is also an indicator of a change in the structure of the paper surface.

Table 2: Grammage, thickness, density, porosity and smoothness of base and treated paper samples

Paper properties	Testing method		Only pulp	Base paper	Base paper +1 ml Silver water	Base paper +2 ml Silver water	Base paper +3 ml Silver water
Grammage	ISO 536:2012	g/m^2	50.89	50.96	50.48	49.68	49.95
Thickness	ISO 534:2011	mm	0.8	0.8	0.8	0.7	0.7
Density	ISO 534:2011	kg/m^3	63.61	63.73	63.12	70.97	71.35
Porosity	ISO 534:2011	%	95.76	95.75	96.46	95.27	95.24
Smoothness (Bekk, top side)	ISO 5627/A1:2004	s	10.98	10.96	14.89	14.92	14.03

From the data on the structural-dimensional properties (Table 2) of the base paper and the silver water-treated papers, it is found out that the addition of sizing agent and retention additive does not affect the smoothness of the paper. Regarding the samples treated with silver water, an increase in the smoothness of the papers was observed, and as the amount of silver water increased, the effect decreased. As expected, the thickness of the samples had mostly the same values with a slight decrease at paper samples treated with 2 and 3 ml silver water. These results are based on the additional moistening of the paper bases with a silver water solution and their subsequent drying on a sheet-making apparatus at 96°C for 5 minutes. During this additional drying process, the effect of temperature and the pressure of the vacuum created by the apparatus have the effect of calendering onto paper, which is also confirmed by the data on the density and porosity indicators of the investigated papers. From the data in Table 2, it can be seen also that as the amount of silver water increases from 1 to 3 milliliters, the density increases and the porosity decreases.

Strength properties of paper are a permanent indicator of all papers, describing the ability of the paper to tolerate processing and determine the level of loading of the products produced from the paper. To describe the strength of the paper, the tensile index, the tensile energy absorption index, the elongation and the tear index of the investigated paper samples are defined and the results are presented in table 3.

Table 3: Strength properties of base and treated paper samples

Sample	Composition	Tensile Index, Nm/g	TEA Index, mJ/g	Elongation, %	Tear Index, $mN.m^2/g$
0	Only pulp	63	1070	2.4	1.1004
1	Base paper	69.5	1430	2.9	1.0989
2	Base paper+1 ml Silver water	66.6	1220	2.7	1.1094
3	Base paper+2 ml Silver water	64.7	1140	2.6	1.0881
4	Base paper+3 ml Silver water	63.6	1090	2.5	1.0889

From the strength properties data in table 3 could be seen that with the greatest change compared to the indicators of the base paper are three indicators - tensile index (Tensile Index, Nm/g), the index of tensile work (TEA Index, mJ/g) and the elongation (Elongation, %) of the papers treated with silver water. In these three parameters, the treatment with silver water has a negative effect, but the reduction remains to the level of the strength of the paper samples with a composition of only cellulose. However, the strength of the paper after treatment does not cause further deterioration and the ability of the cellulose fibres to bond with each other is preserved. As the consumption of silver water increases from 1 to 3 ml, the values of the strength indicators, although within the error of the analysis, decrease. This effect is due to the irreversible destruction of the already formed hydrogen bonds between the cellulose fibres in the paper base, and the subsequent drying after spraying with silver water cannot compensate for the loss of the initially formed hydrogen bonds. Therefore, any additional processing of the paper should be carried out before the complete drying of the paper web, and if it cannot be avoided, the decrease in the strength indicators of the paper should be foreseen. In industrial paper production this reduction could be prevent. The main purpose of silver water treatment is to achieve antibacterial activity, in order to obtain a special type of paper, with application in packaging production in important sectors such as household, food packaging, medical and pharmaceutical products.

The results from the TGA analysis of the single sample analysis are presented in figures from 2 to 5. Figures show the weight loss of the samples as the function of the temperature. From figures could be observed that all samples have 3 stages of weight loss. First stage at sample 0 and 1 of weight loss is between 10°C and 100°C, where at the first part water, moisture evaporation occurs. Then at the second stage, the samples 0 and 1 (Figure 2 and 3) have similar weight loss at temperatures between 256°C and 411°C, with decreased mass of 77.91 % (Sample 0) and 79.52 % (Sample 1). The 3rd stage at both samples (after 411°C) presents the final degradation of the paper.

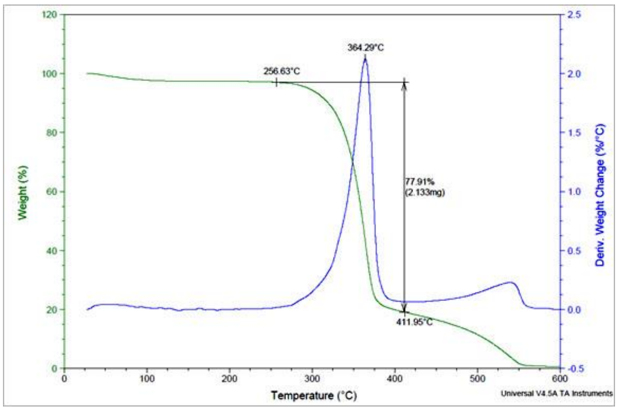

Figure 2: TGA of Sample 0 – only pulp

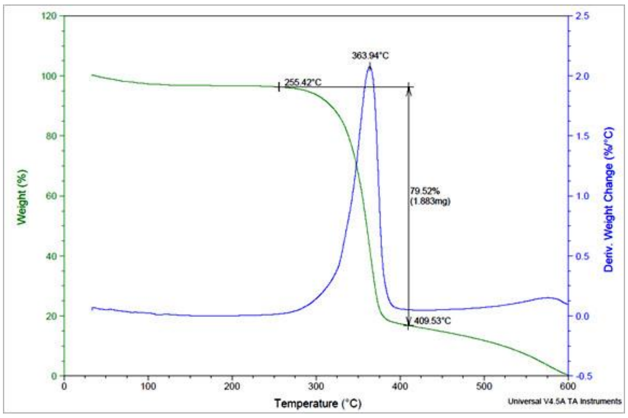

Figure 3: TGA of Sample 1 – Base paper

Figures 4 to 6 show samples with added Ag-water. 3 stages are also here detected. It is observed that with the increase of the amount of Ag-water, the 2nd stage of weight loss is decreasing. At 1 ml Ag-water, the start of the 2nd stage begins at 267.12°C and with the 3ml of Ag-water, the stage begins at 253°C. From the analysis it is also determined that the less the amount of Ag-water was in the sample, the highest weight loss was detected. This confirms that the third stage presents further degradation of the paper (after 400°C) and that certain amount of Ag is probably still present.

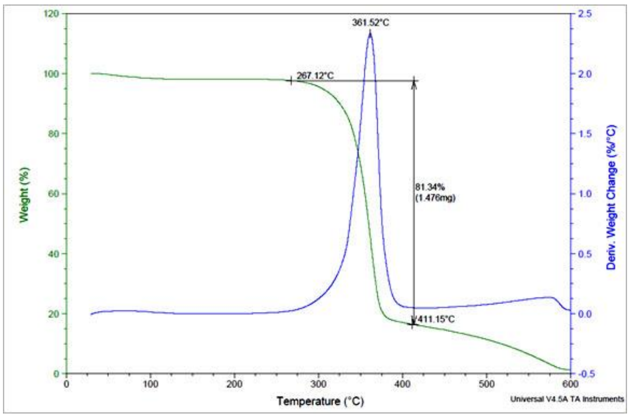

Figure 4: TGA of Sample 2 – Base paper + 1 ml Ag water

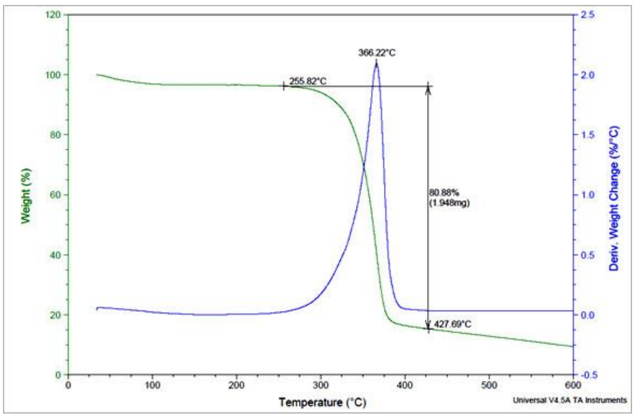

Figure 5: TGA of Sample 3 – Base paper + 2 ml Ag water

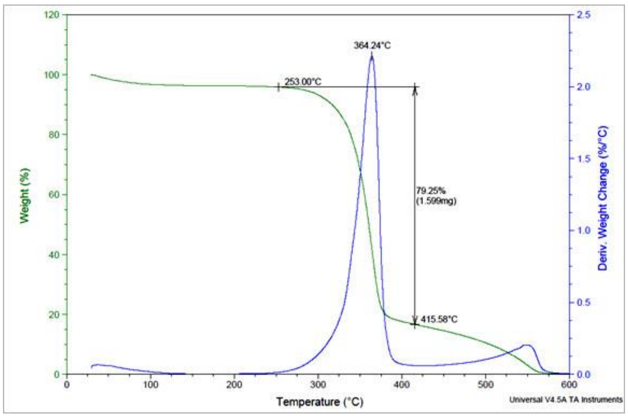

Figure 6: TGA of Sample 4 – Base paper +3 ml Ag water

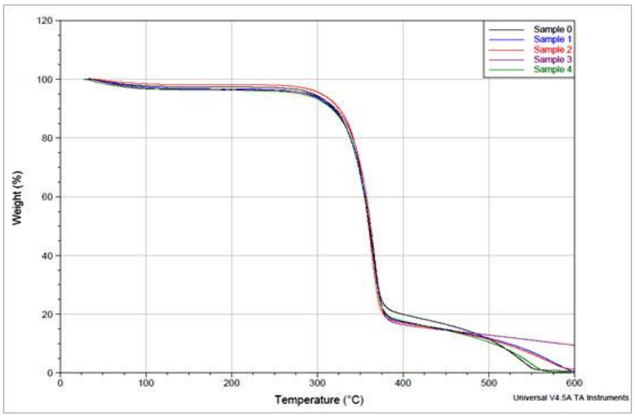

Figure 7: Weight loss at TGA analysis of all paper samples

When comparing the weight losses of the treated samples examined, it was found out that, 2 ml of silver water increased the burn-up temperature of the paper by approximately 15°C. A comparative view of the weight loss of all the investigated samples (only pulp, base paper, Base paper + (1, 2, 3 ml) Ag – water) during TGA analysis is presented in figure 7. The pattern of thermal destruction of the investigated samples is not different, both for the cellulose sample and for the paper base and the papers treated with silver water. Undoubtedly makes an impression the different behavior of the sample with 3 ml of silver water (green line) which burns faster and is characterized with weight of 25 % in the range of 375°C.

Due to the character of the application of the investigated paper, the change of the colour characteristics of the obtained papers over time, determined by accelerated thermal aging at 105°C for 72h, is also of interest.

The process of natural ageing of paper is too slow to permit observing changes in a reasonable period. Thus, different methods of accelerate ageing of paper under dry heat and light exposure have often been used. Accelerated ageing of paper is carried out for three major purposes. The first is to establish in a conveniently short time the relative ranking of materials, or physical combination of materials, with respect of their chemical stability or physical durability. The second is to estimate or predict potential long-term serviceability of material systems under expected conditions of use, and the third is to elucidate the chemical reactions involved (the degradation mechanism) and the physical consequences thereof. The hydrolytic degradation has been looked as the most important reason for the loss of strength properties of the paper and the lignin content as the most important factor for ageing. In the present study, the raw material was bleached pulp (lignin content is lower than 9 %), so that it cannot be of an essential factor for the colour change during thermal ageing, while the silver added as silver water could cause decrease of the thermal stability due to its catalytic action.

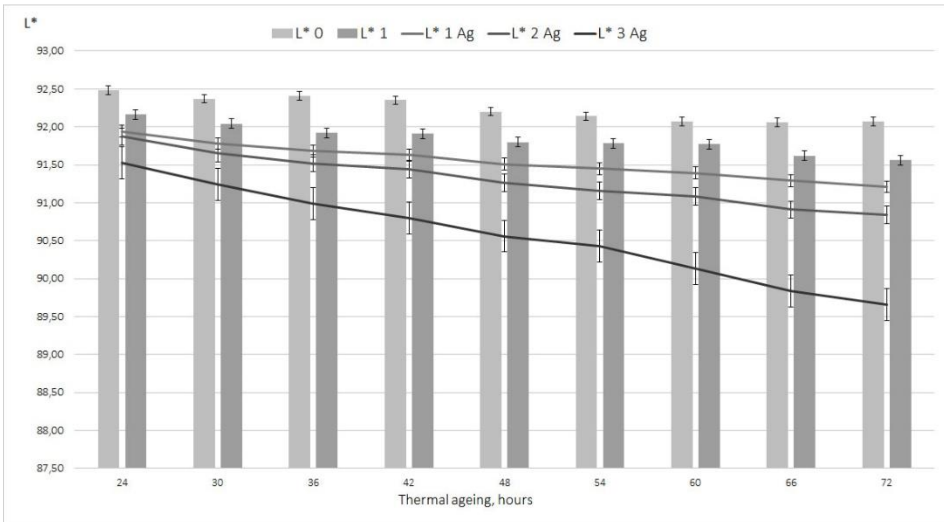

Figure 8: Lightness of the paper samples without and with silver water during 72h thermal ageing

The L* axis in the CIE L*a*b* colour space represents lightness, brightness and the brilliance of the paper. This is vertical; from 0, which has no lightness (i.e., absolute black), at the bottom; through 50 in the middle, to 100, which is maximum lightness (i.e., absolute white) at the top. Just like CIELab, the lighter the colour, the higher the value. The lightness of the paper samples without and with silver water are presented in figure 8.
The colour coordinate - L*, which expresses the lightness, brightness and the brilliance of the paper, decreases with the silver water treatment. The colour parameter variation with time is comparatively low, being most sensitive during the first 24 hours. The differences between samples of cellulose (sample 0) and base paper (sample 1) are small – nearly to the error of the analysis. With increasing the consumption of the silver water and the duration of the thermal ageing, the colour of the paper samples is getting darker and the colour difference is getting bigger. At 3 ml silver water treatment the lightness of the paper samples significantly decrease starting at 91.76 around 24 hour of the ageing with continuous tendency till the end at 72 hours of accelerated thermal ageing at 89.66.
Figure 9 shows the results for the optical properties of the investigated paper samples (colour coordinates L*, a* and b*) with and without silver water treatment before and after 72 hours in each 6 hours of accelerated thermal ageing.

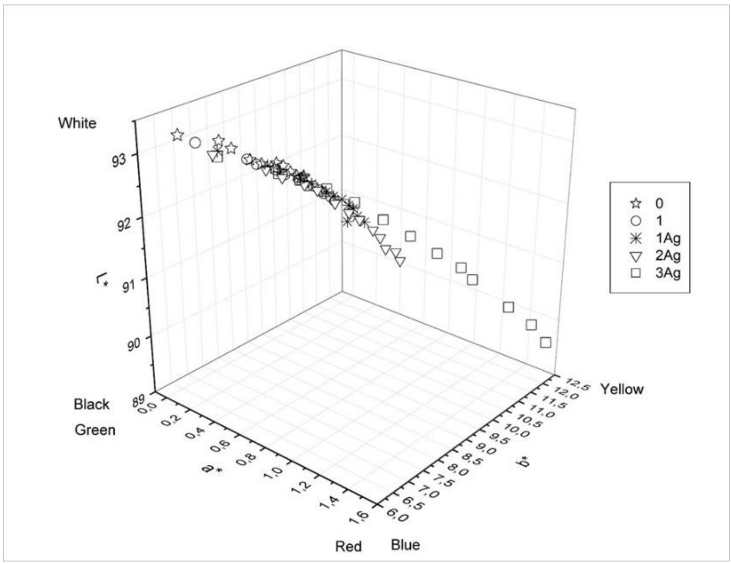

Figure 9: Colour coordinates L, a* and b* of paper samples during 72 hours of accelerated thermal ageing*

From the colour coordinates measurements, presented in figure 9 it is clearly visible that the cellulose (sample 0) and base paper (sample 1) are most stable and there is no drastically amending of the colour. For the other tree examined paper samples treated with 1, 2 and 3 ml silver water the colour amending occurs after the 36 hours of aging. The values of the colour parameters decreases, which means that the paper is getting darker and yellowish. This change is significant and with a larger step for the paper samples treated with 3 millilitres of silver water. Therefore, colloidal silver on the paper surface accelerates the aging by catalyzing the oxidation and hydrolysis of cellulose fibres. This is also confirmed by the observed decrease in the strength indicators, evidencing the destruction of hydrogen bonds between the cellulose fibres in the paper.

4. CONCLUSIONS

Coating and surface treatment of paper with multifunctional chemicals or additives has been proven excellent methods for improving its properties and for advancing the spectrum of its application. From the research carried out with paper samples of bleached softwood and hardwood pulp (80:20) treated with silver water was found out that treated papers has excellent thermal stability, as the colour coordinates do not change significantly during 72h of accelerated thermal ageing. Research has also shown that it is not recommended to be used more than 2 ml of silver water, as silver ions catalyze the aging process and the paper darkens and turns yellow in a greater degree. The change of the weight of the paper samples as a function of temperature was monitored by TGA. When comparing the weight losses, it was found out that for the paper sample treated with 2 ml of silver water the temperature of complete burning of the sample increased by 2.28°C. It moreover makes an impression the different behaviour of the sample with 3 ml of silver water which burns faster and is characterized with weight of 25 % in the range of 375°C. In addition, the surface of the treated paper samples is more even compared to the untreated due to the callandering effect of the manufacturing process.

5. ACKNOWLEDGMENT

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EFFECT OF PERFORATIONS ON THE LOSS OF CORRUGATED CARDBOARD BENDING STIFFNESS

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Abstract: *Bending stiffness of corrugated cardboard is a structural property that gives rigidity and strength. It depends on macroscopic structure of cardboard, different layers and thickness. The structure of corrugated cardboard used for secondary Shelf Ready Packaging (SRP) is weakened by perforations. Perforations serve as separation line used for converting SRP into the shelf-ready tray. The aim of this paper is to analyse the change of corrugated cardboard bending stiffness under the influence of perforations. The focus is on determining which of the explanatory variables affect the corrugated cardboard bending stiffness the most. The explanatory variables are: Type of perforation, Angle of perforation position and Quality of perforated corrugated cardboard. They are used to explain the variability in a measured property. The specimens with and without perforations were prepared using die cutter with machine-made knives. Three types of perforations (labelled: 1/1, 2/1 and 3/1 with the differences in the ratio of cut to uncut part) were positioned in five defined angles (0°, 20°, 45°, 70°, and 90°, where 0° represents Machine Direction, MD) and tested on three different quality of three-layer E-flute corrugated cardboard. Three-point bending tests were carried out using Instron tensile tester in order to observe the behavior of perforated specimens. Statistical analysis was performed to quantify the effect of perforation variables on the change of corrugated cardboard bending stiffness. The analysis showed that the explanatory variable Angle of perforation position was the most influential and provided the most significant information to explain the variability on the loss of corrugated cardboard bending stiffness. The trend in the measured values between all qualities of corrugated cardboard was obvious: the values decrease as the angle of perforation position increases; therefore, the highest values were for angle 0° and the lowest for angle 90°. A quantitative but not qualitative interaction between Quality and Perforation variables appeared. Hence, the "non-perforation – perforation" relationship was qualitatively always the same, although numerically it appeared somewhat different at different cardboard quality. The lowest loss of bending stiffness in the measured values was observed for the perforation type with the same ratio of cut and uncut part (labelled 1/1).*

Key words: bending stiffness, three-point bending, corrugated cardboard, perforation

1. INTRODUCTION

Shelf Ready Packaging (SRP) is secondary packaging with additional solutions for packaging functionality. Collation and protection of the product ensures successful movement through the supply chain. Additional functional requirements needed for a good SRP include ensuring easy identification, easy opening, easy shelfing, easy shopping and easy disposal (Theppituck et al., 2013). SRP should be easy to open to simplify and expedite replenishment and to facilitate in-store supply chain execution (Coles, 2013). However, easy opening should not compromise the structural integrity of the package, which is needed for safe transportation and handling (Hellström & Saghir, 2007). Perforations on corrugated boxes can be used to open the packaging in a desirable and predictable manner. Perforation lines are used to convert secondary packaging into corrugated tray or case displayed on the shelf.
Although SRP is recognized as having a significant impact on a global level by Smithers' study in 2019. with an increase of over $17 billion in 5 years (Smithers, 2019), literature reviews reveal the lack of scientific research of mechanical and structural properties for the purpose of efficient design of mentioned packaging. The classic approach to Shelf Ready Packaging design is the empirical or trial-and-error method. These methods are time-consuming and expensive.
There are studies in the form of guidelines that are created and used as part of the cooperation between international trading companies (Efficinet Consumer Respose Europe, 2007). The focus is on implementing SRP in the marketplace rather than providing tools and knowledge for the functional design of SRP opening.
Understanding the effects of perforation lines on the mechanical integrity of packaging is essential to providing a better product.

An important structural parameter of corrugated cardboard as a packaging material is flexural rigidity or bending stiffness. High bending stiffness provides rigidity and strength to paperboard packaging (Kajanto, 2008) and reduces the tendency for boxes to bulge when the contents are pressed against the wall (Fellers, 2009). Bending stiffness depends on the layered structure of corrugated cardboard that has two characteristic in-plane directions of anisotropy (Garbowski & Knitter-Piątkowska, 2022). This anisotropy results from the fiber orientation, which is commonly approximately symmetrical. Therefore, it can be assumed that the stiffness properties are orthotropic. Two in-plane directions are: Machine Direction (MD) corresponds to the manufacturing direction of the material and coincides with the x-axis; and Cross Direction (CD) corresponds to the transverse direction and coincides with the y-axis (Niskanen, 2008). Bending stiffness increases when the board is thicker and when the liners are heavier. Well-formed flutes also contribute significantly, hence the medium has a critical role both through the structural rigidity of the fluted shape and through its role in maintaining caliper (Urbanik, 2001; Frank, 2013).

It is important to understand the properties of perforated corrugated cardboard as an engineering material to understand where and how perforation decisions can impact the structural stability of the desired product. To provide tools for accomplishing better perforation decision making, three perforation variables were analyzed: Type of perforation, Angle of perforation position, and Quality of perforated corrugated cardboard. The perforation variables are sometimes referred to as explanatory variables in the text, depending on the context. With an optimal combination of perforation variables on corrugated cardboard, it could be possible to improve packaging properties by taking advantage of most of material and structural properties.

The aim of this paper is to identify the effect of perforations on the loss of bending stiffness of corrugated board in order to gain new insights into the structural properties. Furthermore, the perforation variables are analyzed and determined which one affect bending stiffness of corrugated cardboard the most. All data are mean values of ten measurements to obtain a representative result tested in direction MD, and are compared using statistical analysis.

2. METHODS AND MATERIAL

2.1 Perforated corrugated cardboard specimens

All specimens were produced using die cutter Rabolini Imperia with mPower knives, machine-made by Marbach. The perforation variables are divided into three groups and determined as three qualitative explanatory variables. The qualitative variables used to explain the variability of a measured property are:

- Type of perforation: three types of perforations were used and labelled 1/1, 2/1 and 3/1; the ratio of cut to uncut part of the perforation is 1:1, 2:1, and 3:1, respectively.
- Angle of perforation position: the specimens were perforated in five directions at five defined angles: 0°, 20°, 45°, 70° and 90°, with the 0° angle representing the Machine Direction and the 90° angle representing the Cross Direction. The selected angles cover most of the possible angles of perforation positions on SRP.
- Quality of perforated corrugated cardboard: the specimens were cut out from three different qualities of three-layer E-flute corrugated cardboard and labelled 111, 177, 177L. The basic properties of the selected cardboards, which are one of the most commonly used three-layer E-flute corrugated cardboard for perforated corrugated packaging in Croatia, are listed in Table 1.

The geometry and size of the specimens with the type of perforation and angle of perforation position are shown in Figure 1. The non-perforated specimens were also tested separately for each quality.

Table 1: Basic properties of three-layer E-flute corrugated cardboard

E-flute quality	111	177	177L
Outer liner [g/m²]	100 testliner	125 white testliner	160 lux white liner
Fluting medium [g/m²]	90 medium	90 medium	90 medium
Inner liner [g/m²]	100 testliner	125 white testliner	125 white testliner
Grammage [g/m²]	320.7	353	409.5
Thickness [mm]	1.45	1.44	1.50

Figure 1: Real images of selected specimens

2.2 Three-point bending test

Three-point bending tests on perforated corrugated cardboard were conducted on an Instron 5567 - tensile testing machine according to ISO 5628:2019 (International Organization for Standardization, 2019). There are two supports on the bottom of the specimen and a force acting on the specimen from the opposite side (Figure 2). In Figure 2 it can also be seen that the board is bending in both directions.

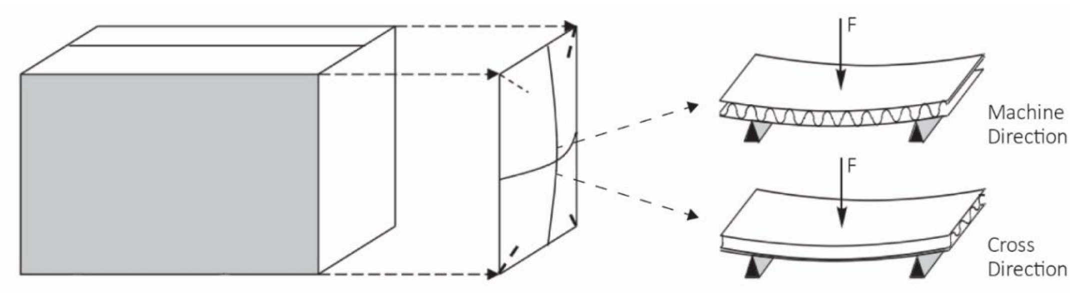


Figure 2: Schematic of corrugated box bending with principle of three-point bending test (Frank, 2013)

The bending is determined in a limited range of deviations in the elastic area with an agreed deviation of 0.2%. The limits of linearity must not be exceeded. The limit value for d_a (millimetres), the maximum allowable deflection, for the three-point loading can be calculated according to the following Equation 1:

$$d_a = \frac{0,33L^2}{t} \quad (1)$$

where L is the test length (millimetres) and t is the test piece thickness (micrometres). For three-point loading, further limitations must be considered to ensure that the errors are less than 5% (Equation 2):

$$d_a \ngtr 0,067L \quad (2)$$

Once the deflection d of the specimen has been calculated, the bending stiffness S (miliNewton metres) also can be calculated using the following Equation 3:

$$S = \frac{FL^3}{48db} \quad (3)$$

where F is a bending force (Newtons) and b is the test width (millimetres) (International Organization for Standardization, 2019).

3. RESULTS

The maximum allowable deflection d_a was calculated using Equation 1 for each quality of perforated corrugated cardboard (Table 2). The obtained results correspond to the limitation from Equation 2.

Table 2: Calculated the maximum allowable deflection d_a

E-flute quality	111	177	177L
d_a [mm]	2.27	2.29	2.20

Based on these results and the known dimensions of the specimen, the bending stiffness was calculated (Equation 3). The results were statistically analyzed to quantify the effect of the perforations on the loss of corrugated cardboard bending stiffness and to determine which explanatory variable most affects corrugated board bending stiffness.

3.1 Effect of Type of perforation on the loss of bending stiffness

In this paper three types of perforations were analyzed with the differences in the ratio between the cut and uncut part. The ratio for the type of perforation labelled 1/1 is 1:1, for the type labelled 2/1 is 2:1; and for the type labelled 3/1 it is 3:1. The data obtained from the tests can be seen as overall or main effect for each type of perforation (Figure 3) where value for perforation type labelled 1/1 are slightly higher, while the other two perforations types 2/1 and 3/1, are almost the same. Overall, the bending stiffness values were affected by the variable Type of perforation (F 12.97 P<0.0001).

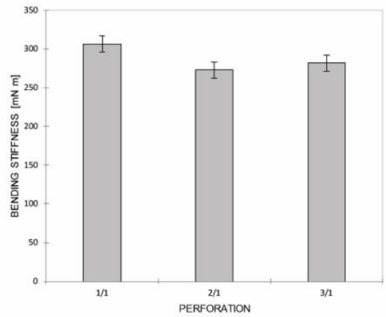


Figure 3: Main effect of variable Type of perforation on bending stiffness

3.2 Effect of Angle of perforation position on the loss of bending stiffness

The perforations on the specimens were positioned at five defined angles, with the angle of 0° corresponding to direction MD. The measured values are presented as overall or main effect for each angle. The differences between the angles are significant and are shown in Figure 4. The values decrease as the angle of perforation position increases; hence, the highest values were for angle 0° and the lowest for angle 90°. The values for angle 20° are close to the values for angle 0°, as well as the values for angle 70° are close to the values for angle 90°. Overall, the bending stiffness values were affected by the variable Angle of perforation position (F 1019.82 P< 0.0001).

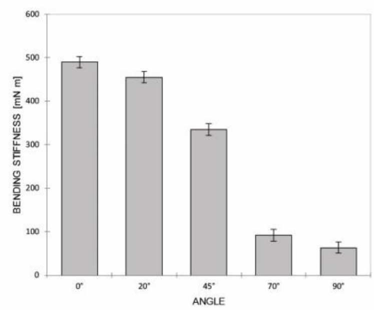


Figure 4: Main effect of variable Angle of perforation position on bending stiffness

3.3 Effect of Quality of corrugated cardboard on the loss of bending stiffness

Specimens cut from three different qualities of three-layer E-flute corrugated cardboard (labelled 111, 177, and 177L) were prepared with three types of perforation, placed on five defined angles, and tested. The data were analyzed and fitted to obtain an overall or main effect for each quality. From the data in Figure 5, it is apparent that the differences between the values for all three qualities are barely visible. Overall, bending stiffness values were affected by variable Quality of perforated corrugated cardboard (F 10,22 P<0.0001).

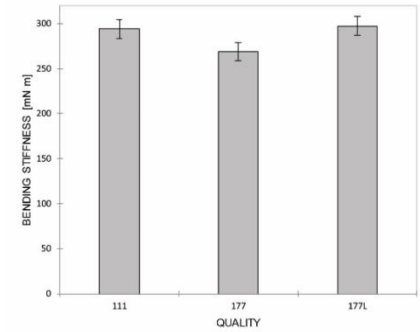
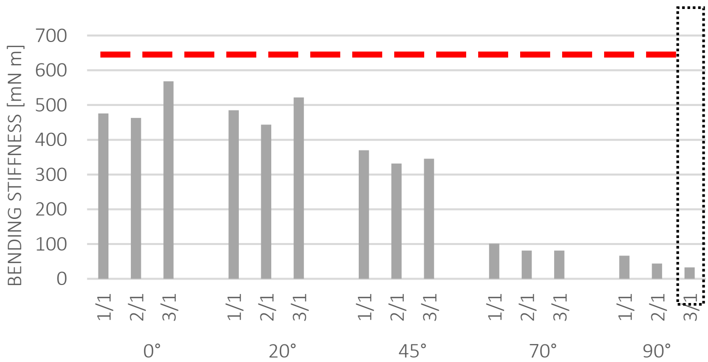


Figure 5: Main effect of variable Quality of perforated corrugated cardboard on bending stiffness

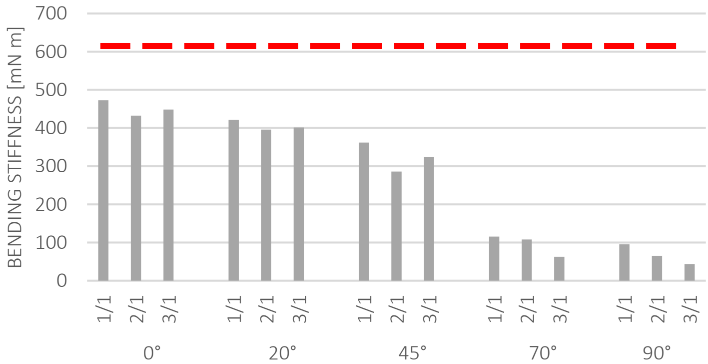
3.4. Comparing reference values and measured values

The reference values denote non-perforated specimens of all three different qualities of three-layer E-flute corrugated cardboard. Non-perforated specimens were tested and the results were compared with those of perforated specimens. Difference between reference values (dashed line) and measured values can be seen in Figure 6. The highest differences between the measured and reference values are seen at an angle of 90°, while the lowest differences occur at an angle of 0°. The highest loss of bending stiffness is observed for the combination of quality 111 with perforation type 3/1 at an angle of 90° (94.89%), while the lowest loss of bending stiffness is observed for the combination of quality 177L with perforation type 1/1 at an angle of 0° (11.49%).

a)
quality 111



b)
quality 177



c)
quality 177L

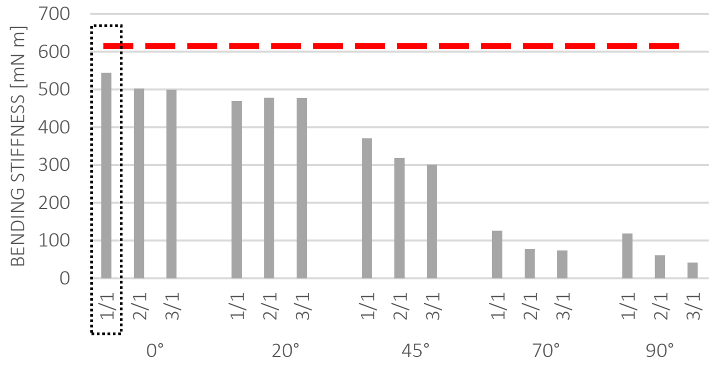


Figure 6: Loss of bending stiffness for qualities labelled: a) 111; b) 177 and c) 177L;
** red dashed line in Figures a, b, c) represent bending stiffness of reference specimen*

4. DISCUSSION

Three explanatory variables are used to explain the variability of a measured property of bending stiffness. All possible combinations were tested: three levels of the variable Type of perforation, five levels of the variable Angle of perforation position, and three levels of the variable Quality of perforated corrugated cardboard. In total, 45 test specimens were involved. Different combinations were tested to investigate the relationship between the perforation variables and the loss of bending stiffness and to identify the most influential variable. Differences in the main effect in variable Type and in variable Quality are visible, i.e. quantitative, but not qualitative. The most significant differences are seen and confirmed between the variable Angle of perforation position (Figure 4); consequently, the variable Angle is the most influential among the explanatory variables (F 1019.82 $P < 0.0001$). The trend in measured values between all qualities of corrugated cardboard was obvious: the values decrease as the angle of perforation position increases (Figure 6). All perforation types had the lowest influence on loss of bending stiffness at angles 0° and 20°. The loss of bending stiffness is less than 36% at these two angles. The greatest influence on the loss of bending stiffness was at an angle of 90°. The values at an angle of 70° were close to the values at an angle of 90°, where at both more than 80% of the loss was seen. Quality labeled 177 has the lowest measured values (Figure 5), which is related to the lowest thickness (Table 1), since the bending stiffness depends on the thickness of the material. The differences between the measured values for Types of perforation are not high, however the type with the smallest cut in the perforation line labeled 1/1 had the highest measured values, as expected.

5. CONCLUSIONS

Perforation lines are used for transforming packaging into shelf-ready trays. These lines must not compromise the structural integrity of the packaging, i.e., the packaging must remain safe and strong enough to withstand the stresses of handling and transportation. Bending stiffness, as a basic structural property of corrugated cardboard intended for packaging, was tested for selected material with different perforation combinations. The three-point bending test was performed for specimens prepared in direction MD, on different three-layer E-flute corrugated cardboards with various perforations at defined angles. The bending test is used to evaluate the protective capability of the package and by determining which variable has the greatest influence on reducing bending stiffness, it helps in the development of SRP to ensure the strength of the box during transportation. Statistical analysis has revealed that among the explanatory variables: Type of perforation, Angle of perforation position and Quality of perforated corrugated cardboard; the variable Angle of perforation position had the greatest effect on bending stiffness. Perforation at 90° has the greatest effect in decreasing bending stiffness, regardless of the quality of the corrugated cardboard or the type of perforation. When angled perforation lines are used, we recommend that an angle lower than 45° should be selected, while perforation lines in CD should be used as minimum as possible or should be used in conjunction with thicker board.

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BIO COATING AS AN ALTERNATE FOR WAX COATING FOR FOOD GRADE PAPER BOARDS

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Abstract: *1.45 million tons of paraffin wax-coated boxes of used products enter landfills every year, and 4.5 million metric tons of carbon dioxide is released during the recycling process. Therefore, the goal of the research is to find out an alternative to the synthetic wax coating seen on food product cartons. This research uses natural coating materials that are more effective than synthetic coating materials, such as hibiscus, gum Arabic, and turmeric. The natural antibacterial herb turmeric's curcumin is extracted using ethonal, and then heating is used to create the hibiscus extract.*
Three layers are coated on the package: the first layer is curcumin, which serves as the package's antimicrobial coating; the second layer is gum Arabic, which serves as a binder to hold the third layer of hibiscus. These two layers serve as a barrier on the packaging, and then the hibiscus extract gel is applied over them. Using a spray gun, these three coats are applied to the packaging. The method used to dry the coatings is air or sun drying.
The test findings are assessed for the burst strength, burst factor, moisture content, smoothness, calliper thickness, and micropsoic analyses of the wax coated and bio coated carton samples.

Keywords: bio-coating, paper board, natural coating

1. INTRODUCTION

The use of petroleum-based derivatives as coatings, such as polyethylene, waxes, and/or flour derivatives, typically regulates the barrier resistance and wettability of sheets. Although using these polymers increases surface hydrophobicity, their unfavourable environmental effects, low recycling capabilities, and environmental worries over creating trash without biodegradation have caused them to lose favour. Alternatively, novel methods for entirely bio-based paper coatings can be developed using biopolymers such as polysaccharides, proteins, lipids, and polyesters. However, the majority of biopolymers may have processing issues because of hydrophilicity, crystallisation behaviour, brittleness, or melt instabilities that prevent complete commercial use. Therefore, it is preferable to blend with other biopolymers, plasticizers, and compatibilizers to enhance the coating performance. The production of bio-based polymersand their composites as paper coatings will be explored, as well as their barrier qualities. Specifically, there are three layers of coating that may act as stability to the paper board, and turmeric is being utilised because it has antibacterial properties. The first layer of paper may have some microorganisms, and the layer of turmeric coating can kill those microbes. Then, the creation of a gum Arabic coating and a hibiscus coating may come next. These layers have binding properties and contribute some waterproofing properties, and the board will also have increased stability and operate as a barrier control. This bio-coating is environmentally friendly, economical and gives excellent results (Piselli et al., 2014).

2. LITERATURE SURVEY

In this section, properties of curcumin and Gum Arabic components for bio-coatings are discussed and presented below,

2.1 Impact of curcumin formulation on its antimicrobial activity

A hydrophobic, yellow-orange substance called curcumin is obtained from the Curcuma longa plant. However, due to its limited water solubility, it is less bioavailable and cannot be used in industry. To increase curcumin's water solubility and dispersibility and enhance its biological effects, it may be changed via micro/nanoencapsulation or nanonization (transformation in nanometric crystals) procedures (Gul & Bakht, 2015). Encapsulated curcumin may also be used as a preservative on foods to lengthen the shelf life of the food product.

2.2 Functional properties of gum Arabic

For example, solubility, viscosity, the degree of association with water and oil in an emulsion, and microencapsulation capability are all determined by gum arabic (GA). GA contains powerful anti-oxidant qualities. Due to its protective colloid activity, GA is an incredibly effective emulsifying agent and has found extensive usage in the mixing of oil and water to create food emulsions. The gum provides a smooth surface to frozen goods by controlling the arrangement of ice crystals due to its high water-holding capacity (Ololade, 2018). The use of GA as an encapsulating material for maintenance has been encouraged by its solubility and low-viscosity emulsion characteristics.

3. METHODOLOGY

The aim is to replace the wax coating with bio coating (Ift, 2007) which is made from materials like turmeric extract, gum Arabic and hibiscus extract. Each material was selected for its physical and chemical properties. Turmeric with the molecular formula $C_{21}H_{20}$, contains the major curcuminoids from turmeric (Curcuma longa) of the Zingiberaceae family. It is used for its antimicrobial activity to destroy any microorganisms present in the sample. Then Gum Arabic was used to act as a binder. The high water holding capacity of the gum makes the surface of dry objects smooth. The solubility and low viscosity emulsion properties facilitate the use of GA as encapsulated articles for personal care. Hibiscus is used with a barrier coating that acts as a barrier (Seas, 2014).

3.1 Layer work

The layer work implies about the number of layer of coating being given for the board and the composition of the coating. There are three layers coated one over another layers, first layer is curcumin, second layer is Gum Arabic and third layer is hibiscus layer.

Layer 3: Hibiscus coating (Top most layer)
Layer 2: Gum Arabic coating (glue to adhere layers)
Layer 1: Curcumin coating(in contact with substrate)

Figure 1: Layers of coating

3.1.1 Tumeric extract layer

Curcumin is a component contained in the root of turmeric and can be extracted from the root itself. Extracting curcumin from turmeric is usually not a very simple process. You may need a solvent such as ethanol or methanol to do this at home (Silva et al., 2018). Temperature control may also be required. One simple process to separate curcumin from turmeric is to separate curcumin from turmeric powder. To extract curcumin, you can follow the process below.

3.1.2 Gum arabic layer

Gum Arabic is a complex, fluffy aggregate of sugars and hemicelluloses composed of an arabic acid nucleus related to calcium, magnesium, potassium, and the sugars arabinose, galactose, and rhamnose (Mariod, 2018). It is supplied in mechanically ground or spray dried form. Solubility varies from 2 hours in raw gum form to 20 minutes in spray dried form. The solubility of the granulated instant soluble gum was found to be less than 5 minutes at room temperature compared to the spray dried form which was 20-30 minutes and 2 hours for the mechanically milled gum. The volume is up to 3 times that of the mechanical form. It was concluded that granulation of the gum under water spray significantly increased solubility. Gum Arabic is solid and hardens when mixed with water. The solidified rubber is originally highly viscous (Alkar & Nour, 2017). Then use the same process you did with the first coating layer. After the first coat, the gun should be cleaned. It can then be filled with hardened Gum Arabic. After the first layer dries, a second layer can be applied.

3.1.3 Hibiscus extract layer

Hibiscus powder is made by drying hibiscus flowers until all the moisture is dry. The dried flowers are then powdered. To prepare the extract, mix the powder with water in a 1:2 ratio and heat to 300°C until the water absorbs the powder extract. Then filter the liquid through Whatman filter paper. Therefore, there is no sediment of hibiscus powder compounds in the extract (Yin et al., 2013).

4. COATING PROCEDURE

The coating are applied layer by layer

STEP 1
Curcumin is extracted by mixing with ethanol in a 1:2 ratio, curcumin is extracted by ethanol and the remaining turmeric settles in the soil (Rastogi & Samyn, P, 2015).
STEP 2
Turmeric extract is filled into a spray gun and applied as the first layer in the sample box board
STEP 3
The second layer is a Gum Arabic coating where GA is in solid form and liquefied by soaking in water in a 1:1 ratio. Same procedure as the first layer. A second layer is coated.
STEP 4
Hibiscus extract is prepared with a composition ratio of 1:2 for 15 minutes at 300° C. to extract hibiscus into water.

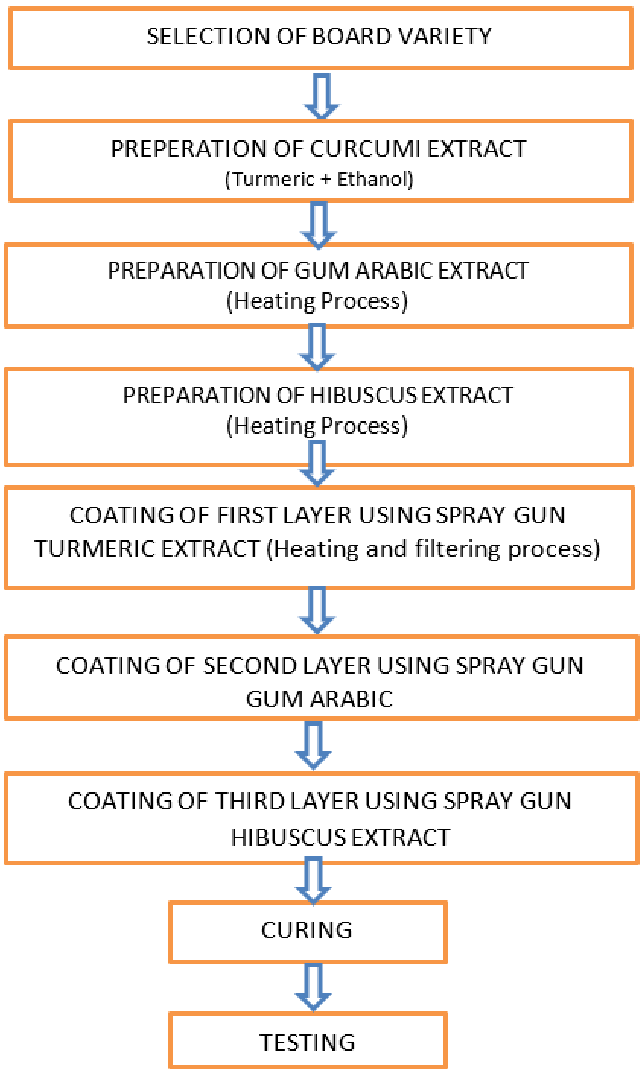


Figure 2: Workflow of coating Preparation

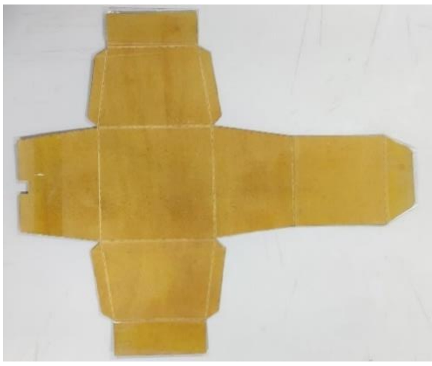


Figure 3: 3 Layer coated Carton

5. RESULT AND DISCUSSION

In this section properties of three types of Baker boards ad Bio coated board are tested their results are given in table 1

Table 1: Testing Results

S.NO.	TEST	RESULTS OF TESTING using 4 types of boards with 400GSM			
		BAKER BOARD1	BAKER BOARD 2	BAKER BOARD 3	BIO COATED BOARD
1	BURST STRENGTH (Kg/cm²)	8	7.5	7.3	8.3
2	BURTST FACTOR	20	18.75	18.25	20.29
3	MOISURE CONTENT (%)	4.1	3.9	3.5	4
4	SMOOTHNESS (seconds)	1600	1500	1300	1100
5	CALIPER THICKNESS (inches)	0.59	0.60	0.52	0.62
6	MICROSCOPIC ANALYSIS	Nano fine granules	Nano fine granules	Nano fine granules	Fine granules

5.1 Burst Strength (Kg/cm²)

A property of paper or paperboard used in packaging measures its tear strength, defined as the hydrostatic pressure required rupturing a sample of paperboard when applied uniformly over its surface. Burst strength is measured with a Mullen tester.

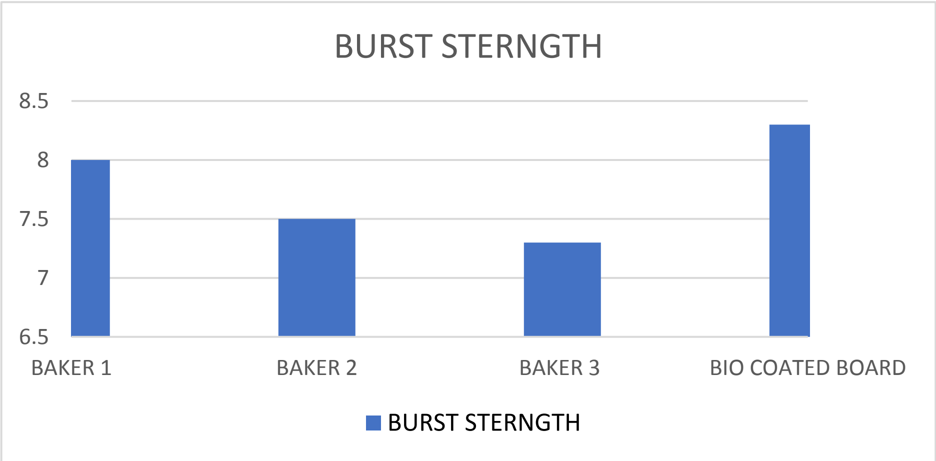


Figure 4: Burst Strength Test

Inference: This test considers three baker's coated paperboard packages along with bio-coated paperboard samples. Bio-coated paperboard gives improved, satisfying and improved results compared to other.

5.2 Moisture Content

Paper moisture varies between 2 to 12% depending on relative humidity, type of pulp used, degree of refining and chemicals used.

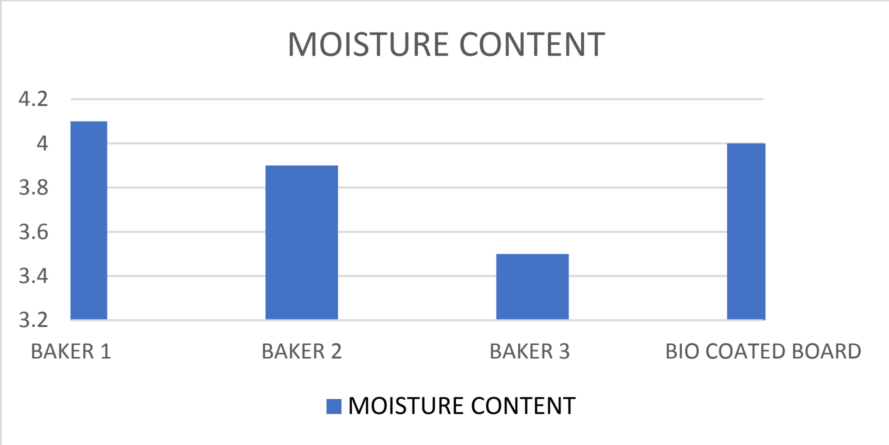


Figure 5: Moisture content Test

Inference: The moisture content of the board was tested at an ambient temperature of 39°C. Also, good results are obtained with bio-coated boards compared to other coated boards.

5.3 Smoothness

The smoothness is a gauge of the irregularities on the paper's surface. Numerous end uses, in particular the aesthetic of printing, are impacted by the feature.

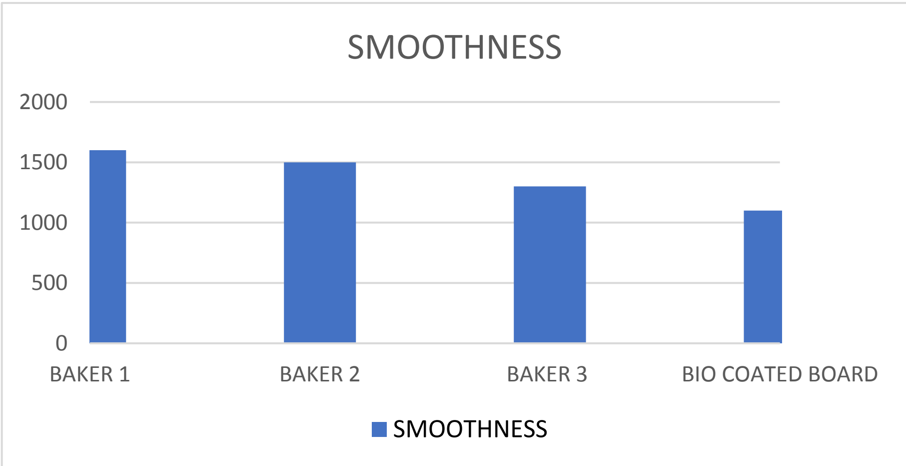


Figure 6: Smoothness Test

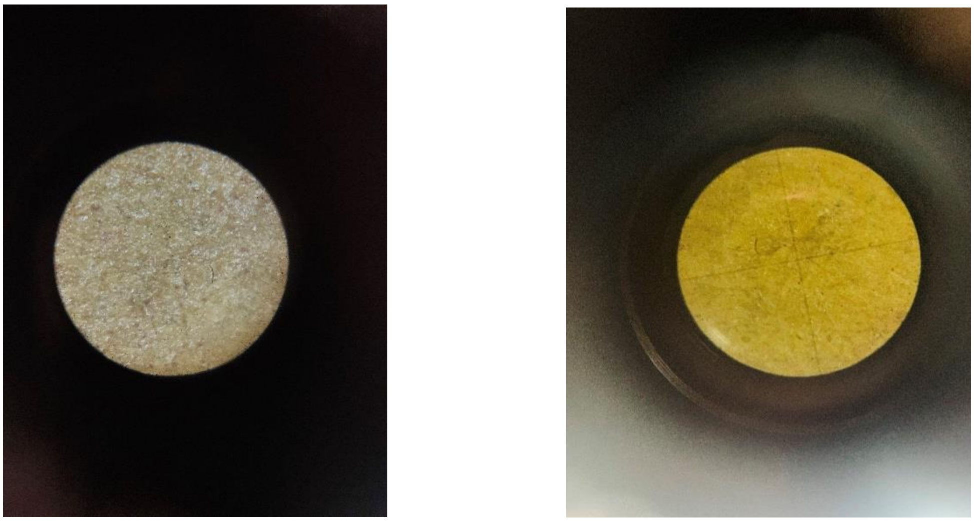
Inference: In a smoothness test compared to three bakers, the bio-coated board shows the smallest result as the wax-coated board contains a particle size of 3 µm. Bio-coated cardboard contains hibiscus granules with a size of 10 µm so it affects the smoothness of the board. But the coating no longer has peaks and valleys.

5.4 Thickness

Thickness is also called caliper. This method describes how to measure the thickness of a piece of paper or cardboard using a synthetic rubber cowl that is soft against the paper to minimize the effects of surface roughness.

5.5 Microscopic analysis

Electron microscopy (EM) is a technique for obtaining high-resolution images of biological and non-biological samples. Used in biomedical research to study the detailed structure of tissues, cells, organelles and macromolecular complexes. High resolution EM images are obtained by using electrons (which have very short wavelengths) as the source of the irradiating radiation. Electron microscopy is used in combination with various auxiliary techniques (thin sections, immunolabeling, negative staining, etc.) to answer specific questions. EM imaging provides important information about cellular function and the structural basis of cellular disease.



(a) *(b)*

Figure 7: Microscopic analysis of the hibiscus granules after coating a) normal filtered coating b) finely filtered granules

6. CONCLUSION AND FUTURE WORK

Therefore, this paper concludes that bio-coated paperboard is more efficient in packaging solid food materials. These paperboards can be used in bakery, solid food packaging, pharmaceutical and grocery applications. The project has been pre-planned and implemented to ensure flexibility and economical operation. This revolutionary coating has made many things desirable and economical. This bio-coating is environmentally friendly and highly promising. This project helps us to understand the importance of natural materials and has great applicability in our daily lives. Compared to wax-coated cardboard used in bakeries, bio-coated cardboard has shown good results during testing.

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PREPARATION AND CHARACTERISATION OF CARBOXYMETHYL CELLULOSE/CARRAGEENAN/JACKFRUIT SEED STARCH BLEND FILM FOR PACKAGING APPLICATIONS

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Abstract: *In this study, carboxymethyl cellulose, carrageenan-based films and a blend film with 1:1 concentration were prepared using the solvent casting method and the influence of various concentrations of jackfruit seed starch (0, 0.5, 1.0, 1.5, and 2 g) on its functional properties were investigated. The effect of jackfruit seed starch on strength properties such as tensile strength and elongation, as well as water-related characteristics such as water contact angle, water vapour permeability, and moisture content, were evaluated and compared with the results of the control blend films. FT-IR, TGA, SEM, XRD were performed to identify the functional group and its potential interactions, thermal stability, surface morphology and crystallinity of prepared films. The results suggests that addition of jackfruit seed starch from 0 to 1.5 g enhanced the tensile strength from 26.62 MPa to 33.26 MPa, but thereafter the tensile strength drops to 32.58 MPa and the elongation decreases. When compared to the carboxymethyl cellulose carrageenan control film, some physical parameters of the film, such as water vapour permeability and moisture content, decreased while thickness and contact angle increased significantly. The results of scanning electron microscopy exhibited rough and heterogeneous morphology for films with more starch content, while the control films exhibited smooth and homogenous structure. The presence of starch increased the crystallinity of all films, which attributed to improved thermal and mechanical stability of the prepared films.*

Keywords: Carboxymethyl Cellulose, Carrageenan, Jackfruit Seed Starch; Packaging Film

1. INTRODUCTION

While plastic has numerous functional applications, humans have developed a dependency on single-use or disposable plastic, which has severe environmental effects. People have been more concerned in recent years about the safety of plastic as a food packaging material, as well as its long-term environmental impact. As a result, scientists are concentrating their efforts on developing new biodegradable packaging materials that provide similar properties to petroleum-based products but with lower environmental implications and manufacturing costs (Ballesteros et al., 2017; Jainan, Deenu & Kamthai, 2018). Biodegradable films made from natural origins have been proposed as a viable substitute to synthetic packaging materials (Pinpru & Woramongkolchai, 2020; Bao, Xu & Wang, 2009). Agricultural waste and products can be used as a matrix material, which can help to reduce pollution levels in the environment (Tavares et al., 2020).

Cellulose is the most common natural resource on the planet, and modified cellulose have extraordinary filmogenic characteristics. Carboxymethyl cellulose (CMC), a modified cellulose which is soluble in water, it is an anionic polysaccharide made by partially replacing the hydroxyl groups in cellulose with carboxymethyl groups (Boontranurak et al., 2020). Because CMC is made up of an aquaphobic polysaccharide network structure connected by numerous carboxylic groups with a high water affinity, it is water soluble (Su et al., 2010). CMC is a promising biopolymer material with good film-forming ability, biodegradability, biocompatibility, non-toxic, and hydrophilic in nature (Ghanbarzadeh & Almasi, 2011).

Carrageenan is a widely used polysaccharide derived from Rhodophyceae seaweed and modified by sulphate. It is made up of repeating unit of disaccharides with alternate α-(1–3)-D-galactose and β-(1–4)-3,6-anhydro-D-galactose (Sun et al., 2018). During the drying process of the film forming solution, the carrageenan forms a compact film due to the creation of a double-helical random coil structure (Shojaee-Aliabadi et al., 2013). To enhance its film-forming property, tensile strength, and brittleness, carrageenan was mixed with various other polymers such as starch (Ghanbarzadeh, Almasi & Entezami, 2010) and sodium alginate (Paula et al., 2015) and reported to have excellent outcomes.

Starch is a low-cost, biodegradable polysaccharide polymer made from a renewable and abundant resource (Tanetrungroj & Prachayawarakorn, 2020). The starch from jackfruit seeds (Artocarpus heterophyllus) is cheap and plentiful all year (Kahar et al., 2019). Starch films reported to have good barrier against gas and lipids characteristics in general (Tongdeesoontorn et al., 2011). When compared to traditional polymeric materials, they have inferior mechanical characteristics and higher water vapour permeability. It is combined with natural polymers such as cellulose and CMC to boost the mechanical property and water vapour barrier property, as well as to maximize its inherent qualities (Pongsawatmanit et al., 2018).

Carrageenan and carboxymethylcellulose blend films had better functional characteristics than its respective control films according to experimental analysis (Hamdan et al., 2019) As a result, there is a greater opportunity to investigate the properties of combination blend films for use as a packaging material. An experiment involving the addition of starch to the carrageenan enhanced the functional characteristics of the control film (Shahbazi, Majzoobi & Farahnaky, 2018). There has been no research on the combination of carboxymethylcellulose carrageenan and starch film, despite the fact that it has a great potential for use as a sustainable packaging material. As a result, the goal of this study is to see how different concentrations of JFS affect the polymer matrix of CMC and carrageenan, as well as to see if this film is suitable for packing applications.

2. MATERIALS AND METHODS

2.1 Materials

Carrageenan (Iota-carrageenan) was purchased from Himedia Laboratories Pvt. Ltd., India and sodium carboxymethyl cellulose from Merck India Pvt. Ltd., India The jackfruit seed was extracted from the ripened jackfruit bought from the local market and manually deseeded. The seed's mucous was entirely removed by intensive washing. The white seed coats and brown spermoderm layers of the seeds were manually removed. The extraction of starch from jackfruit seed was made with reference to experimental procedure outlined by Naknaen, Tobkaew & Chaichaleom (2017).

2.2 Film forming process

The CMC and CAR control films were formulated by solubilising 3 g of each material in 100 mL of deionised water respectively. The film-forming solution CC was prepared by dispersing 1.5 g of CMC and 1.5 g CAR in 100 mL of deionized water with 70^0 C temperature, at 600 rpm revolution for 2 hours using a hot plate magnetic stirrer. The films CCS1, CCS2, CCS3 and CCS4 were prepared by adding JFS with weight of 0.5, 1.0, 1.5, and 2 g respectively to CC film forming solution and continued stirring for 30 minutes. Each of these blend solutions of 100 mL volume was poured onto a glass petri dish of 15 cm diameter. It was allowed to dry for 24 hours at 60^0 C temperature using a ventilated hot air oven and the film was peeled off thereafter. The prepared sample films were kept in the environmental stability chamber with 65% RH and 23^0 C temperature for 24 hours before carrying out each testing.

2.3 Functional Groups

Functional group identification, and its physio-chemical interaction between film forming materials present in the films were determined by Fourier transform infrared spectroscopy (8400 S spectrophotometer, Shimadzu, Japan) and the samples were scanned under a frequency range from 4000 cm^{-1} to 400 cm^{-1}.

2.4 Surface Morphology

The surface morphology of the film was investigated by scanning electron microscopy (SEM) analysis (Tescan, Vega III). The films were sputtered with gold under the vacuum condition and examined at 5 k magnification with 10 microns resolution.

2.5 Thermal property

The thermal properties of the films was determined by a thermogravimetric analyser (TGA, Netzsche 5). A film sample of 2 mg was paced in an aluminium plate and the sample then heated at 10° C/min rate and the changes in mass was scanned within the temperature range of 25° C to 600° C.

2.6 Crystallinity

Crystalline phases of the films were ascertained by using an X-ray diffraction (XRD, Philips X-Pert PRO, 127, Netherlands) instrument with the 40 kV energy, 30 mA current and Cu Kα irradiation (λ= 1.54056 Å).

2.7 Film Thickness and Moisture Content

The film thickness was measured with a digital micrometre (Mitutoyo, Japan) with a precision of 0.1 µm. The thickness value is determined by taking measurements in three random places and calculating the mean of obtained results.

The moisture retention capacity of the film was assessed by employing moisture content test using gravimetric analysis. The pre-cut film sample (2×2 cm) was preweighed and kept at 1050 C for 24 hrs until a constant weight was attained. All the tests were conducted thrice, and the means were taken with standard deviation. Moisture content was calculated by following the equation (Soradech et al., 2012)

$$Moisture\ content\ (\%) = \frac{W0 - W1}{W0} \times 100 \qquad (1)$$

Where W0 is the initial weight and W1 is the final dry weight.

2.8 Water Barrier Property

The water vapour permeability (WVP) of prepared sample films was measured gravimetrically following the ASTM E 95-96 standard as described as follows (Ayana & Turhan, 2009). A clean dry glass vial is filled with 1 g of anhydrous CaCl2 (0% RH) and then covered with the film material to be tested. A sealant was used to prevent any leakage of any moisture across the joints. The prepared vials were placed in a desiccator containing distilled water. The changes in weight of the vial were measured at regular intervals of time and WVP is calculated using the equation below:

$$WVP = \frac{w \times l}{t \times A \times \Delta P} \qquad (2)$$

where, w is the amount of absorbed water (g), l is the average thickness (m), t is the time (s), A is the area of the exposed film surface (m2) and ΔP is the partial vapour pressure difference across the film (Pa).

2.9 Surface Wettability

The surface wettability of the prepared samples was determined by using a contact angle meter (Holmarc, India). The film was mounted on to the sample base and a drop (0.1 µl) of water was released to the film surface by the micro-syringe. At room temperature, the angle of contact (θ) of water droplet was determined.

2.10 Mechanical Properties

The tensile strength (TS) values of the samples were used to determine the sample film's mechanical strength. Elongation at break (EAB) values was used to assess dimensional stability or stretchability. For the experimental investigation, a universal testing machine (H10K-S, Tinius Olsen, UK) with a 100 N load cell and a 150 mm gauge length was used, and the ASTM D882–12 standard was followed. Three samples were used to obtain measurements, and the average values were recorded. The following formulae were used to compute the TS and EAB values:

$$Tensile\ strength\ (MPa) = \frac{F}{A} \qquad (3)$$

$$Elongation\ at\ break\ (\%) = \frac{\Delta L}{L0} \times 100 \qquad (4)$$

Where, F was the Force (N) at maximum load, and A was the initial cross-sectional area (mm2) of the film specimen. ΔL was the difference in length of film at the break, Lo is the original length of the film.

2.11 Statistical Analysis

All tests were run at least three times, and data was collected using the determined mean and standard deviation. The analysis of variance (ANOVA) tool in SPSS software 13.0 was used to do statistical analysis on a completely randomised design. To discover the differences in the means, Tukey B Test was used, and $p<0.05$ was regarded statistically significant.

3. RESULTS AND DISCUSSION

3.1 Functional Groups

The figure 1 represents the FT-IR spectra of prepared films. The spectra of all samples show a wide band around 3450 cm-1 and is corresponding to the hydrogen bonding by the OH stretching vibration, which is considered to be the characteristic peak of materials with high moisture content. In CMC film spectra, the small peak at 2920 cm-1 was due the C-H stretch linked to the hydrogen atoms methane ring (Ma, Chang & Yu, 2008). The transmission peak at 1224 cm-1 was assigned to the development of the sulphate ester group, while the bands at 924 cm-1 and 842 cm-1 were assigned to the C-O stretch of 3, 6 anhydro galactose and the C-O-SO3 stretch of D galactose 4 sulphate stretching of the polysaccharide skeleton, respectively (Akhtar et al., 2018).

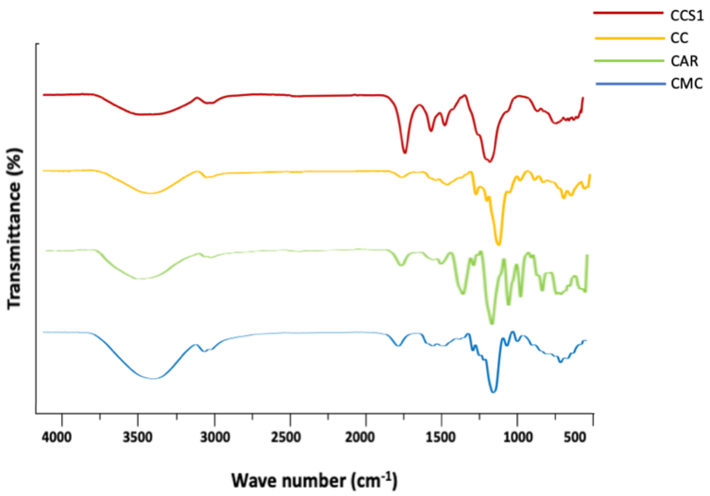

Figure 1: FTIR spectra of CMC, CAR, CC, and CCS

The asymmetric stretching of C-H groups is credited to the FT-IR spectra of CAR control film, which peaks at 1937 cm-1. The asymmetric stretching of ester sulphate groups (O=S=O) is responsible for the absorption band around 1226 cm-1 (Li et al., 2022). C-O-C stretching of 3,6 anhydro galactose and C-O-S stretching of galactose 4 sulphate are represented by the distinctive peaks at 923 cm-1 and 845 cm-1, respectively (Kanmani & Rhim, 2014). CMC-Carrageenan film (CC) does not show any variations in the peak as the FTIR spectra of CMC and carrageenan show similar functional groups.
The starch film (CCS1) is having an intensity of the broad OH bond at 3800 cm-1 - 3000 cm-1 indicates the presence of hydroxyl groups. A single peak found at about 1646 cm-1 is assigned to the strongly bound moisture presence in the JFS structure due to its hydrophilic character (Nzenguet et al., 2018). The peak at 1409 cm-1 and 1433 cm-1 is related to the C-H bending of CH2 and peak at 1240 cm-1, 1299 cm-1, and 1333 cm-1 are linked to O-H bending of primary or secondary alcohol (Van Soest et al., 1995). The intensity bands at 982 cm-1 were associated to C-O stretching
In the blend film CS1, there is a displacement of peak from 1648 cm-1 to 1597 cm-1 by the addition of JFS suggesting a probable interaction with CMC and CAR (Tongdeesoontorn et al., 2011). The inclusion of JFS lowered the water affinity of the produced films by lowering certain characteristic peaks, particularly

peaks associated with the O-H group. As a result of the effect, the water-related properties of the sample films may have a direct influence.

3.2 Surface Morphology

Scanning electron microscopy (SEM) was used to analyse the microstructures of the film to understand the film's smoothness, cracks, and homogeneity. The film sample CC in figure 2(a) shows a smooth homogenous surface without any cracks or pores. This indicates that the CMC and CAR were blended well and do not form any agglomerates suggesting a good intermolecular interaction between CMC and CAR (Ma et al., 2017; Suriyatem, Auras & Rachtanapun, 2019). By the addition of JFS, the film surface shows an increasing heterogeneity nature. The film surface shows a good nonporous structure without much agglomerate for JFS concentration of 1.5 g and above. This suggests a good molecular bonding, which could contribute to improved mechanical and barrier properties (Tavares et al., 2020). The surface of the films with 1.5 g and greater starch concentrations shows some white spots, indicating uneven JFS mixing with the solution. This could be because the solution reached a saturation threshold with 50% JFS concentration (1.5 g).

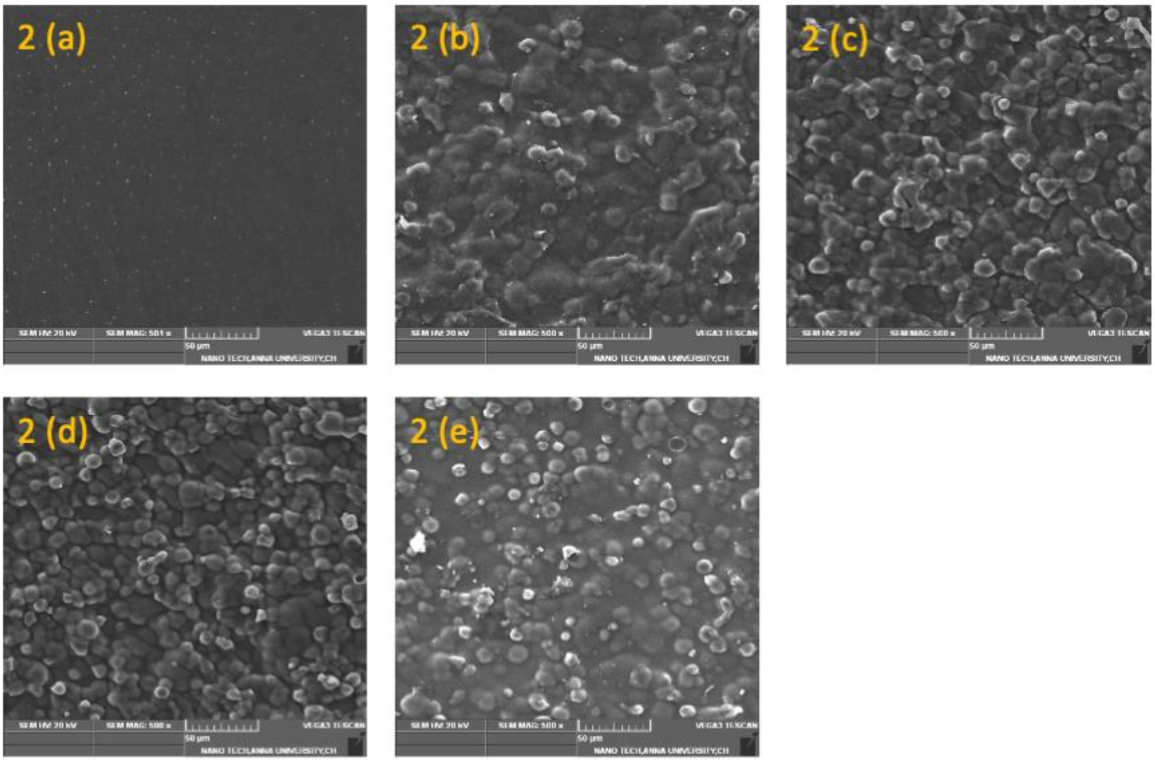

Figure 2: SEM surface structure representing 2(a) (CC), 2(b) CCS1, 2(c) CCS2, 2(d) CCS3and 2(e) CCS4, respectively.

3.3 Thermal Property

Thermogravimetric analysis (TGA) was carried out to evaluate the thermal stability of the films by the addition of JFS. The CC film sample shows three weight loss changes when the film was exposed to heating until 6000 C as shown in figure 3. The evaporation of water absorbed by the material, produced by the breakdown of O-H bond, causes the first weight loss between 600 C and 1200 C (Kanmani & Rhim, 2014; Akhtare et al., 2018). Between 1700 C and 2400 C, the second stage of mass loss starts, which was connected to structurally bound moisture content. The degradation range of most of the polysaccharide thin films occurs in the range of 2400 C –3600 C (Suriyatem, Auras & Rachtanapun, 2019; Jaramillo et al., 2016).

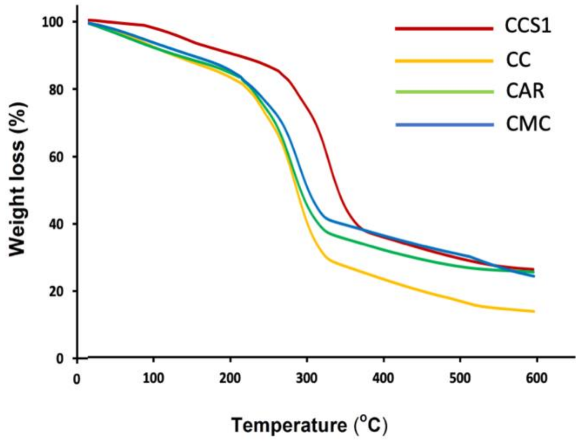

Figure 3: TGA of CMC, CAR, CC and CCS1

3.4 Crystallinity

The X-ray Diffraction (XRD) image of CMC and CAR control films and CC blend films are shown in figure 4. The control film CC displayed a wide peak about 20.00 which reflects the amorphous nature of CMC as well as CAR (Nanaki et al., 2009; Hazirah, Masp & Sarbon, 2016). The broad peak at 51.00 represents a low crystallinity (Ghanbarzadeh & Almasi, 2011). Similar characteristic peaks in XRD pattern were observed in films with a minor peak shift to 21.00 by the addition of starch component (Hazirah, Masp & Sarbon, 2016).

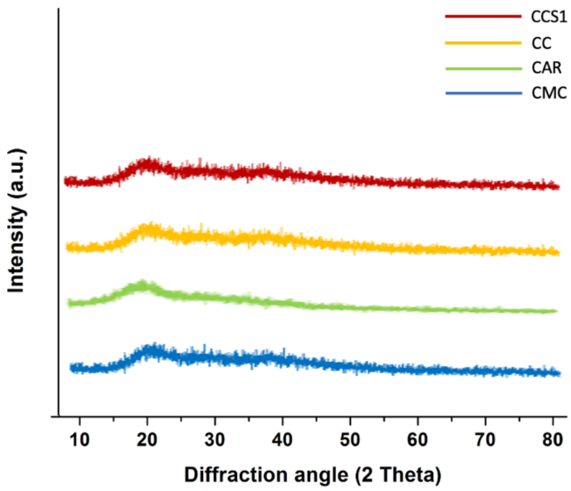

Figure 4: XRD of CMC, CAR, CC and CCS

3.5 Film Thickness and Moisture Content

From the observed values from table 1, the thickness of the control film (CC) is 140.39 μm and the addition of JFS increased the film thickness significantly. The sample film CS1 had a thickness of 148.58 μm and it gradually increases with the increasing concentration of JFS. The highest thickness value was observed for CS4 sample with 158.62 μm. From the inferred data in table 1, it can be concluded that increasing concentrations of starch positively influences the thickness of the prepared films (Shahbazi, Majzoobi & Farahnaky, 2018) .

Moisture content data from table 1, gives the hydrophilic nature of the film and how it was affected by the addition of starch. The inclusion of JFS altered the moisture retention capacity of the film, according to the findings. The film's moisture content decreased from 22.08 % to 10.19 %, and the changes were found to be gradual and significant. The control film CC shows the highest moisture content of 22.08%

(Shojaee-Aliabadi et al., 2013; Ballesteros et al., 2017) compared to all the films with starch content, CCS1, CCS2, CCS3 and CCS4. The presence of active hydrogen and ester bonds created by the hydroxyl and carboxyl groups of CMC with the hydroxyl groups of starch which was responsible for improving the interactions between molecules and the cohesion of the matrix of the polymer blend and there-by decreasing the water affinity of the film (Tongdeesoontorn et al., 2011).

Table 1: Film thickness and moisture content of prepared sample films.

Film Sample	Concentration of CMC/CAR/JFS (g)			Film Thickness (μm)	Moisture Content (%)
	CMC	CAR	JFS		
CC	1.5	1.5	0	140.39 ± 1.12^{e}	22.08 ± 0.53^{a}
CCS1	1.5	1.5	0.5	148.58 ± 1.23^{d}	20.42 ± 0.73^{b}
CCS2	1.5	1.5	1.0	153.44 ± 0.92^{c}	17.55 ± 1.10^{c}
CCS3	1.5	1.5	1.5	155.36 ± 1.01^{b}	14.69 ± 0.77^{d}
CCS4	1.5	1.5	2.0	158.62 ± 0.79^{a}	10.19 ± 0.36^{e}

All data represent mean ± standard deviation; the different superscript letter (a-e) in the same column indicate significant difference ($p < 0.05$). Values are expressed as mean ± SD (n = 3).

3.6 Moisture Barrier Property

Water vapour permeability (WVP) is an imperative parameter for a packaging film as it determines the amount of water vapour transferred between the surrounding atmosphere and the product it packed inside, and hence affects the shelf life of the food product. A biopolymer film with lower WVP is better considered for packaging food products as it limits less passage of water vapour. The control film shows a WVP of 2.85×10-10 g/m·S·Pa. By the addition of 0.5 g of JFS the WVP decreases to 2.94×10-10 g/m·S·Pa, similar observations were also reported in WVP of the film with starch and CMC content (Tavares et al., 2019). Further addition of JFS of 1.0, 1.5, 2 g the WVP decreases gradually from 2.94×10-10 g/m·S·Pa to 3.85×10-10 g/m·S·Pa. The blending of starch into the matrix reduced the WVP of the film due to the chemical interaction between the carboxylic group of CMC with the hydroxyl groups of the starch (Li et al., 2008). This reduced the number of available hydroxyl groups, thus restricted the mobility of water molecules (Kristo & Biliaderis, 2007).

Table 2: Tensile strength (TS), Elongation at break (EAB), and Water vapour permeability (WVP) of film samples

Film Sample	TS (MPa)	EAB (%)	WVP (g/m·S·Pa)	CA
CC	26.62 ± 1.17^{d}	38.33 ± 0.81^{a}	2.85E^{-10} ± 8.5E$^{-12\ c}$	49.56 ± 1.26^{d}
CCS1	29.48 ± 1.04^{c}	23.45 ± 1.21^{b}	2.94E^{-10} ± 9E$^{-12\ c}$	52.49 ± 1.18^{c}
CCS2	31.03 ± 0.75^{bc}	18.94 ± 0.95^{c}	3.26E^{-10} ± 7.5E-$^{12\ b}$	53.72 ± 0.93^{c}
CCS3	33.26 ± 0.94^{a}	17.54 ± 1.25^{c}	3.32E^{-10} ± 1.1E$^{-11\ b}$	56.54 ± 1.00^{b}
CCS4	32.58 ± 1.05^{ab}	17.37 ± 0.93^{c}	3.85E^{-10} ± 1E$^{-11\ a}$	59.31 ± 0.99^{a}

All data represent mean ± standard deviation; the different superscript letter (a–d) in the same column indicate significant difference ($p < 0.05$). Values are expressed as mean ± SD (n = 3).

3.7 Surface Wettability

The surface wettability of the sample films was evaluated by the contact angle study. As shown in table 2, wettability of the sample film is decreasing with the increasing amount of JFS. The control film shows a contact angle of 49.560, similar observations are also reported in studies of CMC and CAR based packaging films (Ballesteros et al., 2017; Yadav & Chiu, 2019). Incorporation of JFS of different concentrations resulted in an increased contact angle and reached to 59.310 for CCS4. The increased contact angle value was due to the functional groups of CAR, CMC, and JFS interact through hydrogen bonds, which provided more stiffness for the prepared films and lower hydroxyl groups on the surface (Shahbazi, Majzoobi & Farahnaky, 2018) . This impact due to hydroxyl group deficiency can also be seen in the observed values of WVP results, where the WVP drops significantly when JFS concentration was increased gradually.

3.8 Mechanical Properties

Mechanical properties such as tensile strength (TS) and elongation at break (EAB) are very important parameters for a packaging film, as it determines the strength and stretchability of the material. Table 2 shows the TS and EAB values obtained for the film samples. The CC control film shows a TS value of 26.62 MPa and EAB of 38.33%, which concurred with similar experiment (Hamdan et al., 2019). By the addition of 0.5 g, to 1.5 g of JFS, the TS increased from 29.48 MPa to 33.26 MPa and the EAB value decreased from 23.45% to 17.54% respectively. The increased strength might be due to the increase in the intermolecular interaction between the CAR and the JFS, as starch molecules have affinity to create molecular bonding with CAR (Abdou & Sorour, 2014). The TS dropped for CCS4 with 2 g JFS, possibly due to increased solid content above the saturation point as seen in SEM examination. Similar experiments found that when the amount of starch in the mixture increased, the strength characteristics reduced (Roy & Rhim, 2020). The lower EAB values suggest that the film stiffened at the highest concentration of JFS and became more dimensionally stable when the JFS concentration was increased.

4. CONCLUSIONS

The carboxymethyl cellulose, carrageenan- based functional polymer films with various concentrations of jackfruit seed starch were prepared by the solvent casting method. The addition of jackfruit seed starch influenced the physical and functional properties of the prepared blend films. The tensile values improved by the addition of starch up to a concentration of 1.5 g, beyond that the tensile strength decreases. The SEM images explain this tendency in the mechanical property as the analysis show a complex heterogenous structure beyond 1.5 g concentration of jackfruit seed starch. The results show that the thickness and contact angle of the film were increased whereas the water vapour permeability and moisture content were reduced, which implies an increase in water barrier properties. The XRD analysis shows an increasing crystallinity for the film with starch content, whereas TGA analysis shows an improved thermal stability for film with starch content. The results shows that carboxymethyl cellulose carrageenan jackfruit seed starch ternary blend films can be used as an assuring substitute for synthetic polymer-based single use packaging material.

5. CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DEVELOPMENT OF NEW UV LED CURABLE INKJET VARNISHES

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Abstract: *We have prepared three UV curable varnishes for inkjet printing that can be cured by UV LEDs (365–395 nm). The advantages of UV LEDs compared to medium pressure mercury lamps (conventional source of UV radiation) are lower energy consumption, possibility of immediate switching on/off, no IR radiation, no ozone generation and are mercury free. UV LEDs cannot effectively (or at all) cure formulations designed for mercury lamp curing. Developed UV varnishes enable the creation of special varnish effects on printed substrates (including 3D) thanks to partial curing with UV LEDs. Evaluated properties of prepared varnishes were viscosity, surface tension, reactivity, long-term stability and printability. The printing properties of prepared UV curable varnishes were tested on commercially available inkjet printing machine (Spotmatic 36, KOMFI). The cured varnish layers (thickness 20 and 40 μm) were evaluated in terms of mechanical properties (adhesion, elasticity) and optical properties (yellowness). Namely, the study of mechanical properties included the evaluation of adhesion by Tape test, quality of the varnish layer with respect to cutting and grooving, and elasticity/adhesion of grooved varnish layers after folding (180 °). Results showed that prepared UV LED curable varnishes have very good elasticity and adhesion to various printing substrates and enables further trouble-free mechanical processing of varnished products, such as cutting, grooving or bending.*

Key words: inkjet, varnish, UV LED, curing, mechanical properties

1. INTRODUCTION

UV curable inks and varnishes are often used in the printing industry due to the advantages that these inks/varnishes exhibit. The most significant advantage includes very fast curing (for radical polymerization it is a fraction of a second), which allows immediate processing of the printed materials in the finishing. UV curable inks/varnishes have very good chemical and abrasion resistance. From the point of view of mechanical properties, the cured layers can be flexible or, on the other hand, very hard, depending on the choice of binder system (mixture of reactive monomers and oligomers). A significant advantage is also the lower energy consumption needed for curing compared to inks/varnishes drying by solvent evaporation. UV curable inks/varnishes can be used to print a wide range of materials, such as various types of papers, cardboards, plastics, metals, etc. UV-curable inks/varnishes are used in almost all printing techniques, most often in offset printing, flexographic printing, screen printing and inkjet printing.

Inkjet printing has become the major printing technology for sign and display applications, as are posters, billboards, etc. The using of UV curable inkjet systems is the fastest growing technology within this segment (Mondt & Graindourze, 2015). According to Smithers Pira, the UV inkjet printed products market sector was forecasted to reach almost 16 billion USD (in 2008 it was 4 billion USD) (Lee, 2015). The CAGR (Compound Annual Growth Rate) for UV inks sales between 2007 and 2020 was + 4.5 % (Engberg, 2021).

Two curing mechanisms may be used to polymerize UV curable formulations. The more often used is free radical polymerization and the second one is cationic polymerization. Free radical polymerization currently predominates because of its low cost, wide selection of usable components (monomers, oligomers, and photoinitiators) and faster curing (fraction of second). The main disadvantages of free radical polymerization are mainly oxygen inhibition and lower adhesion to common polymeric substrates, as are PE, PP, or PET. Compared to this, cationically polymerizable systems are not inhibited by oxygen and their adhesion to polymeric materials is generally higher. The disadvantages lay in higher cost of ink formulations, slower curing speeds (final properties of the cured film are achieved within 24 hours after UV exposition depending on ink/varnish formulation, UV dose/irradiation and ambient conditions) and inhibition caused by impurities as bases and high humidity (Green, 2010).

Hybrid polymerization is formed by a combination of free radical and cationic polymerization. Both mechanisms can run simultaneously or consequentially. Ink formulation contains typically both types of monomers/oligomers polymerizable by free radical or cationic mechanism and photoinitiators starting both polymerization reactions. Main advantages of hybrid polymer systems consist of combination of the properties of the constituent polymers, increased curing speed, faster development of the final properties of cured films, lower sensitivity to inhibition by air oxygen and improved mechanical properties of the produced films (Jašúrek, 2008; Lin & Stransbury, 2003).

There are a lot of parameters that need to be considered in the UV inkjet ink/varnish formulation. Among the main problems belongs the choice of suitable monomers/oligomers according to the final mechanical film properties, their reactivity, compatibility, toxicity and viscosity. Inkjet inks/varnishes have lower viscosity than conventional flexography, screen or offset printing inks. Typically, the optimal viscosity of UV inkjet inks for industrial printing heads is between 10 and 15 mPas at 40 °C (Mondt & Graindourze, 2015). Due to the low viscosity and small volume of drops ejected from the printheads, the atmospheric oxygen can easily diffuse into inks/varnishes causing serious problems with surface curing. Other parameters that must be considered when formulating inkjet inks are optimization of initiation system, optimization of formulation with additives (in the case of inks also addition of pigments/dyes), curing speed, oxygen/base inhibition, adhesion, long-term stability, printing quality/stability, yellowness (important mainly in UV-LED curing of varnishes), etc.

The most commonly used radiation source for curing of UV curable inks and varnishes are medium-pressure mercury lamps. They are relatively cheap and are produced in various lengths and outputs. Another advantage is emission of UV radiation in the form of emission bands throughout the UV region (UV-A, UV-B and UV-C). Disadvantages include short lifetime (approximately 1500 hours), produce large amounts of infrared radiation, need to be cooled, produce ozone and contain toxic mercury. Relatively new source of UV radiation are UV-LEDs (diodes emitting radiation in UV region). UV-LEDs began to be used in printing industry about 15 years ago. The advantages of UV LEDs compared to medium pressure mercury lamps are lower energy consumption, possibility of immediate switching on/off, no IR radiation, no ozone generation and are mercury free. Disadvantages include higher cost and radiation emission in a narrow region of the spectrum (emission band width around 30 nm). UV LEDs cannot effectively (or at all) cure formulations designed for mercury lamp curing and inks/varnishes have to be reformulated for curing with UV-LEDs.

The aim of this work was to develop hybrid UV LED curable inkjet varnishes with better mechanical properties (higher adhesion and elasticity) than commercially available ones (free radically polymerizable).

2. MATERIALS AND METHODS

Prepared hybrid inkjet varnishes (3 modifications) consists of acrylate, oxetane, and vinylether monomers. The initiation system consists of initiators and sensitizers of free radical and cationic polymerization. Additionally, stabilizers of premature polymerization for each polymerization mechanism and wetting agent were added. First prepared hybrid inkjet varnish (HV1) is partially cured by UV LED (365, 385, or 395 nm) and final curing is ensured by UV exposition with medium pressure mercury lamp. Another two hybrid varnishes (HV2 and HV3) are fully cured with UV LED sources (365, 385, 395 nm).

The hybrid inkjet varnishes were compared with two commercially available ones. The first varnish is K-flex UVV H-cure from the company Kao Chimigraf (cured by medium pressure mercury lamp) and the second one is KomfiFlex LED Alfa N varnish from company Nazdar Ink Technologies (cured by UV LED or medium pressure mercury lamp). A matt laminated cardboard (polypropylene foil) was used as the printing substrate for printing and evaluating of mechanical properties of varnishes. The surface free energy of the printed material was adjusted by corona treatment (38 mN/m).

Surface free energy of varnishes was evaluated by Du Noüy Ring method with tensiometer K6 (Krűss). The measurements were performed at room temperature (22 °C). The measurement accuracy is 0.5 mN/m. The rheological properties of varnishes were measured by rheometer RotoVisco 1 (HAAKE) at 40 °C with measuring system DG43 up to the shear rate 3 000 s^{-1}.

Inkjet varnishing machine Spotmatic 36 (KOMFI) was used for printing of all tested varnishes. As UV sources were used UV-LEDs emitting at 365 nm or 395 nm (Shenzhen Bird UV Technology, irradiance 10 W/cm^2 and 16 W/cm^2 respectively) and medium pressure mercury lamp (120 W/cm). The thickness of the printed layers was 20 and 40 μm.

From the mechanical properties were evaluated the adhesion of printed layers to matt laminated cardboard by Tape test (Tesa tape 4104), the quality of the varnish layer after cutting, and adhesion/elasticity of varnish layer after grooving by machine GPM 450 SA (Cyklos Choltice) and bending varnish substrate at the point of the groove by 180°. The grooving tool had a U profile (depth 0.7 mm, width 1.4 mm).

Optical properties (yellowness) were evaluated by spectrophotometer X-Rite 530. Measured parameters were L^*, a^*, b^* coordinates of CIELAB colour space. From these coordinates was calculated the colour difference ΔE (Equation 1). The reference material for the calculation of ΔE^* was white paper with laminating film made of PP, which was used for printing of varnishes.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

ΔL^* is the difference of coordinates L^* of the measured sample and the reference
Δa^* is the difference of coordinates a^* of the measured sample and the reference
Δb^* is the difference of coordinates b^* of the measured sample and the reference

3. RESULTS AND DISCUSSION

Three inkjet varnishes polymerizing by hybrid mechanism (combination of free radical and cationic polymerization) were prepared. The first one (HV1) is partially cured by UV LEDs (365, 385, or 395 nm) and the final curing is ensured by exposition with medium pressure mercury lamps. The second one (HV2) and the third one (HV3) are fully cured by UV LEDs.

The surface free energy of the prepared hybrid varnishes was 24.0 mJ/m^2 (HV1), 25.0 mJ/m^2 (HV2), and 24.5 mJ/m^2 (HV3). Both commercially available varnishes have surface free energy 23.5 mJ/m^2.

The dynamic viscosity of all tested varnishes was evaluated in the range of shear rates 100–3000 s^{-1} at 40°C. The dynamic viscosity in all cases slightly increases with increasing shear rate (HV1 10.2–12.1 mPas, HV2 9.1–10.8 mPas, HV3 9.5-11.1 mPas, KomfiFlex LED Alfa N 11.4–12.6 mPas, K-flex UVV H-cure 9.7–11.8 mPas).

The stability of the prepared hybrid varnishes was tested at room temperature for 3 months and at elevated temperature (60°C) for 10 days. The stability of the hybrid varnishes was very good for all samples and only a slight increase in viscosity (1–4 mPas) occurred during testing.

The printing speed differs due to the different need for irradiation to ensure a dry and nonsticky film. HV1 can be printed with printing speed 12 m/min (medium pressure mercury lamp), HV2 with 6 m/min (UV LED 395 nm), and HV3 with 20 m/min (UV LED 395 nm).

The adhesion and elasticity of the prepared hybrid varnishes and two commercially available ones was evaluated by three methods. The first one was Tape test (Tesa tape 4104). Adhesion of varnishes to matt laminated cardboard was tested for layers with thickness 20 and 40 μm.

All hybrid varnishes have very good adhesion to matt laminated cardboard. During the tests, no damage of hybrid varnish layers by Tesa tape 4104 was observed for both varnish thicknesses. In the case of commercially available varnishes, approximately 30 % of the tested samples were damaged (varnish layer 20 μm) regardless of varnish type. When testing thicker layers (40 μm), only a few samples (less than 10 %) were damaged by Tesa tape and the adhesion of commercially available varnishes with this thicker layer was only slightly worse than the hybrid ones.

Second method was evaluation of the quality and adhesion of the varnish layer after cutting. All tested varnishes (HV1–HV3 and both commercially available ones) were undamaged after cutting, but there was a significant difference in adhesion at the edge of cut. The hybrid varnishes (HV1–HV3) exhibited very good adhesion at the edge of the cut (no peel off), while both commercially available varnishes were easily peeled off.

The third method was focused on the evaluation of the adhesion/elasticity of varnished layer on matt laminated cardboard after grooving and bending the substrate at the point of the groove by 180°. After grooving, no peeling off was observed for all tested varnishes. Difference between varnishes was observed after substrate bending. Hybrid varnishes (thickness 20 μm) showed no defect at the groove and bending (Figure 1a). With a thicker layer (40 μm), approximately 25 % of the samples with hybrid varnishes HV1 and HV2 were damaged (slight cracking of the varnish layer or partial peeling off) and approximately 75 % for HV3. The commercially available varnishes (thickness 20 μm) exhibit peeling off after bending (approximately 30 % of samples) and in case of thicker layer (40 μm), peeling off and also cracking of the varnished layer (more than 75 % of samples, Figure 1b, c). The poorest results of adhesion in bending tests exhibits varnish K-flex UVV H-cure from Kao-Chimigraf.

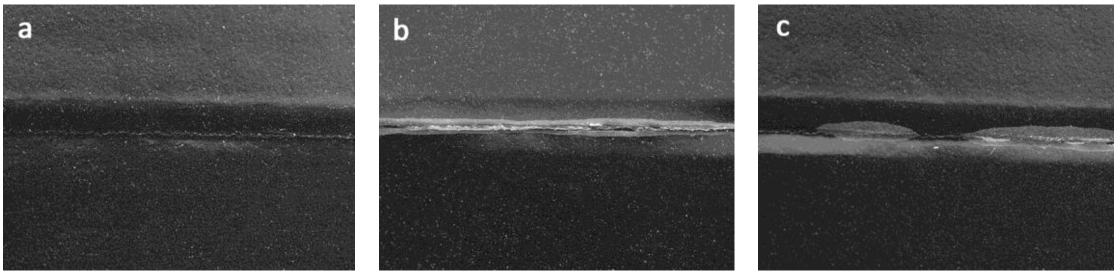

Figure 1: Defects of varnish layer (40 μm) after grooving and bending, a – Hybrid varnish HV1, b – K-flex UVV H-cure from Kao Chimigraf, c – KomfiFlex LED Alfa N from Nazdar Ink Technologies

Yellowness of the prepared hybrid varnishes (HV1 and HV2) was better than the commercial ones. Yellowness of HV1 and HV2 was mostly in range of ΔE^* 2.5–4 (thickness 20 μm) and 4–6 (thickness 40 μm). Commercially available varnishes have ΔE^* around 4–7 (20 μm), respectively 8–11 (40 μm). Hybrid varnish HV3 has ΔE^* 7–8, respectively 14–15. Yellowness of hybrid varnish HV3 is higher and is suitable to use it for printing of thinner layers, approximately till 15 μm. Compared to this, with HV1 and HV2 is possible to create special varnish effects with a thickness of tens (hundreds) of micrometers with low yellow tint (Figure 2).

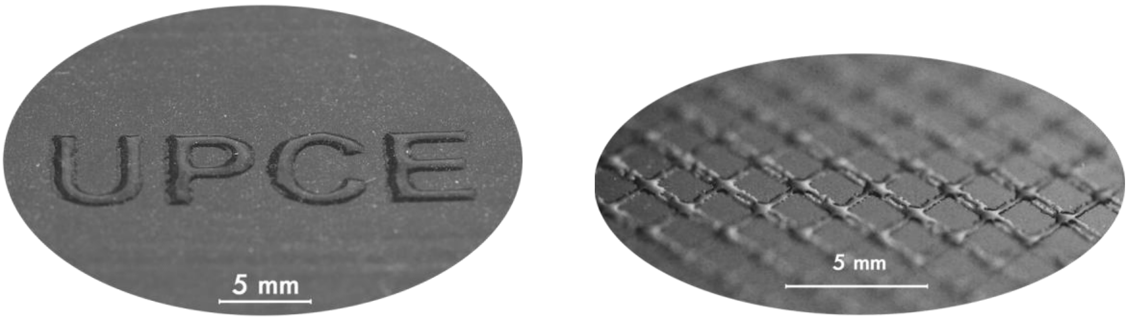

Figure 2: Examples of varnish effects with Hybrid varnish HV1

5. CONCLUSIONS

Three inkjet varnishes polymerizing by hybrid mechanism (combination of free radical and cationic polymerization) were developed. The first one (HV1) is partially cured by UV LED (useful for spot varnishing and creation of special varnish effects and 3D structures) in the range of tens or hundreds of micrometers. Final curing is ensured by exposition with medium pressure mercury lamps. The second one (HV2) is hybrid varnish that can be cured fully with UV LED. The main advantage of HV1 and HV2 is their high elasticity, very good adhesion, and low yellowness. The third one (HV3) is also fully cured by UV LED and its advantage is the possibility to print with high printing speed (20 m/min). This varnish has also very good adhesion. Due to lower elasticity and higher yellowness, it is not suitable for printing thicker layers (> 15 μm). All developed hybrid varnishes have good long-term stability at room and elevated temperature (60 °C) and show stable behavior during printing.

6. ACKNOWLEDGMENTS

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LAMINATION OF ELECTROPHOTOGRAPHIC PRINTS

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Abstract: *Lamination of electrophotographic prints is more problematic than lamination of prints from conventional printing techniques as is for example offset printing. The main problem is worse adhesion of laminating films and due to partial or full delamination can occurs when prints are mechanically stressed. Often problem is also creation of optical effect called silvering. The aim of this work was to compare adhesion of two laminating films (PKCCO BOPP Thermal Laminating Film and Derprosa™ Matte Premier) to prints from different electrophotographic printers (e.g. Xerox, Canon, Konica-Minolta). The lamination conditions were as follows: lamination speeds 10 and 20 m/min, application temperature 120 ˚C and lamination pressure 400 kPa. The adhesion of the laminating film was evaluated by a Peel tester 1 hour, 1 day and 14 days after lamination. The quality of the lamination after the grooving and bending test was evaluated visually. The last measured parameter was colour difference between laminated and non-laminated prints and this parameter was evaluated 1 hour and 14 days after lamination.*

Key words: lamination, electrophotography, adhesion, peel test, colour difference, grooving

1. INTRODUCTION

Lamination is finishing process in printing where thin polymeric film is bind to paper or cardboard mostly by pressure or heat. Lamination of prints is generally used to protect papers/cardboards from general wear and tear, improve the longevity of prints and to improve the appearance of prints. Amorphous thermoplastic polymer films such as polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), polyvinyl chloride (PVC) or others are used for lamination. There are many different types of laminating films differing in appearance (matte, glossy, velvety, textured, holographic, etc.), useful properties (e.g. barrier properties, increase of light-fastness), thickness, etc. Laminating film is bind with prints by adhesive. The used adhesives must meet several basic parameters. In particular, it is a matter of ensuring good adhesion of both materials (print and laminating film), they must be sufficiently clear, flexible and must not react with inks. Four basic types of adhesives are used: hot melt adhesives, dispersion adhesives, pressure sensitive adhesives and UV-curable adhesives.

In terms of technology, there are cold lamination, hot lamination and lamination with using of UV radiation. Cold lamination takes place at room or slightly elevated temperature (usually 30–40 ° C) using pressure sensitive adhesives (dry lamination) or using water-based acrylic adhesives (wet lamination). Hot melt adhesives are used for hot lamination. Hot melts are pre-applied to the polymer films and activated by heating (usually 90–130 °C). Hot melt adhesives are thermoplastic materials that are solid at room temperature (solvent-free) and become tacky when heated. Hot melt adhesives based on EVA (ethylene-vinyl acetate) copolymer are most often used. UV curable adhesives contain reactive monomers, oligomers and photoinitiators. After UV exposition, polymerization reaction starts (mostly free radical polymerization) and liquid adhesive is change to solid-state in fraction of second and connect laminating film with print.

The quality of lamination depends on several parameters, the most important are the settings of the laminating equipment (temperature, pressure, speed), type of laminating film and adhesive, printed product (printed material, type of ink, tone value, etc.) and time between lamination and printing.

Lamination of prints can be accompanied by a number of problems due to the interaction of the laminating films, adhesives, printing inks and the printed materials. Defects can occur both in appearance (e.g. uneven gloss, change of color, silvering) and in the useful properties of the laminated product (insufficient adhesion, cracking, waviness, etc.). If the inks are insufficiently dried, wrinkles may appear immediately after lamination or at longer interval. In addition, components (solvents, dyes, pigments, etc.) of non-dried inks can diffuse through the paper to the other side of the sheet (unlaminated). For porous materials, the adhesive may also diffuse and the sheets may stick together.

Prints from many printing techniques are laminated, such as offset, screen-printing, flexographic printing and also digital printing. Lamination of prints from digital printing presses (especially from electrophotography) is generally more problematic and there are problems mainly with worse adhesion

of laminating films. The result is local/full delamination, which occurs especially in places where prints are mechanically stressed (e.g. grooving, bending, etc.). The reason is a different type of ink (digital electrophotography uses powder toner) and the thickness of printed layer (tens of micrometers in case of electrophotographic print (Schleusener & Volkhard, 2006) vs. few micrometers (Kipphan, 2001) in case of offset or flexographic printing).
The aim of this work was to compare adhesion of two laminating films (PKCCO BOPP Thermal Laminating Film and Derprosa™ Matte Premier) to prints from different electrophotographic printers (Canon, HP Indigo, Konica-Minolta, Xeikon and Xerox). The adhesion of laminating films to prints was evaluated by a Peel tester 1 hour, 1 day and 14 days after lamination.

2. MATERIALS AND METHODS

Seven different printing presses were used for preparation of prints for lamination. They are listed in Table 1 together with used cardboards (all cardboards are coated and their grammage is between 150 and 300 g/m^2). Two sets of printed samples were prepared in case of HP Indigo Press WS6800 (with and without primer DigiPrime® 680). DigiPrime® 680 improves the transfer and adhesion of HP Indigo Electroinks. Figure 1 shows a printing sheet (format SRA3, 320×450 mm) for lamination quality evaluation. The adhesion of laminated sheets for the individual printing presses was evaluated on green strips (30×180 mm).

Table 1: Printing presses and used cardboards

Printing presses	Cardboard (grammage)
Canon imagePRESS C710	Top Coated Graphic$^+$ Silk (200 g/m^2)
HP Indigo Press WS6800	MC Elite 2S-200 FSC (200 g/m^2)
Konica Minolta Accurio Press c3070	MultiArt Silk Matt (150 g/m^2)
Xeikon 8000	Color Copy (250 g/m^2)
Xerox c1000i	MultiArt Silk Matt (150 g/m^2)
Xerox Color C75 Press	Color Copy (300 g/m^2)
Xerox Iridesse Production Press	Color Copy Coated (170 g/m^2)

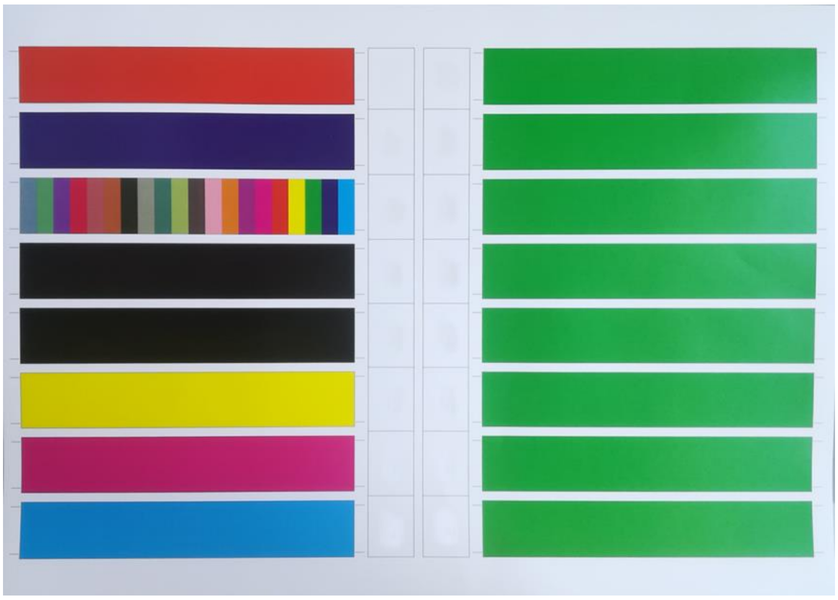

Figure 1: Printed sheet for evaluation of lamination adhesion

Lamination of printed sheets was done with laminator Amiga 52 (hot lamination) from company KOMFI. Two lamination films were used. First one is Derprosa^{TM} Matte Premier (thickness 35 μm) that is mostly used for lamination of electrophotographic prints. Second one was PKCCO BOPP Thermal Laminating Film

(thickness 24 μm) mostly used for lamination of offset printings. Conditions of lamination were as follows: lamination temperature 120 °C, lamination pressure 400 kPa, lamination speed (10 and 20 m/min.).
A Peel tester from company KOMFI (software K-UG-02, KOMFI) was used for evaluation of lamination film adhesion. The evaluated parameter was the weight required to peel the laminating film from the printing sheet. Set parameters were as follows: peel-off length 150 mm, peel-off speed 250 mm/min. The adhesion of the laminating film was evaluated 1 hour, 1 day and 14 days after lamination. Eight strips for every printing press were used for calculation of average weight needed for peel off the laminating film. Evaluation of peeling force of a T-shaped bonded assembly of two flexible adherends by a T-peel test is described in ISO 11339:2010 (International Organization for Standardization, 2010).
The grooving of the samples was performed by a grooving machine GMP 450 SA (Cyklos Choltice). The grooving tool had a U profile (depth 0.7 mm, width 1.4 mm).
Color difference (ΔE^*_{76}) between laminated and non-laminated prints was evaluated by spectrophotometer Konica Minolta FD-5 (1 hour and 14 days after lamination). Measured parameters were L^*, a^*, b^* coordinates of CIELAB colour space. From these coordinates was calculated the colour difference ΔE^*_{76} (Equation 1). The reference material for the calculation of ΔE^*_{76} was the non-laminated prints.

$$\Delta E^*_{76} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

ΔL^* is the difference of coordinates L* of laminated and non-laminated sample
Δa^* is the difference of coordinates a* of laminated and non-laminated sample
Δb^* is the difference of coordinates b* of laminated and non-laminated sample

3. RESULTS AND DISCUSSION

Tables 2 and 3 summarize results of Peel test. Measured parameter was weight needed to peel off the laminating film from green strips (see Figure 1). In general, samples from the HP Indigo Press WS6800 printing press (with/without primer) have the lowest adhesion for both laminating film. The use of a primer increased the adhesion of the PKCCO BOOPP Thermal Laminating Film, but in case of Derprosa™ Matte Premier were results similar. Better results of laminating film adhesion were obtained with lower lamination speed (10 m/min). Larger differences between adhesion (lamination speed 10 or 20 m/min) are in case of Derprosa™ Matte Premier laminating film, where at a lamination speed of 20 m/min, the weights required to peel off the laminating film are only in tens of grams (except samples of Canon imagePRESS C710 and Xeikon 8000). At a lamination speed of 10 m/min, the weight required for peeling off the laminating film is most often in the range of 500–900 g.
For Derprosa™ Matte Premier laminating film, larger differences in adhesion were found for different printing presses (best results Canon imagePRESS C710, Konica Minolta Accurio Press c3070 and Xerox Color C75 Press). In the case of PKCCO BOPP Thermal Laminating Film, the results of different printing presses were similar (for both lamination speeds mostly between 400 and 700 g).

Table 2: Average weight (w) required for peel off the Derprosa™ Matte Premier laminating film 1 hour, 1 day and 14 days after lamination, lamination speed 10 and 20 m/min, tested green strips, σ - standard deviation.

	1 hour		1 day				14 days			
	10 m/min		10 m/min		20 m/min		10 m/min		20 m/min	
	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)
Canon imagePRESS C710	907	76	944	55	828	44	967	53	978	54
Konica Minolta Accurio Press c3070	824	44	835	50	46	7	875	33	66	5
Xeikon 8000	588	43	716	43	635	43	743	37	710	35
Xerox c1000i	504	45	511	49	18	6	479	19	40	4
Xerox Color C75 Press	837	65	907	62	86	7	991	60	101	8
Xerox Iridesse Production Press	455	83	743	71	10	4	660	67	32	4
HP Indigo Press WS6800	294	12	209	21	87	14	222	15	117	11
HP Indigo Press WS6800 (primer)	torn film		204	10	96	15	225	14	151	16

Table 3: Average weight (w) required for peel off the PKCCO BOPP Thermal Laminating Film 1 hour, 1 day and 14 days after lamination, lamination speed 10 and 20 m/min, tested green strips, σ - standard deviation.

	1 hour				1 day				14 days			
	10 m/min		20 m/min		10 m/min		20 m/min		10 m/min		20 m/min	
	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)
Canon imagePRESS C710	515	13	406	13	584	12	438	5	660	13	499	11
Konica Minolta Accurio Press c3070	527	9	387	8	596	8	458	15	735	10	523	14
Xeikon 8000	459	18	345	13	576	26	474	13	677	26	560	13
Xerox c1000i	600	26	372	25	687	16	548	18	797	18	444	17
Xerox Color C75 Press	415	29	345	18	484	28	376	11	696	29	494	12
Xerox Iridesse Production Press	612	38	494	27	697	39	513	21	799	38	589	21
HP Indigo Press WS6800	306	23	218	18	340	26	227	8	459	27	272	10
HP Indigo Press WS6800 (primer)	518	20	439	24	601	23	447	7	749	24	523	10

The adhesion of the PKCCO BOPP Thermal Laminating Film increased with increasing time interval from lamination (1 hour, 1 day, 14 days). In the case of Derprosa^{TM} Matte Premier laminating film, the results were similar or the increase was not so significant.

Table 4 summarizes the results of adhesion of PKCCO BOPP Thermal Laminating Film 1 hour and 1 day after lamination (green strips, lamination speed 10 m/min), where laminated prints were before peel test irradiated by medium pressure mercury lamp (160 W/cm, belt speed 10 m/min). Samples irradiated by medium pressure mercury lamp (Table 4) are marked "After Ir.". It is clear from the results that after irradiation, there was a significant increase in the adhesion of the laminating film in almost all printing technologies, with the exception of HP Indigo Press WS6800 (without primer).

Table 4: Average weight (w) required for peel off the PKCCO BOPP Thermal Laminating Film 1 hour and 1 day after lamination (samples irradiated after lamination by medium pressure mercury lamps – "After Ir."). Lamination speed 10 m/min. Tested green strips. σ - standard deviation.

	1 hour				1 day			
	Without Ir.		After Ir.		Without Ir.		After Ir.	
	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)	w (g)	σ (g)
Canon imagePRESS C710	515	13	870	30	584	12	907	35
Konica Minolta Accurio Press c3070	527	9	812	53	596	8	903	54
Xeikon 8000	459	18	673	31	576	26	694	21
Xerox c1000i	600	26	1334	59	687	16	1322	54
Xerox Color C75 Press	415	29	1046	33	484	28	1022	21
Xerox Iridesse Production Press	612	39	1526	78	697	39	1595	54
HP Indigo Press WS6800	306	23	279	18	340	26	345	15
HP Indigo Press WS6800 (primer)	518	20	661	24	601	23	768	29

Tables 5 and 6 show results of grooving of laminated prints for both laminating films. The evaluation of grooving was performed visually according to a five-point scale (0 – no defects after grooving, 1 – minimal (local) silvering at the groove, 2 – slight silvering along the entire length of the groove, 3 – delamination/extensive silvering along the entire length of the groove, 4 – delamination/extensive silvering along the entire length of the groove, which further extends beyond the groove area). Similar behavior was observed for the CMYK process colors and others for the colors (red-R, blue-B, black-K_{CMY}) created by overprinting of process colors. For both laminating films, the CMYK process colors showed less defects and lower damage than the colors prepared by their overprinting. The reason is probably the thickness of the ink layer. In the overall comparison of both laminating films with all printing presses, PKCCO BOPP Thermal Laminating Film shows less defects.

Table 5: Grooving of laminated prints (Derprosa™ Matte Premier), lamination speed 10 m/min, CMYK (process inks), RBK_{CMY} (red, blue, black)

	10 m/min				20 m/min			
	Grooving		Grooving & Bending		Grooving		Grooving & Bending	
	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}
Canon imagePRESS C710	0	0	0	0	0	0	0	1
Konica Minolta Accurio Press c3070	0	0	0	0	0	0	2	3
Xeikon 8000	0	0	0	0	0	0	0	0
Xerox c1000i	0	0	0	1	0	0	2	3
Xerox Color C75 Press	0	0	0	0	0	0	1	1
Xerox Iridesse Production Press	0	0	0	0	0	1	2	1
HP Indigo Press WS6800	0	0	2	4	0	0	3	4
HP Indigo Press WS6800 (primer)	0	0	1	3	0	0	3	4

Table 6: Grooving of laminated prints (PKCCO BOPP Thermal Laminating Film), lamination speed 10 m/min, CMYK (process inks), RBK_{CMY} (red, blue, black)

	10 m/min				20 m/min			
	Grooving		Grooving & Bending		Grooving		Grooving & Bending	
	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}	CMYK	RBK_{CMY}
Canon imagePRESS C710	0	0	0	0	0	0	1	1
Konica Minolta Accurio Press c3070	0	0	0	0	0	0	0	1
Xeikon 8000	0	0	0	0	0	0	0	0
Xerox c1000i	0	0	0	0	0	0	1	1
Xerox Color C75 Press	0	0	0	0	0	0	0	0
Xerox Iridesse Production Press	0	0	0	0	0	0	0	1
HP Indigo Press WS6800	0	0	0	0	0	0	0	0
HP Indigo Press WS6800 (primer)	0	0	0	0	0	0	0	0

The last parameter evaluated was the color changes of CMYK process colors after lamination. Color difference (ΔE^{*}_{76}) was evaluated 1 hour and 14 days after lamination. The measured color differences for both lamination films are given in Tables 7 and 8. For PKCCO BOPP Thermal Laminating Film, the color difference was mostly up to 3. The exception are prints from the Xeikon 8000 printing press, for which the color difference was in the range of 4.1–10.5. The opposite behavior was observed with the lamination film Derprosa™ Matte Premier, where the prints from Xeikon 8000 had the lowest color differences (0.7–1.8). The color difference of other prints ranged from 2.7 to 12.2.

Table 7: Color difference (ΔE^*_{76}) of laminated prints 1 hour and 14 days after lamination (Derprosa™ Matte Premier)

	ΔE^*_{76}							
	C		M		Y		K	
	1 hour	14 days	1 hour	14 days	1 hour	14 days	1 hour	14 days
Canon imagePRESS C710	3.5	3.6	6.7	6.9	7.8	8.1	11.8	12.2
Konica Minolta Accurio Press c3070	3.6	4.1	4.9	5.6	5.9	6.7	8.8	10.1
Xeikon 8000	1.0	1.1	0.7	1.6	1.3	1.8	1.2	1.8
Xerox c1000i	4.0	4.8	4.1	4.9	7.5	8.3	7.7	8.9
Xerox Color C75 Press	2.7	3.0	3.8	4.5	4.7	4.8	4.4	6.9
Xerox Iridesse Production Press	2.9	2.9	4.4	4.8	6.9	7.4	10.2	11.3
HP Indigo Press WS6800	3.0	3.3	3.9	4.4	5.1	5.4	7.4	8.4
HP Indigo Press WS6800 (primer)	3.3	3.5	3.9	4.3	4.4	4.7	7.4	8.8

Table 8: Color difference (ΔE^*_{76}) of laminated prints 1 hour and 14 days after lamination (PKCCO BOPP Thermal Laminating Film)

	ΔE^*_{76}							
	C		M		Y		K	
	1 hour	14 days	1 hour	14 days	1 hour	14 days	1 hour	14 days
Canon imagePRESS C710	0.8	5.1	3.4	3.9	1.6	2.4	0.7	1.7
Konica Minolta Accurio Press c3070	1.0	5.9	0.8	6.7	0.8	3.7	2.5	2.9
Xeikon 8000	4.1	4.1	6.1	6.1	7.8	7.9	10.4	10.5
Xerox c1000i	2.6	2.7	2.3	3.2	1.6	1.8	2.9	3.4
Xerox Color C75 Press	0.9	0.9	1.2	1.6	2.4	2.4	3.0	3.2
Xerox Iridesse Production Press	2.3	2.4	1.0	1.3	2.5	2.7	1.3	1.5
HP Indigo Press WS6800	1.4	1.6	0.4	0.5	0.7	0.8	2.5	2.7
HP Indigo Press WS6800 (primer)	0.8	0.9	1.5	1.6	0.7	0.8	0.9	1.3

4. CONCLUSIONS

The aim of this work was to evaluate the quality of lamination of electrophotographic prints of various printing presses. In particular, the adhesion of the laminating film to prints and defects caused by grooving and bending were evaluated. The measured values of adhesion of laminating films for electrophotographic printing presses show the importance of choosing a suitable laminating film and optimization of the lamination conditions for individual printing presses to achieve sufficient adhesion between the laminating film and prints, which will not cause defects of laminating prints. For each type of laminating film, it is necessary to find suitable parameters of lamination (temperature, pressure, speed) and, if necessary, adjust them for a specific type of print (printer, type of toner).

The best adhesion results of Derprosa Matte Premier laminating film were achieved with prints from Canon image PRESS C710, Konica Minolta Accurio Press c3070 and Xerox Color C75 Press. In the case of PKCCO BOPP Thermal Laminating Film, the differences between the adhesion results of the evaluated printing presses were not large, with the exception of the HP Indigo Press WS6800 without the use of a primer (lower adhesion of the laminating film).

In terms of the color change of the laminated print, DerprosaTM Matte Premier for lamination of prints from the Xeikon 8000 can be recommended and PKCCO BOPP Thermal Laminating Film for lamination of prints from other evaluated printing presses (except Xeikon 8000) can be recommended.

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ACCELERATED PHOTODEGRADATION OF DYE-BASED INK-JET PRINTING INKS IN AN AQUEOUS SOLUTION AND ON A SUBSTRATE

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Abstract: *When studying the process of photodegradation, we often deal with the durability of the individual ink colour components, the durability of the printing material or the durability of the ink on the printing material. Less frequently, ink degradation in the solution is compared to the print. However, it is essential to consider all the crucial external and internal factors that influence the photodegradation process in the context of the durability of printed materials. When studying photodegradation, external factors such as light, temperature and humidity are relatively easy to control. On the other hand, the control of internal factors in the photodegradation process is much more complex since the internal factors are related to the composition of the ink used, the substrate and the physical and chemical processes between them. The study aims to analyse the complex degradation process of prints made with an ink-jet printer compared to the degradation of the same inks in an aqueous solution. The study included two types of paper and an ink-jet printer using dye-based inks. A high-pressure mercury lamp was used to irradiate and accelerate the degradation process, and a specially adapted reactor was used to irradiate solutions and prints. The results showed how short-wave UV radiation significantly influences the changes of the printing material, ink and prints. In some cases, the difference between the ink stability in solution and ink stability on the printing material can be observed. The effect of paper on the durability of the print is, however, negligible in the case of short-wave UV radiation. The process of photodegradation of the paper under UV radiation was mainly manifested by the loss of specific surface and optical properties.*

Key words: UV-C radiation, photodegradation, dye-based ink, ink-jet printing

1. INTRODUCTION

Photodegradation is an interactive process between light and material since this process takes place only when the material can absorb light (Feller, 1994; Steiger & Brugger, 1999). Among the most crucial factors affecting the lightfastness of colourants are dye concentration, degree of aggregation, pigment particle size, chemical and physical structure of the printing material, energy between the colourant and the printing material, spectral distribution of the light source and composition of the atmosphere, including relative humidity as well as the presence of pollutants in the air (Zollinger, 2003).

Light fastness has always been of interest, although the photodegradation process has not been fully explained yet (Zollinger, 2003; Giles, 1965; Padfield & Landi, 1966; Vikman et al, 2005). During irradiation with average daylight, samples are exposed to a broad spectrum of energy levels of electromagnetic waves [Feller, 1994; Wypych, 2008]. Exposure to a more significant proportion of UV radiation leads to accelerated chemical degradation of materials (Aydemir & Yenidoğan, 2018). Many processes accompanying the degradation of organic materials depend on temperature; therefore, the degradation rate is directly proportional to the increase in temperature (Feller, 1994; Blaznik, Gregor-Svetec & Bračko, 2017). Moisture further accelerates the degradation process (Bamfield, 2001; Wypych, 2008). The joint contribution of humidity and temperature is mainly expressed in changes in materials' mechanical properties (Černič, 2008; Fellers et al, 1989). Also, the presence of oxygen in the surroundings negatively affects the degradation process. After all, oxidation is the fundamental reason for the decomposition of organic materials. The combined influence of heat and light forms free radicals that initiate a chain reaction and accelerate materials' deterioration (Feller, 1994).

Prints made with an ink-jet printer represent a complex system in terms of print analysis, as they connect an infinite number of combinations of printing materials, colourants, and other internal and external factors (Jürgens, 1999). The purpose of our research was to study the photodegradation of ink-jet inks in an aqueous solution as well as prints made with an ink-jet printer under the influence of a high-pressure mercury lamp, which was used to accelerate the photodegradation process. Using appropriate analytical methods, we have monitored the colour changes, ink amount and its half-life as well as the substrate's roughness. Consequently, we evaluated the influence of the immediate environment of the ink and dye on the process of degradation.

2. METHODS

The Epson L130 (T2) printer was included in our experimental part, which uses water-based ink-jet printing inks. The printer contains four cartridges with four dye-based primary colour inks.
A sample of individual dye-based ink (C, M, Y, K) was taken directly from the cartridge using the syringe and diluted 1:3000 with water. Four colour fields (C, M, Y, K) with a resolution of 2400 dpi were printed on plain office and permanent paper.
The office paper was labelled PPO and was produced by Officeline under the name Super Quality paper. PPO has a grammage of 80 g/m^2, and according to the manufacturer, the use of paper PPO is versatile. Permanent paper (TPI) with a grammage of 80 g/m^2 was produced by the Institute for Pulp and Paper in Ljubljana and labelled as ICP-PP1. Paper TPI was made in accordance with the standard for durable papers EN ISO 9706 and ISO 11108. According to the ISO 4287 standard, we measured the roughness on the upper side of the paper. A TR2000 profilometer (Time Group Inc. China) was used for measurements.
The high-pressure mercury lamp was used to irradiate water solutions of ink and prints (Figure 1). Due to the heating of the lamp, the lamp was water-cooled. 30 ml of dye solution was poured into the reactor and exposed for 15 minutes to the radiation of the lamp. That approach enabled us to maintain the liquid samples' temperature between 16 and 20 °C, although they were only 2 cm away from the lamp. For the prints, the reactor needed to be modified. Therefore, a stand with an aperture was constructed to ensure a uniform distance from the radiation source and 50 ml of water was added to the reactor to maintain the temperature.

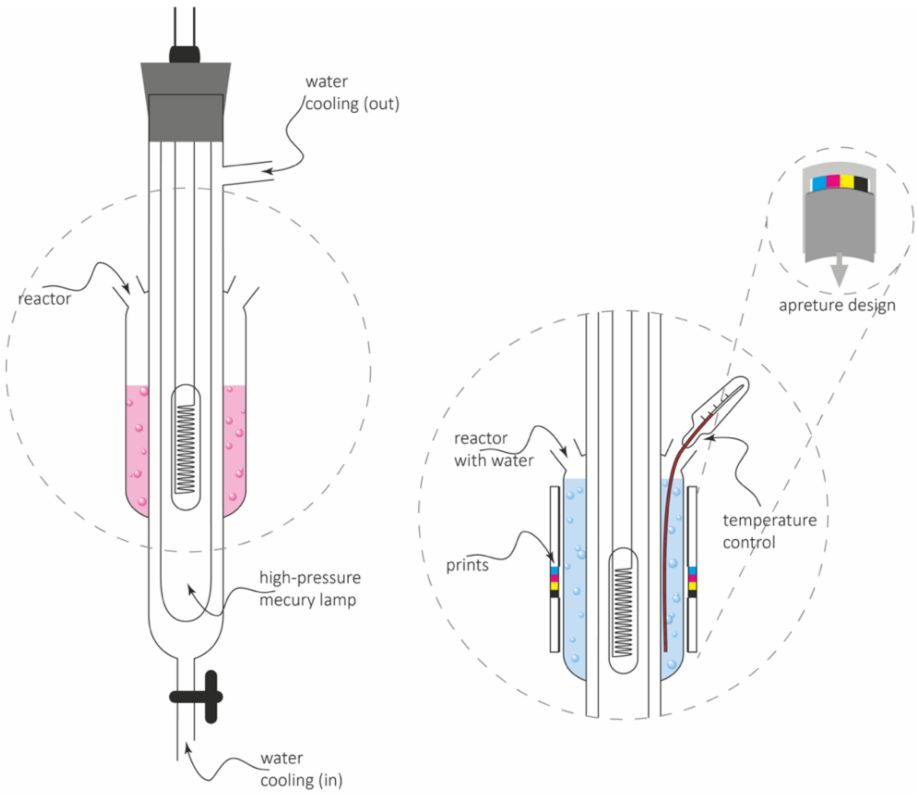

Figure 1: Scheme of reactor during operation of the high-pressure mercury lamp for liquid samples and prints

After the exposure, for the liquid samples, the measurements of absorption in two repetitions in the range between 380 in 730 nm were performed using UV/VIS spectrophotometer Cary 1E (Varian, USA). For prints, the measurements were performed in accordance with ISO 13655 standard on white backing, 45°:a:0° and 10° observer using spectrophotometer iOne (X-Rite, USA). From the measured values of the reflection, the colour differences were calculated using the CIEDE2000 equation 1 (Commision Internationale de L'Eclairage, 2018).

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

The ink amount (IA) in the aqueous solution was calculated according to equation 2. The IA represents ink amount in %, A_i represents the absorption value after the irradiation, and A_0 represents the absorption value before irradiation.

$$IA\,[\%] = \frac{A_i}{A_0} \times 100\,\% \quad (2)$$

According to the Beer-Lambert law, the ink amount (IA) on the substrate was calculated according to equation 3, where the IA represents ink amount in % on the substrate, and R_i represents the reflection value after the irradiation, and R_0 represents the value of reflection before irradiation.

$$IA\,[\%] = \frac{\log\left({}^{1}/_{R_i}\right)}{\log\left({}^{1}/_{R_0}\right)} \times 100\,\% \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Ink-jet ink in aqueous solution

The spectra presented in figure 2 are related to the colour change after irradiation with a high-pressure mercury lamp. Considering the width of the absorption bands, the number of absorption maxima and the previous studies (Blaznik et al, 2021; Blaznik et al, 2022) carried out on these samples, we conclude that the inks included in the survey represent a mixture of different colourants used by the manufacturer to achieve the desired ink properties. From the absorption spectra, we detect a shift of the absorption maxima towards shorter wavelengths in the case of cyan, yellow, and black inks. The absorption maxima decreased most for black ink (18%, λ = 594) and the least for cyan ink (5%, λ =695).

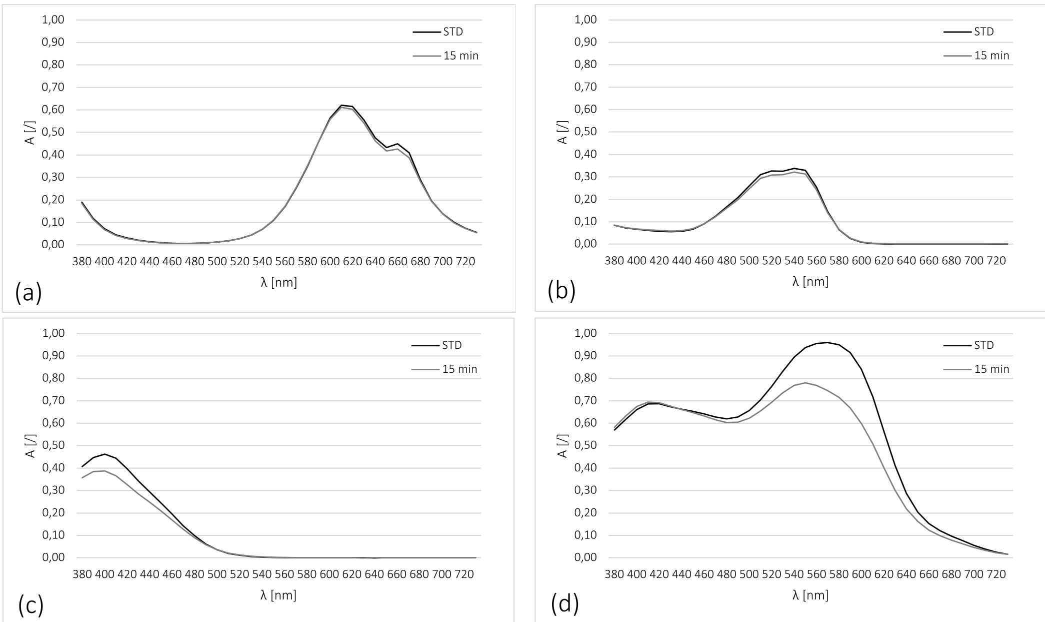

Figure 2: Absorption spectra of cyan (a), magenta (b), yellow (c) and black (d) inks in aqueous solution before (STD) and after 15 minutes of exposure to the high-pressure mercury lamp

The ink amount (IA) in the solution after irradiation was determined using equation 2 (Table 1) based on the absorption values measured. The IA values show that the most significant change after irradiation occurred with the black ink in an aqueous solution, as the amount decreased to 78 % of the initial absorbance.

By monitoring the rate of photodegradation and calculating the slope (k) of the line, the degradation rate and half-life ($t_{1/2}$) were determined (Table 1). According to the results (Blaznik et al, 2021; Blaznik et al

2022), the photodegradation reaction likely follows the pseudo-first-order kinetic model for best fit. The degree of photodegradation was most notable in the case of the black and yellow inks. On the other hand, the degradation of cyan ink was less evident.

Table 1: Ink amount (IA), coefficient (k) and half-life ($t_{1/2}$) of ink samples in aqueous solution under the influence of a high-pressure mercury lamp

	IA [%]	k [s^{-1}]	$t_{1/2}$ [min]
EC	98	–0.0013	533
EM	95	–0.0035	198
EY	84	–0.0118	59
EK	78	–0.0165	42

3.2 Substrate

From figure 3a, we can conclude that PPO paper contains optical brightening agents, which disintegrate after irradiation with a high-pressure mercury lamp. Therefore, changes in the colour of the paper were observed mainly on the b* axis, i.e., on the yellow-blue axis, as the hue of the paper shifted from slightly bluish towards yellow. On the paper TPI (Figure 3b), we detected changes in a broader part of the short-wave spectrum and consequently yellowing of the paper ($\Delta b^* > 2.5$).

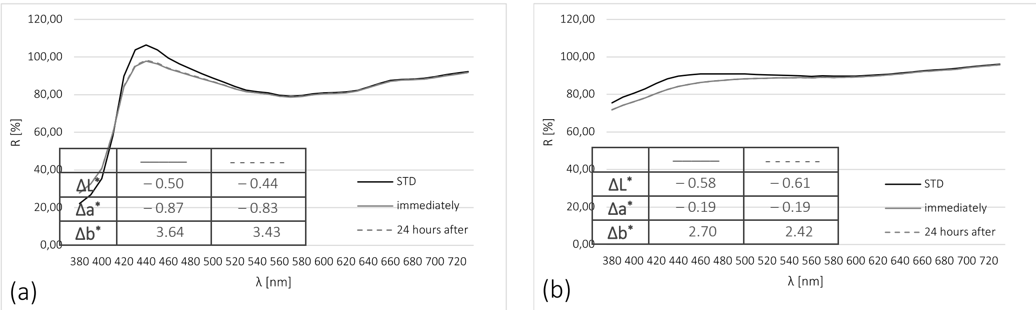

Figure 3: Reflection spectra of office paper PPO (a) and permanent paper TPI (b) before (STD) and immediately after exposure to the high-pressure mercury lamp

Table 2 shows the calculated values of colour differences (ΔE^*_{00}) and roughness (Ra) changes before and after irradiation with a high-pressure mercury lamp for PPO and TPI papers. After 15 minutes of irradiation, more significant differences in roughness were measured for paper PPO. Regarding colour differences, we noticed a slightly more significant difference in colour on paper TPI.

Table 2: Roughness (Ra) of substrate PPO and TPI before (STD) and 24 hours after exposure. Colour difference (ΔE^*_{00}) of substrate immediately and 24 hours after exposure to the high-pressure mercury lamp

	Paper	Ra [/]		ΔE^*_{00} [/]	
		STD	after 24 hours	immediately	after 24 hours
Substrate	PPO	2.92	3.25	1.30	1.21
	TPI	3.12	3.25	1.58	1.43

3.3 Ink-jet ink on substrate

Under the influence of the high-pressure mercury lamp, the so-called bronzing or red shift of cyan prints (Figure 4) occurred. Bronzing of cyan disappeared after 24 hours. The phenomenon of bronzing of prints is usually the result of the dye's structural characteristics and some external factors such as ozone (Bugner, 2002; Fujie et al, 2009), which was a by-product of the operation of the high-pressure mercury lamp. Therefore, the reflection of all prints and substrates was measured twice, immediately after exposure.

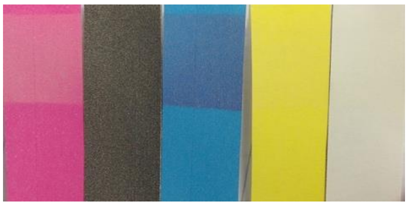

Figure 4: Bronzing of cyan prints

The most representative bronzing effect after UV light exposure is visible on the cyan prints (Figure 5a, b). The comparison of the reflectance curve of different colours (CMYK) on different substates (TPI, PPO) shows that it was not so much dependent on printing material as on colour (Figure 5a–5h).

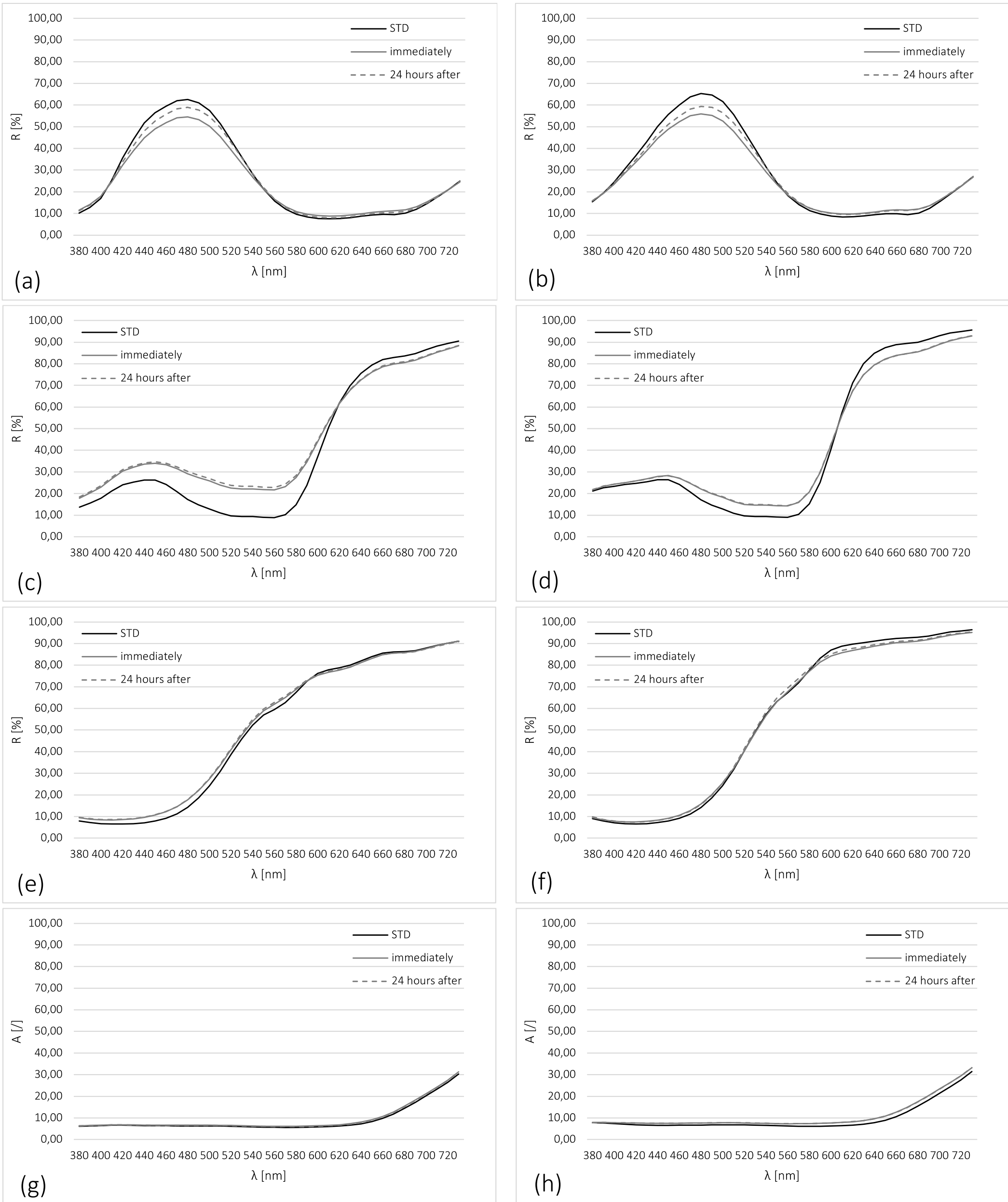

Figure 5: Reflection spectra of cyan (a, b), magenta (c, d), yellow (e, f) and black (g, h) prints on office paper PPO (left column) and permanent paper TPI (right column) before (STD), immediately and 24 hours of exposure to the high-pressure mercury lamp

Table 2 shows calculated values of ink amount (IA) and colour differences for the prints. The IA was calculated according to equation 3. According to the results (Table 2), changes in the value 24 hours after irradiation can be observed due to the bronzing, the most significant changes in IA are observed on the cyan prints. Also, the positive influence of the printing material can be observed since, using a TPI paper, the IA values are higher. Magenta prints are considered the least durable; however, the use of TPI paper gave better results. The decrease of IA on magenta prints is significant both on TPI (IA = 81 %) and even more on PPO paper (IA = 61%).
Regarding the colour differences of the prints (Table 2), we find that, in line with expectations, the most significant colour differences occurred on magenta prints ($\Delta E^*_{00,M,PPO} > 12$ and $\Delta E^*_{00,M,TPI} > 5$). We can also find out how the value of ΔE^*_{00} changed 24 hours after the irradiation. A colour change can be observed, especially on cyan prints, resulting from the bronzing of the cyan print after irradiation with a UV lamp. In the case of magenta prints on paper PPO, notice that the ΔE^*_{00} increased by almost 1 after 24 hours of irradiation. Comparing the colour differences of prints on TPI paper, we can find that ΔE^*_{00} values immediately after irradiation and 24 hours after irradiation are somehow more constant compared to prints on PPO paper.

Table 2: Colour difference (ΔE^*_{00}) of prints on office (PPO) and permanent paper (TPI) immediately and after 24 hours of exposure to the high-pressure mercury lamp

	Paper	IA [%]		ΔE^*_{00} [/]	
		immediately	after 24 hours	immediately	after 24 hours
EC	PPO	94	98	2.27	1.05
	TPI	94	95	2.79	1.42
EM	PPO	64	61	12.04	12.96
	TPI	81	81	5.25	5.47
EY	PPO	91	90	2.16	2.29
	TPI	95	95	1.22	1.09
EK	PPO	97	98	1.15	0.82
	TPI	93	93	2.72	2.65

4. CONCLUSIONS

The degradation process of ink-jet inks in solution depends on internal factors such as the dye's chemical structure, the dyes' catalytic effect and the presence of various solvents in the accompanying liquid. According to the results, short-wave UV-C radiation had no significant impact on the cyan ink in the solution or the prints. However, bronzing of the cyan print indicates that several inter-related processes occur during the exposure to radiation, which can influence the durability of the prints and can also affect the testing procedure.
In an aqueous solution, black ink exhibited inadequate durability, which was probably due to the catalytic effect due to some of the components, as black inks consist of a mixture of different colourants to achieve the desired colour shade. However, the same ink mixture printed on paper did not show as significant colour changes as in a solution.
Surprisingly, the magenta in the solution proved to be relatively stable, but it still holds first place among the least durable inks on the print, regardless of the substrate used.
Therefore, we conclude that when researching the fastness of prints, it is crucial to consider the composition of the ink, which is usually a mixture of several dyes that influence each other and behave unexpectedly in different environments. It is inevitable to consider both characteristics of dye or ink alone as well as its resistance and durability when applied to the substrate.

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THERMOCHROMIC PRINTS ON BEVERAGES PACKAGING: THE RESISTANCE OF PRINTED LABELS UPON ETHANOL

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Abstract: *Today, the packaging industry is increasingly transforming, especially in terms of development of new sustainable materials and smart solutions in order to attract customers when choosing products, and to be competitive in the market. The use of colour changing packaging can give added value to the product since this kind of packaging can in that way interact with the consumer and provide a massage upon the product. During its lifecycle, the packaging can be exposed to the influence of various agents, for example the spilling of beverages over the printed labels. For this reason, the prints need to be resistant to certain agents, in this case, ethanol. In the end, the spill of ethanol can cause visual alterations of the print due to the colourants or the substrate itself not being resistant to the particular agent. Thermochromic inks are widely used as indicators for beverage packaging which can often be exposed to different concentrations of alcohol that may affect the functionality of that same indicator. Thermochromic inks differ in their composition from classic printing inks, which in the end results in lower stability when exposed to UV radiation and various chemicals. Thus, this study explores the influence of ethanol on the functionality of TC prints on labels. Different label papers were printed with one TC ink, with an activation temperature of 12°C. The samples were exposed to different concentrations of ethanol (8%, 12%, 25%, 35%, 42% and 96%) to simulate the real conditions in which it is possible to spill different alcoholic beverages on the thermochromic print on the packaging of an alcoholic product. It can be concluded that alcohol affects the stability of microcapsules even in the smallest concentrations because the largest changes of colour were observed at low temperature, while smaller colour changes determined at 23 ° C indicate that the classic process ink is more stable to the influence of alcohol. The results of this test showed that the chemical stability of the thermochromic print depends on both, the printing substrate and the external conditions to which the print is exposed. The results show that the proper choice of printing substrate can improve the stability of the thermochromic print in reaction with ethanol.*

Key words: thermochromic ink, packaging, labels, alcohol, ethanol, colour difference

1. INTRODUCTION

The design and colour of the packaging have been used for a long time in marketing as a tool for influencing customer purchase behaviour (Shukla et al., 2022). The stability and the quality of the prints on packaging can significantly improve the impression of the quality of the product itself. Also, the role of the colour on the packaging is very often a key factor when choosing a product, and the type of printing substrate can influence a different experience of the printed ink. Today, changes in the behaviour of consumers, are the cause of increased demand for different forms of packaging, for example due to the increase in online shopping but also the increase in the consumption of takeout food and food delivery. In order to meet consumer expectations, packaging should be functional and attractive. Recently, intelligent packaging serves as a medium that provides consumers with the necessary information about the quality and safety of packaged goods. Thermochromic printing inks, which can be applied to a variety of printing substrates, can convey a message to the consumer by changing the colour of the print they see. The use of chromogenic colours, i.e., colours that change their characteristics due to external influences, can intrigue the customer and thereby increase the price value of the product. The concept of thermochromic colours is often associated with the image of a ceramic cup, i.e., a product that uses this phenomenon, which changes colour when a hot drink is poured into it. But today, more and more applications of thermochromic colours appear on different papers and labels that have the role of indicators that provide information about the best consumption temperature of the product or as a design solution that gives the product added value.
Thermochromic materials change their colour depending on the temperature change. Colour changes can be reversible or irreversible. Materials that change colour reversibly are thermochromic pigments based on leuco dyes or cholesteric liquid crystals (Seeboth et al., 2010). Thermochromic pigments based on

leuco dyes generally change from coloured to colourless or to another colour with increase of temperature. Cholesteric liquid crystals show a "colour play effect" passing through the entire spectrum with increasing temperature (Kulčar et al., 2012). Thermochromic printing inks have a rather short shelf life and poor stability. In addition, thermochromic inks have low light fastness (Friškovec et al., 2013; Rožić et al., 2015; Vukoje et al., 2022). Very few studies so far have investigated the influence of different chemicals (chemical resistance) on the stability of the TC print. Jamnicki Hanzer et al. 2020. Showed that exposure of TC prints to ethanol caused severe damage to the prints and the bleeding of the colourants from the prints was also detected (Jamnicki Hanzer et al., 2020).
The aim of this paper is to determine the effect of alcohol ethanol on the stability of the thermochromic prints, as well as to determine whether contact alcohol - thermochromic print gives an immediate reaction of the colour change of the print. Thermochromic prints could be exposed to the effect of ethanol in real conditions during the use of products on which they are applied as indicators, for example cooling indicators for the beverages, and the effect of alcohol alone can cause irreversible changes in the colouring of the print and thus affect its functionality.

2. METHODS

2.1. Materials

Six label papers (manufactured by Brigl & Bergmeister) were selected as printing substrates with properties given by the manufacturer and presented in Table 1. The used printing substrates were chosen for this application precisely because of the properties they possess. The manufacturer claims that the chosen labels are intended for applications that should be resistant to moisture and chemicals, such as alkali. This includes, for example, paper labels for beer bottles as well as many other drinks and foods (sparkling wines, spirits, liqueurs, vodka, gin, as well as for jars of vegetables, fruits or jams). The label paper must not only produce good print results in these applications, but also withstand the external influences that occur during filling, transport, storage or cooling, and use. Used label papers differ in grammage, surface properties, surface treatment, etc.

Table 1: Characteristics of the used papers according to the manufacturer

Label type	Abbreviation	Grammage, g/m^2	Thickness, µm	Cobb 60, g/m^2	Characteristics
Niklakett Special	NKS	68	61	17	functional coating on the reverse side
Niklakett Medium Fashion	NMF	70	73	17	embossed label paper, surface patterns (e.g. linen structures) in combination with the - like fine fabric -
Niklakett Premium	NP	75	64	17	highly polished surface
NiklaSelect	NS	80	65	22	Very well closed surface
Niklakett Brilliant	NB	80	64	17	high gloss and the high smoothness
Chromolux	CHR	80	84	>8	woodfree, cast coated and smooth finished paper

One UV-curing thermochromic printing ink from a commercial manufacturer was used for printing on the printing substrates. The used TC colour changes to a different colour below a certain temperature and when heated. The used TC ink is coloured orange below the activation temperature (TA = 12°C) and changes its colour to yellow when heated above it. The TC ink used is reversible, i.e., the original colour is returned by heating. This TC ink consists of two types of pigments: microencapsulated thermochromic pigments based on leuco dyes and conventional pigments. It can be assumed that the TC colour used was created by adding red leuco dyes (TC microcapsules) to conventional yellow pigments. Thus, while the print is exposed to room temperature (above TA), the thermochromic microcapsules are colourless and the colouring of the conventional yellow pigment dominates. By lowering the temperature, TC microcapsules are activated and they turn red (Figure 1). The combination of the red colouration of the microcapsules and the yellow classic pigment results in an orange colouration of the print.

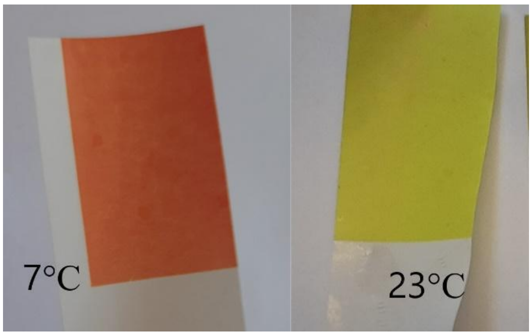

Figure 1: Visual presentation of the print colour change at temperature below TA (7°C) and at temperature above TA (23°C)

2.2. Methods

For the evaluation of printing substrate surface roughness, the MarSurf PS 10 (Mahr GmbH, Gottingen, Germany) surface roughness gauge was used. Measurements were performed ten times in fibre direction.

The assessment of the chemical resistance of TC prints was carried out in accordance with the standard method ISO 2836: 2004. The international standard ISO 2836: 2004 in the area of the printing industry defines the methods of assessing the resistance of prints to liquid and solid agents, solvents, varnishes and acids (ISO 2836, 2004). In this work, the chemical resistance of the prints to water and ethanol was evaluated. In this way, an attempt was made to simulate real conditions, i.e., the spilling of various alcoholic beverages on the print, i.e., the label. The prints were immersed in test tubes containing water and alcohol ethanol concentrations of 8%, 12%, 25%, 35%, 42% and 96%. These concentrations were chosen in order to simulated by different alcoholic beverages, from mild ones like beer and wine to strong alcoholic drinks like brandy or whiskey. The method of testing the chemical resistance of prints to ethanol was carried out by immersion of the print in the solvent in the test tube for a continuous duration of 5 minutes. After the reaction, the samples were air-dried, after which the colour change on the prints was monitored.

Determination of print's colour changes was obtained using a spectrophotometer "OceanView" and software Ocean Optics, which was additionally used for the calculation of CIELAB values, with standard observer 2° and taking into account illuminant D50. The colour of the samples was measured at two fixed temperatures (7°C and 23°C), one temperature below the activation temperature (12°C) and one above. Each sample was heated with a water block (EK Water Blocks, EKWB; Slovenia). From the obtained colorimetric parameter colour differences were calculated using the CIEab (ΔE_{ab}) colour difference formula (CIE Central Bureau, 2004).

3. RESULTS AND DISCUSSION

In order to conclude if surface properties such as surface roughness contribute to the ethanol resistance of the prints, the surface roughness of the used labels was measured. This assumption was derived from the fact that surface roughness affects the printing substrate's affinity for the ink (ink demand) and ink pigment penetration due to formation of temporary fibre-fibre gaps suitable for penetration in the printing nip and subsequent relaxation of fibres to their original state (Eriksen et al., 2007) and from the assumption that higher ink demand will result in the increased ethanol resistance of the prints.

Table 2 presents the results of measured roughness parameters R_a, R_z, and R_{max}. The R_a parameter describes absolute values of the profile heights over the evaluation length and gives a general description of the height surface variations, R_z parameter defines average value of the absolute values of the heights of five highest profile peaks and the depths of five deepest valleys within the evaluation length, R_{max} parameter, indicating the largest single roughness depth within the surface length (Rubert&Co.Ltd, 2022). From the presented results it is evident that two types of used labels (CHF and NB) significantly differ in their surface roughness from the other. NP label has higher surface roughness than the previously mentioned but lower than following NKS and NS, with similar surface roughness around 6.500 µm. NMF label with embossed surface patterns shows the highest surface roughness, as expected. The same behaviour is seen for all presented surface parameters (Table 2).

Table 2: Roughness parameters measured on used label types (printing substrates)

Label type	R_a (µm)	R_z (µm)	R_{max} (µm)
CHR	0.253±0.033	1.411±0.256	1.983±0.601
NB	0.397±0.053	2.171±0.150	2.768±0.231
NP	0.5653±0.072	3.317±0.593	5.564±1.393
NKS	0.687±0.023	4.270±0.456	5.616±1.311
NS	0.696±0.059	4.311±0.797	5.373±1.137
NMF	1.104±0.223	5.340±1.073	6.858±1.409

Figures 2-4 show the results of colorimetric difference determination. The results show a trend of colour difference increase with an increase of the EtOH concentration. At lower alcohol concentrations (8-42%), colour changes are greater at 7°C. Precisely in these alcohol concentrations, there is a higher proportion of water. This means that the stability of microcapsules is affected by water as well as ethanol. At 23°C, the colour changes are somewhat smaller, so it can be assumed that the influence of water on the stability of the yellow process colour is smaller. The high concentration of ethanol (96%) significantly affects the colour change of the print, and to a greater extent the yellow coloration of the classic process colour (measured at 23°C) than in the case when the TC microcapsules are active at 7°C. This can easily be explained by the interactive forces between materials, i.e., hydrogen (δ_H), polar (δ_p) or dispersive interactions (δ_d). The polar interactions are considerably lower compared to dispersion and hydrogen interactions. Hansen solubility parameters (HSP) can be a useful tool in the prediction of materials compatibility (miscibility) based on their interactive forces (Rožić et al., 2017). The use of HSP has a wide range of applications, such as in polymer compatibility determination, interactions at pigment surfaces, and the prediction of the chemical and solvent resistance of the coatings and films (Lambourne, 1999). Taking this into account we can assume about the print's interaction with used alcohol concentrations. Water interacts mostly with hydrogen bonding, while ethanol reacts by polar interactions (Table 3) (Rožić et al., 2017). In used ethanol solutions from 8- 42%, hydrogen interactions predominate, with somewhat lower dispersive interactions. In 96% EtOH solution, the polar interactions are dominant. Taking that in mind, we can conclude that classic process printing ink interacts mostly by high polar interactions as evident from the high colour difference measured at 23°C, while TC microcapsules interact with dispersive forces.

Table 3: Hansen's solubility parameters for water and ethanol (EtOH)

Solvent	δ_d	δ_p	δ_H
Water	15.6	16.0	42.3
Ethanol	15.8	8.8	19.4

The biggest difference in the colour change of the print at a temperature of 7°C is shown by the prints on the CHR, NB and NP substrates (Figure 1), which points to the degradation of the microcapsules because they are active at that temperature. The used labels (CHR and NB) have the smoothest surface in comparison to other printing substrates (Table 2). With the increase of surface roughness, the resistance of prints to ethanol slightly increases. The biggest changes in the colour of prints at a temperature of 23°C are shown by all prints treated with 96% alcohol in all cases. Since a rougher printing surface has higher ink demand, the resistance of prints to ethanol is greater.

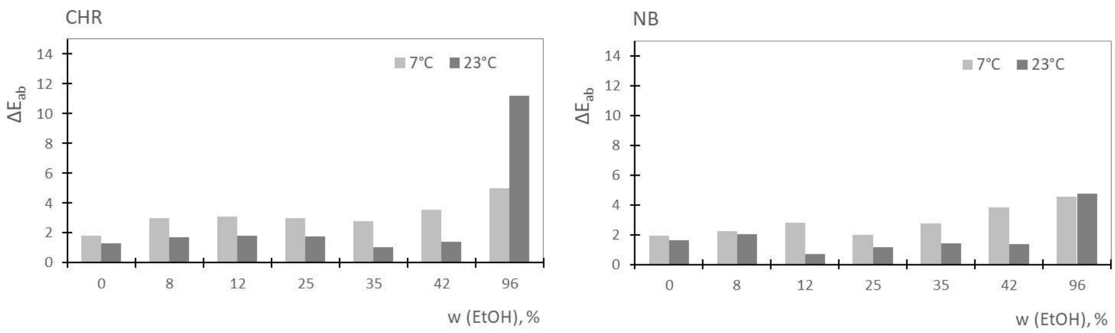

Figure 2: Total colour difference (ΔE_{ab}) of TC prints on CHR and NB labels, measured at 7 and 23°C after their exposure to different concentrations of ethanol

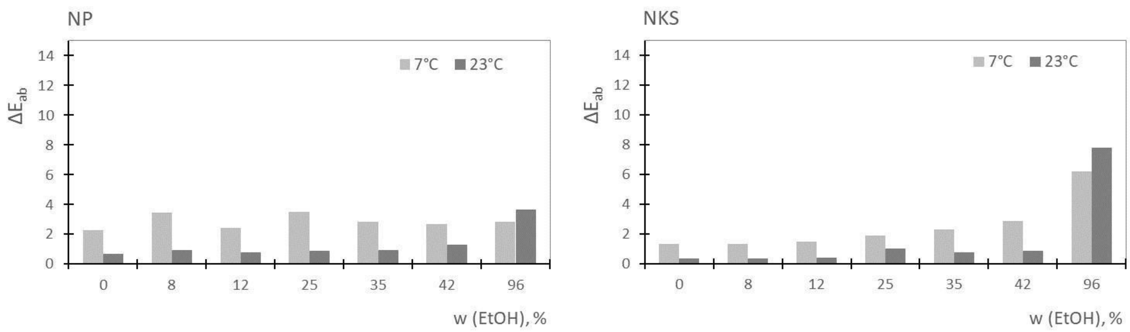

Figure 3: Total colour difference (ΔE_{ab}) of TC prints on NP and NKS labels, measured at 7 and 23°C after their exposure to different concentrations of ethanol

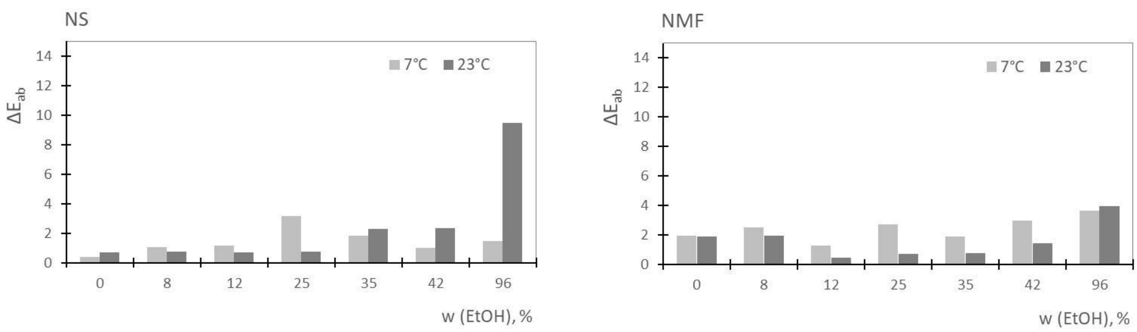

Figure 4: Total colour difference (ΔE_{ab}) of TC prints on NS and NMF label, measured at 7 and 23°C after their exposure to different concentrations of ethanol

Despite the negative impact of ethanol on TC prints, one interesting observation was made during the experiment. When thermochromic prints were exposed to ethanol, the colour of the TC print changed from yellow to orange at room temperature. The orange colouration of the TC print indicates a low temperature (below 12°C). In that case, the sample was not exposed to low temperature even though it was coloured orange (Figures 5 and 6). This indicates that the alcohol evaporation reaction leads to an endothermic reaction, which creates a lower temperature on the surface of the print and changes its colour. Also, this fact indicates that the evaporation of ethanol on the surface of the TC print creates a temperature lower than 12°C. This reaction of the alcohol can give a false colour response of the print when spilling alcohol over a thermochromic print. Due to the heating of the spectrophotometer, this change of the print colour due to the endothermic evaporation reaction, was impossible to record, so only a visual assessment was recorded (Figures 5 and 6). This phenomenon was recorded on all samples, for all ethanol concentrations. In addition, this points to the conclusion that thermochromic printing inks with low activation temperature (cold-activated) can be a useful indicator for endothermic reactions.

Figure 5: Change in the colour of the print as a result of the ethanol endothermic evaporation reaction on the CHR sample at room temperature (23±2°C) indicating a temperature below 12°C in areas where coloured in orange

Figure 6: Change in the colour of the print as a result of the ethanol endothermic evaporation reaction on the NMF sample at room temperature (23±2°C) indicating a temperature below 12°C in areas where coloured in orange

4. CONCLUSIONS

The aim of this study was to determine whether the chemical stability of thermochromic prints depends on the printing substrate on which the thermochromic ink is printed and to determine how different concentrations of alcohol (ethanol) affect the stability of thermochromic print. From the obtained results, it is evident that the chemical stability depends on the substrate on which the thermochromic ink is printed, and that with an increase in the alcohol concentration to which the thermochromic ink is exposed, the chemical stability of the TC print decreases, i.e., TC print loses the properties it had before exposure to ethanol. The samples were exposed to pure water (0% ethanol) and six different concentrations of ethanol: 8%, 12%, 25%, 35%, 42% and 96% to simulate the real conditions in which it is possible to spill different alcoholic beverages over the thermochromic print on the packaging of an alcoholic product. Moreover, it was concluded that besides ethanol, water affects the stability of the prints. The results of this test showed that when choosing a printing substrate for the printing thermochromic ink for alcoholic beverages packaging applications, the printing substrate with higher surface roughness should be considered. An additional benefit of this research was the fact that a TC print with a low activation temperature can be used as an indicator of endothermic reactions.

5. ACKNOWLEDGMENTS

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PREPARATION OF CONDUCTIVE AND FLAME-RETARDANT PU/GO/DOPO PRINTED FILMS

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Abstract: *Printed electronics are emerging technology products that we use in every moment of our daily lives. It is used in many fields from health, textile, electronics to communication. Inks with nanometal or organic content can be used in printed electronics. The ability of printed electronics to withstand temperature makes its use widespread in the electronics industry. Main aim of the study is to combine surface modified graphene oxide-based conductive inks with flame retardant materials.*
In this study, an effective and simple approach for the preparation of polyurethane acrylate (PUA) screen printing ink containing surface modified reduced graphene oxide (rGO) which has flame retardant activity. A new and effective flame-retardant additive; 9,10-dihydro-9,10-oxa-10-phosphaphenanthrene-10-oxide (DOPO), silane coupling agent and reduced graphene oxide was synthesized. In this synthesis, first reduced graphene oxide was modified with (methacryloyloxy)propyltrimethoxysilane, and then reacted with DOPO to obtain a flame-retardant monomer containing P and Si. Based on the successful modification reactions, screen-printing ink containing polyurethane acrylate and different amounts of modified graphene oxide content (0, 5 and 10 wt%) were prepared and screen printed on the paper surface. In addition, coatings were made on the paper surface to determine some the properties. LOI values, thermal properties, contact angle values, conductivity and surface properties of the obtained prints and coatings films were investigated. As a result, conductive screen-printing ink resistant to high temperatures was successfully produced and printed coatings and free films were formed.

Key words: reduced graphene oxide, polyurethane acrylate coating, UV curable coating, flame retardant, printed electronics

1. INTRODUCTION

Printed electronics have the potential to produce flexible, low-cost electronic devices and systems to realize new applications such as wearables, portable electronics, wireless communications, healthcare, sensors (Gengenbach et al., 2020; Saengchairat et al., 2016; Hines et al., 2021). The most important component of printed electronics are functional inks based on nanomaterials. The ink portfolio is constantly evolving from materials of print conductors, passive components (e.g., capacitors, resistors) and active components (e.g., transistors, diodes) (Garlapati et al., 2018; Wu., 2017). The formulation of high-performance functional inks is a key factor in achieving these goals and demonstrates enormous potential to produce printed electronics (Hong et al., 2022; Zhang et al., 2020; Cronin et al., 2018). Recently, in numerous commercial products and literature, nano-silver particles/flakes, graphene, single-walled carbon nanotubes, organic/oxide semiconductors and conductive polymers is used to prepare conductive inks (Liang et al., 2016; Hyun et al., 2015; Kell et al., 2017; Cao et al., 2018; Chiolerio et al., 2015). The large surface areas of the nanoparticles allow for greater contact area, which contributes to higher conductivity and stability (Faddoul et al., 2012). Moreover, the nanoparticles showed good compatibility with various base polymer resins. Recently, two-dimensional (2D) nanomaterials such as graphene, MXenes and boron nitride (BN) have been extensively investigated due to their good electrical or thermal conductive properties (Sreenilayam et al., 2021; He et al., 2019; Joseph et al., 2016). For example, graphene, one of the inorganic carbon nanomaterials, is one of the fillers used to increase the thermal conductivity of the polymeric matrix with an electrical conductivity of 6000 S cm^{-1} and a high thermal conductivity of 5000 W m^{-1} K^{-1} (Burk et al., 2018).
Important printing techniques such as screen printing, offset printing or inkjet printing have been adapted for the use of functional printing inks (Cronin et al., 2018). Apart from these printing techniques, new printing techniques such as aerosol-jet printing and electrohydrodynamic ink-jet printing have been developed for functional printing applications (Verboven & Deferme, 2021). After the ink is deposited

onto the substrate by the printing process, one or more processing steps such as curing, drying, and sintering are required to obtain the desired functional layer. Most of the previous research and commercial products show the necessity of a high temperature curing process to achieve high electrical conductivity (Htwe & Mariatti, 2022). This high temperature curing process (above approximately 160 °C) after screen printing inevitably causes shrinkage/deformation and strength reduction in most electronic systems. Although alternative techniques such as direct current sintering (DCS), microwave flash sintering, and laser have been reported to successfully achieve high electrical conductivity at low temperature, the complexity of processing, the requirement for expensive equipment, and limited volume manufacturing limit their practical use (Cronin et al., 2018; Perelaer et al., 2009). Recently, UV-curable conductive inks are a potential solution for substrates with low temperature resistance.

UV-initiated radical polymerization has made significant progress in recent years. This is predominantly due to the fast-curing speed at a relatively low temperature with low emissions of volatile organic compounds, which allows printed flexible electronics prepared by UV curing to be more environmentally friendly and more attractive (Mendes-Felipe et al., 2019). Conductive inks prepared from UV-curable prepolymers, and monomers are used to produce printed electrolytes due to their fast UV curing rates, energy efficiency and high dimensional stability (Saleh et al., 2017). However, two major challenges remain for the currently available UV-curable conductive ink. The first challenge comes from the compatibility between UV-curable resins and conductive fillers, as well as the optimization of conductive filler distribution. On the other hand, due to the trade-off between mechanical strength and electrical properties, increasing the conductive filler content to achieve higher electrical conductivity will increase the hardness of the printed electronics, thereby reducing flexibility. Therefore, it is critical to conduct studies on UV-curable conductive ink in different compositions and ratios to produce high-performance printed electronics.

Today, natural, and synthetic polymeric materials are widely used in different fields such as coating, electronics, and cable due to their superior properties such as low density, resistance to erosion and ease of processing (Song et al., 2009; Kashiwagi et al., 2005). These polymeric materials are inherently flammable. However, the fire hazards associated with the use of flammable polymeric materials, which cause great loss of life and property, limit their use in some areas. For this reason, increasing the flame retardancy of polymeric materials becomes a more important and necessary issue for the protection of the environment and human health. For environmental concerns, halogen-free flame-retardant materials have received great attention because halogen-containing flame-retardant materials can produce a lot of smoke and toxic gases during the combustion process (Liu et al., 2010; Chen et al., 2014).

In this study, a new UV-curable conductive ink was prepared and then applied to the paper surface by screen-printing technology on the other hand, these inks are coated on paper as varnish. Silane modification has been used as a surface treatment for the functionalization of reduced graphene oxide (rGO). Acrylate modified rGO was prepared using silanization of rGO with 3-(Trimethoxysilyl)propyl acrylate. A novel flame-retardant additive, DOPO/acrylate modified rGO is synthesized and characterized. The thermal behaviors and flame retardances of the ink/coatings are investigated and found to be influence by the structural features of the m-rGO nanoarticles used. Moreover, contact angle values, surface properties and conductivity of the obtained ink/coatings were investigated.

2. METHODS

2.1 Materials

Reduced graphene oxide (rGO) was obtained from the company Nanography (Turkey). 3-(Trimethoxysilyl)propyl acrylate and trimethylolpropane triacrylate (TMPTA) were obtained from Sigma-Aldrich. 9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide (DOPO) was obtained as a gift from MCTCHEM (Turkey). 2-hydroxy-2-methyl-1-phenyl-1-propanone (Darocur 1173) were obtained from Ciba Specialty Chemicals. Polyurethane acrylate was obtained from Sartomer (CN9782).

2.2 Modification of reduced graphene oxide

0.3 g of rGO was dispersed in 270 ml of ethyl alcohol through ultrasonication for 1 h; 6 g of 3-(Trimethoxysilyl)propyl acrylate was added and the mixture was stirred vigorously at a temperature of 78 °C for 18 h. The mixture was filtered and washed several times with deionized water and ethyl alcohol. Finally, acrylate-modified rGO (acr-rGO) was obtained after vacuum drying at 50 °C for 12 h. Structural characterization were performed with the FTIR. The scheme of the modification is given in Figure 1.

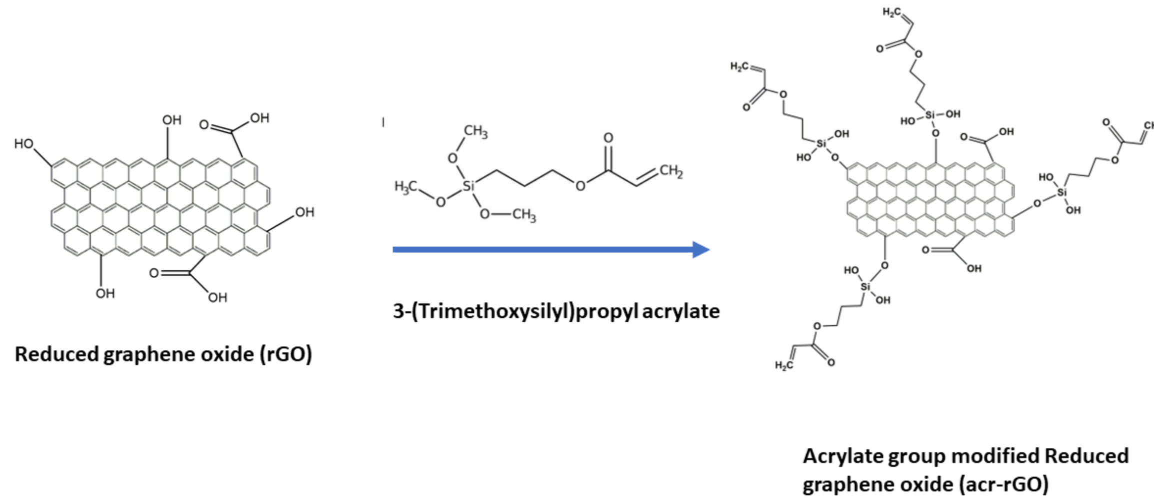

Figure 1: Schematic illustration of the acrylate modification of rGO

The obtained acrylate functional rGO nanoparticles, DOPO (2 g) and Xylene (50 mL) were added into a round bottom flask equipped with magnetic stirring. The reaction was performed for 5 h at 125-130 °C under arc N_2 atmosphere. The mixture was filtered and washed several times with deionized water and ethyl alcohol. Finally, DOPO modified acr-rGO (m-rGO) was obtained after vacuum drying at 40 °C for 12 h. Structural characterization were performed with the FTIR. The scheme of the reaction is given in Figure 2.

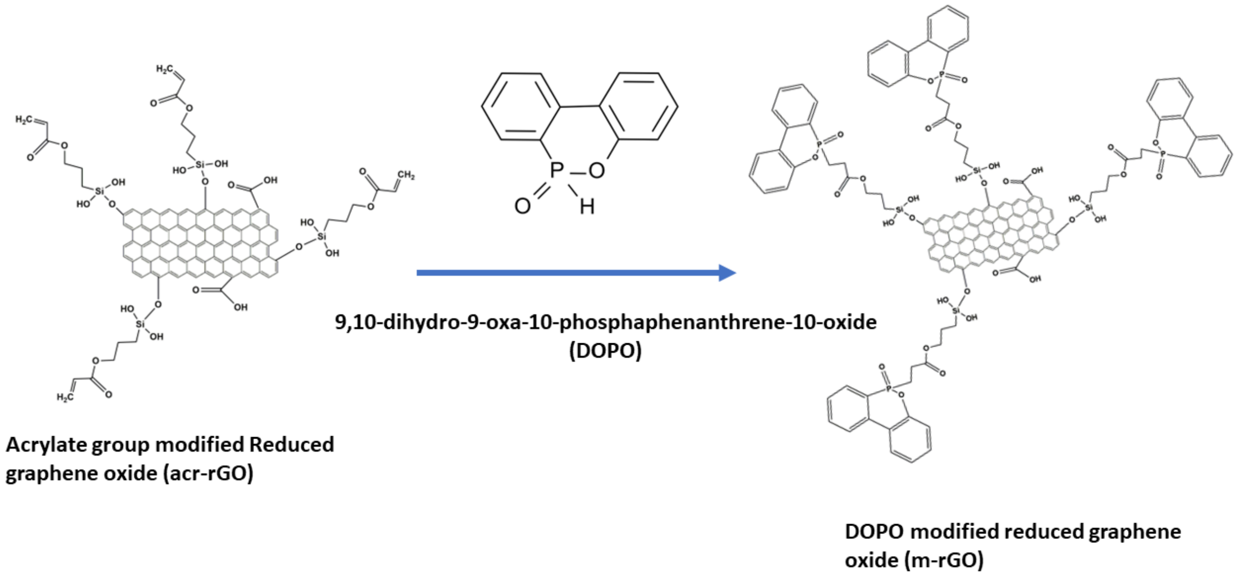

Figure 2: Schematic illustration of the DOPO modification of acr-rGO

2.3 Preparation of UV-curing conductive ink and coating formulations

Four components were used to produce UV-curable conductive ink: conductive filler (surface modified reduced graphene oxide), polymer (polyurethane acrylate), photoinitiator (Darocur 1173), and diluent (TMPTA). The polymer provides ink formation for printing conductive patterns and contributes to the dispersion stability of conductive particles.

In this study, reduced graphene oxide nanoparticles were chosen as the conductive materials. The large surface contact areas between the reduced graphene oxide nanoparticles produce high electrical conductivity and a low permeation threshold. Preferred for improved fill distribution for higher print quality and resolution. PUA as a polymer was chosen to support the flexibility and softness of the printed conductive layers after curing. TMPTA was used as diluents to reduce the viscosity of conductive inks, they can improve the ink penetration through the screen mesh and ink transfer during the screen-

printing process. Darocur 1173 was chosen as the photoinitiator capable of generating reactive species (i.e. free radicals) and initiating chain growth of acrylates when exposed to UV light.
First, three different UV-curing formulations for conductive ink/coating were prepared according to the weight ratios given in Table 1 by mixing PUA, TMPTA, Darocur 1173, m-rGO. Each formulation was taken into a 10 mL beaker and surrounded by aluminum foil. It was kept in an ultrasonic bath until a transparent and homogeneous mixture was obtained. The homogeneous mixtures were degassed in a vacuum oven. The prepared resin was applied to the paper surface by screen-printing method and exposed to 3 minutes UV rays (printed coatings). In addition, coated films were prepared from the obtained formulations for LOI and TGA analyses.

Table 1: UV-curing conductive ink formulation

Ingredients (g)	F0m-rGO	F5m-rGO	F10m-rGO
PUA	3	3	3
TMPTA	2	2	2
m-rGO	-	0,25	0,5
Darocur 1173	0,15	0,15	0,15

2.4 Characterization

Fourier-Transform Infrared Spectroscopy (FTIR) spectra were recorded on a Bruker IFS 66/S spectrometer with ATR capability. Thermal gravimetric analysis (TGA) was carried out by using the Perkin Elmer Instrument STA6000 instrument. The TGA measurements were performed between 30 °C and 750 °C (under N_2, rate 10 °C/min). The limit oxygen index (LOI) values of the coatings were measured by using a FTT (Fire Testing Technology) type instrument, according to ASTM D2863. The test specimen bars of 120 × 6 × 3 mm^3 were prepared for the LOI test. The colours of the obtained coatings were measured by X-Rite eXact portable spectrophotometer according to the ISO 13655:2017 standard. The measurement conditions of the spectrophotometer were determined as polarization filter with 0/45° geometry with 2° observer angle and D50 light source in the range of 400-700 nm. Colour differences were calculated according to the CIELab (2000) technique. 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.

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

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, respectively. 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, respectively.
The gloss measurements of all coatings were carried out with the BYK Gardner GmbH micro gloss 75° geometry in accordance with ISO 8254-1:2009. The contact angles of coatings were found on Pocket Goniometer Model PG-X, version 3.4 (FIBRO Systems AB, Sweden). Surface-free energy was calculated according to ASTM D5946 standard test method, depending on the water contact angle. The images of droplets were then recorded by using a CCD video camera. Conductivity was calculated with the formula given below. Voltage and current values were measured with Fluke 179 True RMS Digital Multimeter.

$$V=IR \tag{2}$$
$$R=\rho l/A \tag{3}$$

4. DISCUSSION

4.1 Structural characterization of surface modified reduced graphene oxide

Surface modified reduced graphene oxides (m-rGO) were structurally characterized by FTIR spectroscopy and the spectra are given in Figure 3. As shown in Figure 3, compared with the spectrum of rGO, the newly formed absorption bands around 2886 cm^{-1} mean that the C–H stretching in aliphatic CH_2 groups. More clear evidence for the successful acrylate group modification can be confirmed by strong stretching vibrations for Si–O–C at 1112 and 692 cm^{-1} as well as the stretching and bending vibrations of Si–O at 1056 cm^{-1}, respectively (Huang et al., 2018). Compared with the spectrum of DOPO, the characteristic peak of P-H (in DOPO/acr-rGO) disappeared at 2385 cm^{-1}. By comparison with the spectrum of acr-rGO, the characteristic peak of C=C (in DOPO/Acr-rGO) disappeared at 1623 cm^{-1}. Several new characteristic peaks were observed: 913 cm^{-1} (P-O-phenyl), 1245 cm^{-1} (P=O), 1429 cm^{-1} (P-phenyl), 1581 cm^{-1} (phenyl), 1595 cm^{-1} and 1608 cm^{-1} (Ma et al., 2018; Lin et al., 2020). From the FTIR analysis, it was evident that m-rGO was successfully synthesized.

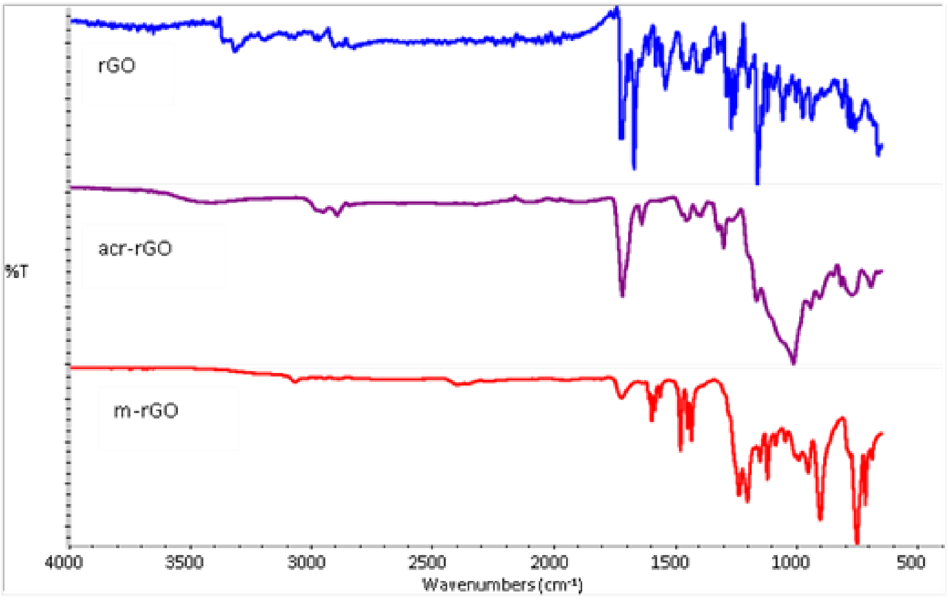

Figure 3: FTIR spectra of the surface modified reduced graphene oxide

4.2 Thermal properties and flame retardancy of the photocured free films

To examine the thermal properties only in terms of polymeric materials, free films were produced. The thermal degradation profiles of the photocured free films were determined TGA. The TGA spectra is presented in Figure 4. The results of the TGA are also collected in Table 2.

Table 2: Thermal properties of the free films

	$T_{max}{}^{a}$ (°C)	Char (%)	LOI
F0m-rGO	388,13	0,681	18,5
F5m-rGO	404,61	3,594	20
F10m-rGO	407,21	5,309	20,5

[a] The maximum weight loss temperatures, which were determined from the maximum of the corresponding derivative curves.

Mainly, the free films exhibited a one-step degradation process. The maximum decomposition stages were around 400 °C and this weight loss was attributed to the decomposition of aromatic groups. It was observed that as the amount of m-rGO increased in the formulations, the thermal strength increased slightly.

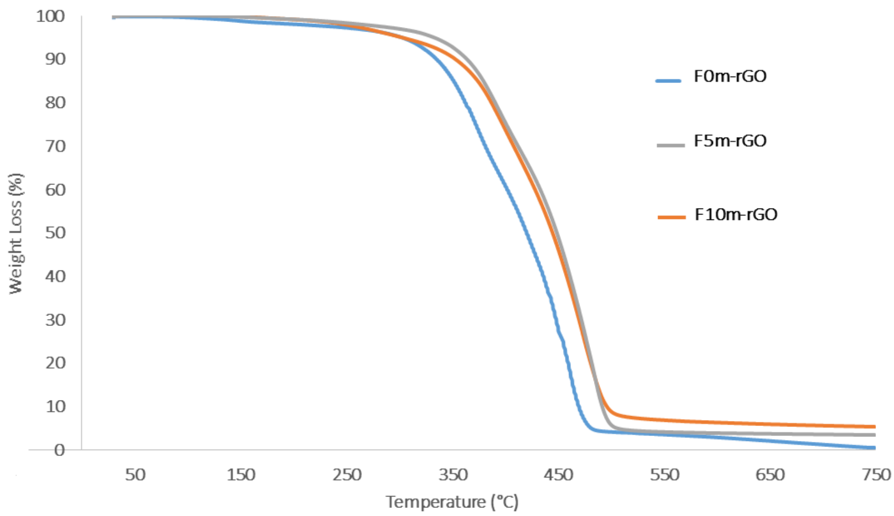

Figure 4: TGA thermograms of the free films

The char yields increased gradually with the increasing amount of m-rGO. When 10 wt% m-rGO nanoparticles are added, the amount of char yields increased from 0,681 to 5,309. The amount of char yields is generally associated with the flame retardancy of materials. Thus, it can be said that the flame retardancy of the m-rGO nanoparticles-containing free films and conductive inks were improved. We further evaluated the flame retardancy of the free films by the LOI test in which the minimum amount of oxygen that is needed to support flaming combustion is measured.

The LOI values of the free films are given in Table 2. The F0m-rGO encoded free film had a LOI value of 18,5. As m-rGO nanoparticles was increased in the free films, the LOI values increased slightly. It is thought that this is because a small amount of DOPO modified reduced graphene oxide (5 and 10% wt) is added to the formulations. The amount of P in the nanoparticles whose surface is modified with DOPO is quite low.

4.3 Printability of coatings

The colour and gloss properties of the obtained coatings were measured and given in Table 3. When the Table 3 was examined, it was seen that the colour of the base paper changed completely with all coatings. In F0m-rGO coatings, which do not contain m-rGO nanoparticles, the colour shifted slightly towards yellow. This is a feature that polyurethane acrylate brings to the coating and is compatible with the literature (Liu & Liu, 2018). It was observed that the coatings added with m-rGO nanoparticles caused a great change in the L value. On visual inspection, the colour of these coatings is black. With the Delta E difference, it is proved that the colour is completely different. As the number of m-rGO nanoparticles increased, the colour difference increased and the colour became darker. Similar results are in the same direction in the literature (Cao & Wang, 2017).

Table 3: Colour and gloss characteristics of coatings

	L	a	b	ΔE_{00}	Gloss
Base paper	100.00	0.02	0.01	-	6.3
F0m-rGO	93.11	-0.21	5.04	4.7	13.4
F5m-rGO	38.68	-0.37	5.55	48.1	11.1
F10m-rGO	29.66	-0.45	6.00	58.2	10.7

When the gloss results were examined, it was determined that the gloss of the coatings was higher than the uncoated paper because the gaps on the surface were filled with the coatings. In the coatings to which m-rGO nanoparticles were added, a small amount of roughness was created, and the gloss decreased a little. This decrease varies depending on the m-rGO nanoparticles ratio. Results are similar to literature (Arman-Kandırmaz et al., 2020).

4.4 Contact angle and Surface energies of coatings

For an ink to adhere to a substrate, there must be a harmony between the surface and the ink, the surface energy, and the contact angle. For this reason, the contact angle of the obtained coatings was measured and given in Figure 5. When examined, the highest contact angle was obtained in the coating without m-rGO nanoparticles. The addition of m-rGO nanoparticles reduced the contact angle. As the number of m-rGO nanoparticles added increased, the decrease in the contact angle increased. The results obtained are compatible with the literature (Tissera et al., 2015). This shows that the interest of the coated substrate has increased against water-based ink. Surface energies were calculated using the obtained contact angles. Surface energies of F0m-rGO, F5m-rGO, F10m-rGO coatings were determined as 40.8, 46.6, 47 (mJ/m^2) respectively. The surface energy increased as the contact angle decreased. These are the expected results (Ozcan et al., 2020).

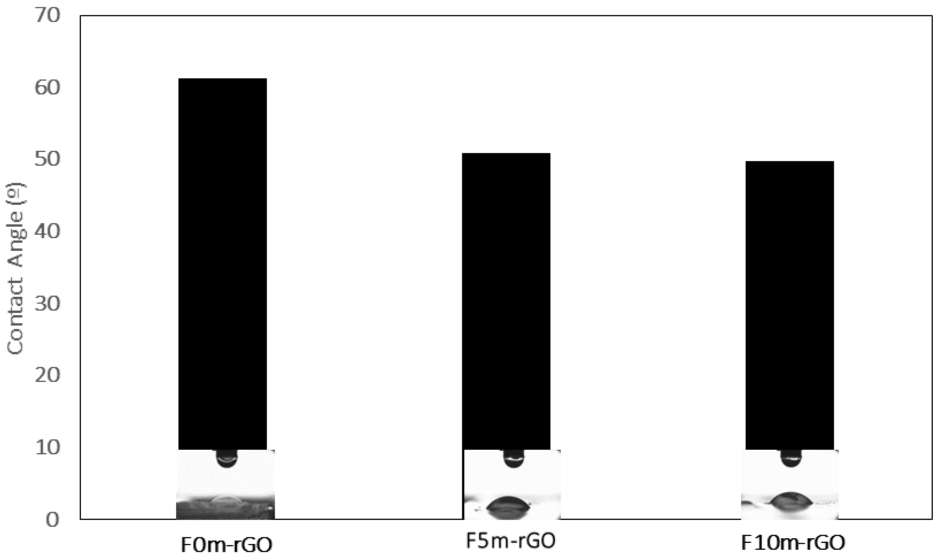

Figure 5: Contact angles of coatings

4.5 Conductivity of screen-printed lines

The electrical conductivity of the screen-printed lines was measured and given in Figure 6. Figure 6 showed that the conductivity of polyurethane acrylate coating is low, 1.82×10^{-17} S/cm, which belongs to insulator. When m-rGO nanoparticles were added, the conductivity increased remarkably. It could be explained that the conductivity results of nano materials. With the increase of the content of m-rGO nanoparticles the contact density between conductive fillers increased, the conductive path became more, and the conductivity increased rapidly. Results are consistent with the literature (Li et al., 2019).

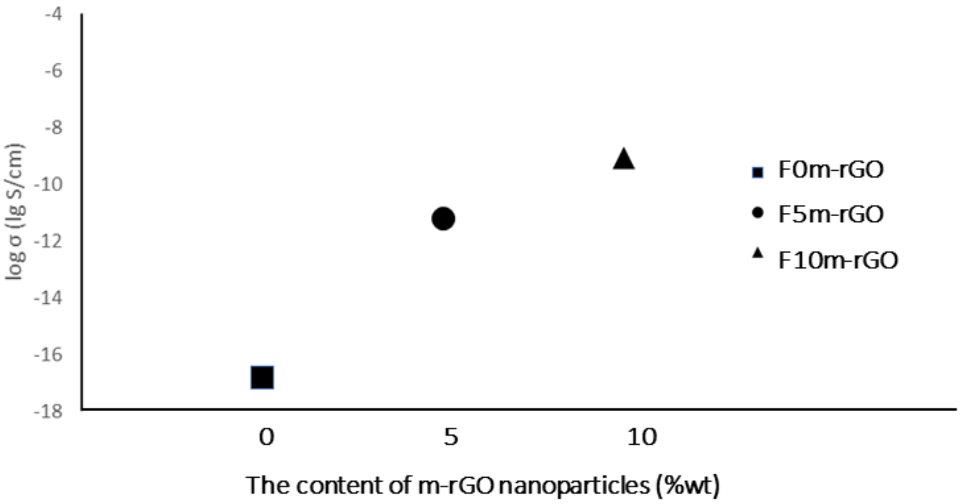

Figure 6: Electrical conductivity m-rGO nanoparticles of added PUA screen printed lines

5. CONCLUSIONS

In summary, surface modified reduced graphene oxide nanoparticles loaded UV curable conductive inks based on PUA chemistry were formulated. A focus was spent on understanding the composition effects on the ink properties that subsequently dictates its screen printability and finally the electrical, thermal and flammibility properties. For this purpose, acr-rGO was prepared and successfully characterized using FTIR, then acr-rGO was reacted with DOPO and surface modified r-GO (m-rGO) was obtained. Based on the successful modification reactions, screen-printing ink containing TMPTA, PUA and different amount of m-rGO content (0, 5 and 10 wt%) were prepared. The prepared ink formulations were applied to the paper surface by screen printing (printed coatings). The electrical properties, thermal properties and LOI values increased as expected as the amount of surface modified graphene oxide nanoparticles increased. But the values are not very high, we can attribute this to the low amount of the nanoparticle's additive added. It has been determined that printed conductive paths with the same formulation as coatings with good printability properties balance the insulating structure of PUA towards the conductor. It has been concluded that the obtained ink can be used in printed electronic applications in future studies.

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PRODUCTION OF INK CONTAINING THERMOCHROMIC DYESTUFF

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Abstract: *Security inks are functional inks containing a binder and a special colorant used in money, checks and valuable documents. In security inks, thermochromic dyes, UV emitted, infrared emitted dyes can be used. Thermochromic dyestuffs provide different colors at different temperatures and ensure the requirements in the field of security. Thermochromic inks are generally used in smart packaging applications, high temperature alarms and security inks. Thermochromic dyes are generally metal-containing chemical materials.*
In this study, ink will be produced for metal surfaces by using commercial thermochromic dyestuff and it will be provided to act as a temperature warning plate. For this purpose, UV spectra of the thermochromic dyestuff was determinate with different temperature.
Solvent-based ink with polyurethane binder containing 1; 3; 5% commercial thermochromic substance was produced. Screen prints were made on the metal surface with the produced ink. The color and gloss properties of the prints were measured with a spectrophotometer and glossmeter, respectively, at different temperatures. Print quality and surface properties were determined with an optical microscope. In addition, alkali, nitro, acid resistance tests were carried out. The reusability (color change) number was determined depending on how many temperature changes the print has. As a result, inks that change color at 38 °C with commercial thermochromic material were produced and successfully printed.

Key words: security ink, screen printing, UV –Viz. Spectroscopy, printability

1. INTRODUCTION

The reversible coloration that occurs as a result of temperature change is called thermochromism. The color change of thermochromic substances occurs rapidly and at a certain temperature, called the thermochromic transition temperature. Taking advantage of these properties, thermochromic paints are generally used in the textile industry, thermometers, metal surfaces, cosmetics or food packaging application areas (Civan et al., 2021; Arman et al., 2021)

Thermochromic dyes; It is suitable for use on various base materials such as metals, polypropylene, polyethylene, PVC and polystyrene. In this way, color-changing plastics are obtained. Polymers are light, inexpensive, easily shaped and non-corrosive materials. Today, the mechanical and thermal durability of polymers, increasing their resistance to solvents and insulating properties, as well as their conductive properties, have become important. As a result, it has been focused on the conductivity properties of polymers (Arman et al., 2021).

In this study, a polymeric coating was obtained for metal surfaces by using commercial thermochromic dyestuff. The prepared polymeric material was coated on the metal surface and its usability as a warning sign was determined.

2. EXPERIMENTAL

2.1 Materials and Instrumentation

2-hydroxy-2-methylproplophenone NaOH and HNO_3 were purchased from Merck. Aliphatic urethane acrylate resin was obtained MCT chem. Thermochromic dye (TS Orange) 31 was used.

Shimadzu UV-Vis spectrophotometer was used for spectrophotometric measurements.IR spectrums was obtained by Perkin Elmer Spectrum100 ATR-FTIR in the wavelength range 4000-400 cm^{-1}

2.2 Method

2.2.1 Synthesis of UV curable coatings

Thermochromic dye (1,3,5 wt.%), aliphatic urethane acrylate resin (100 wt.%), were added to a round-bottom flask. Manual mixing was done for 3 minutes. Afterwards, an ultrasonic bath was used to ensure homogeneous distribution. Then, the photoinitiators (2-hydroxy-2-methylproplophenone (IRGACURE

2022) were added. The prepared matrix was then poured into a Teflon® mold (10 mm radius circle). After 180 s irradiation under UV light, photocured polymeric coatings were obtained (Aydın Urucu et al. 2020). F1, F3, F5 contain 1, 3, 5 thermochromic dye respectively. Figure 1 shows the production of the polymer coating.

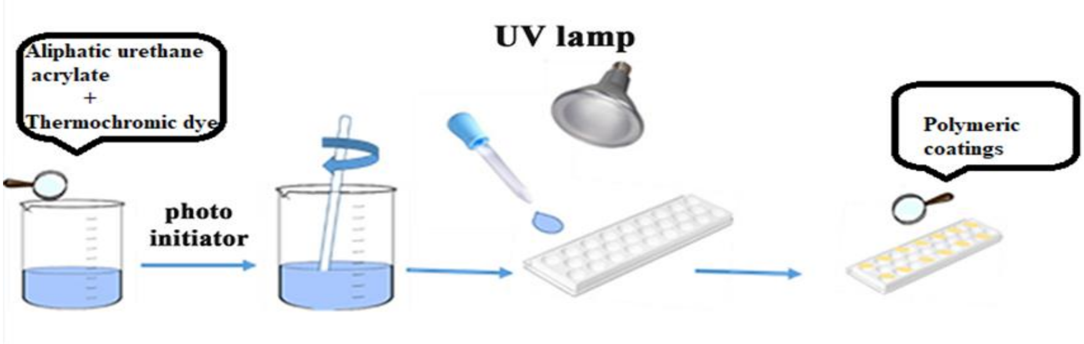


Figure 1: The production of the polymer coating

3. RESULTS AND DISCUSSION

In the IR spectra of the UV curable coatings, the band at around 3348 cm^{-1} is due to the -NH groups of the urethane bond. Urethane carbonyl groups were observed at around 1713 cm^{-1} while the peaks at around 1637 cm^{-1} were attributed to the characteristic methacrylate double bonds. Addition to these, the absence of the -C=C- double bond peak around 1640 cm-1 in the IR spectrum proves that the UV curable coatings were prepared (Figure 2)

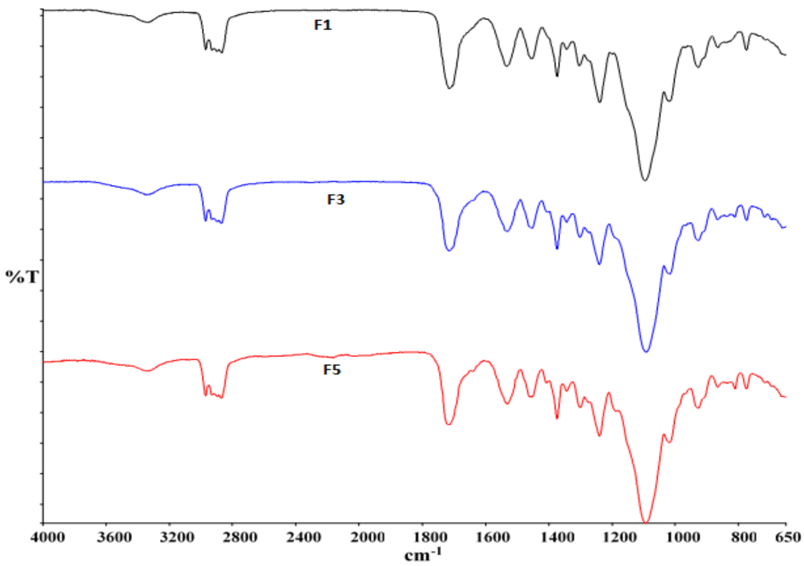


Figure 2: ATR-FTIR spectra of UV curable coatings

The discoloration of the thermochromic polyurethane coating by increasing with temperature was investigated by UV spectroscopy. Figure 3 shows the UV spectrum of the thermochromic polyurethane film at 25 °C and 40 °C. At a temperature of 25 °C, the absorption band due to the orange color of the UV curable coating (F5) gives maximum absorbance at about 520 nm (Figure 3). However, when heated to 40 °C; the color suddenly became transparent and the peak disappeared at 520 nm.

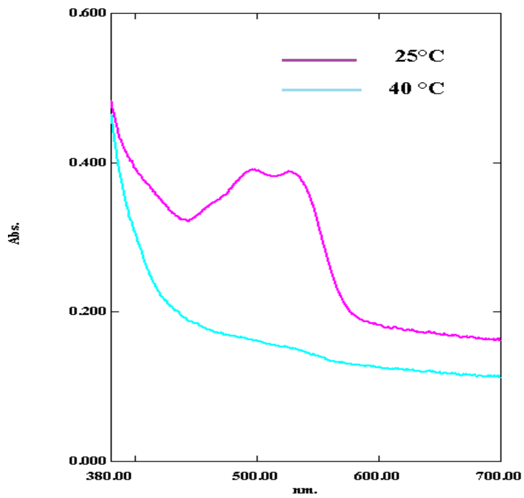


Figure 3: UV absorption spectra of UV curable coating (F5)

Figure 4 shows the colors of UV curable containing at two different temperatures (25℃ and 40 ℃). While the orange color is obvious at 25 ℃, it is observed that the color disappears with increasing temperature. (Contains thermochromic dye in the ratio F1:1%; F2:3%; F3:5%)

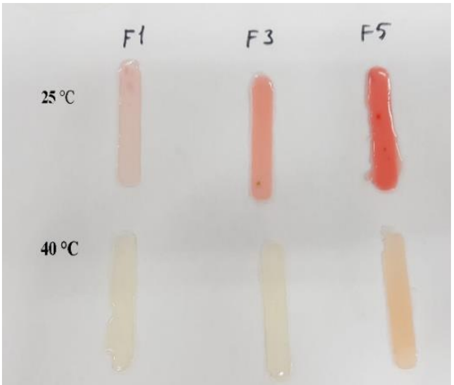
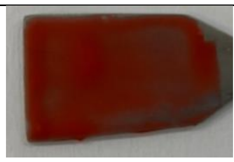


Figure 4: UV curable coating at two different temperatures

For the alkali, acid and alcohol resistance tests of the polymer coating, 1% NaOH, 1% HNO_3 and isopropyl alcohol were used, respectively. It has been observed that the coating is resistant to acid, base and alcohol.

The metal surface was coated with a polymer coating prepared with thermochromic dyestuff and the color values were compared at different temperatures. The results are summarized in Table 1.

Table 1: Color characteristics and glosses of thermochromic prints at different temperature

	L	a	b	Delta E	Gloss	Image
Thermochromic print at 25 °C	21	40	34		14.8	
Thermochromic print at 40 °C	36	5	14	33.74	12.7	

4. CONCULUSION

In this study, a UV curable coating, which can be used as a warning sign, was successfully obtained. According to the color results, it is seen that the color is orange at 45℃, colorless at 25℃, and the color difference was 33.74. While this color change can be clearly observed with the spectrophotometer, it can also be determined very easily with the eye. Thus, an easily recognizable and inexpensive metal warning sign material was produced. The gloss values of the obtained coating are quite high. When the amount of thermochromic dye used in the preparation of the coating material is increased by more than 5%, there are difficulties in its synthesis. Therefore, dyes were used in amounts below the percentage.

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LIGHTFASTNESS OF LITHOGRAPHIC PRIMARY COLOURS COATED WITH NANOCOMPOSITES COMPOSED OF TiO_2 AND WATER-BASED VARNISH

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Abstract: *The UV radiation causes inks to fade. The ink fading will lead to the degradation of the visual appearance of printed imprints making them less attractive to the user. To deal with this that phenomenon, one of the solutions is to create a coating that could challenge these issues. In order to create efficient protective coating against UV induced degradation, nano scaled titanium dioxide (TiO_2) wasl added to the commercial water-based varnish. To determine influence of the amount of TiO_2, was homogenized in various weight ratios. The prepared nanocomposites were applied onto offset (lithography) prints made in accordance with Fogra PSO, i.e. ISO 12647-2:2013 on gloss coated paperboard. The samples have been subjected to artificial UV induced aging for 30 hours. The protective properties of the nanocomposite TiO_2 coating was determined by calculating colorimetric and densitometric change on full tone and determining tone value change of half tones.*

The results showed that the prepared nanocomposite coating has relatively little effect on the printed colour of the samples. However, some coating compositions exceed the allowed tolerance ΔE_{ab}> 5, however in those cases the initial colorimetric value of WB (ΔE_{ab}) was close to the FOGRA PSO border value. The coatings with TiO_2 will increase resistance to accelerated ageing on full and halftone.

To conclude, this research has provided the new perspective on modulation possibilities of commercially available varnishes in order to cope a designated problematics and downsides of coatings which was, in this case, UV induced fading and degradation of visual appearance. The further research should investigate the applicability of this kind of modulated varnish in other coating techniques as well the use of other kind of nano sized compounds.

Key words: Coating, Nanoparticles, Titanium dioxide (TiO_2), Lightfastness, Packaging

1. INTRODUCTION

All industrial areas are generally impacted by two factors, the available technology, and the overall costumer's needs. Printing industry is no exception where some sectors have decreased in volume, leading the overall revenue decrease of the industry in general. Cardboard packaging is no exception where it has a vast and growing share in the packaging industry. Regardless of the grim prognosis, the forecast is that the total growth should reach about 269 billion US by the year 2024 (*Justpaint, n.d*). Furthermore, "green" agenda also pushed the graphic industry even further labelling it as the "forest killer"(Berg & Lingqvist, 2019). Despite these negative influences, the need for printed packaging has a projected and continuously growth worldwide *Statista*, n.d.).

Industries are faced with the new trends, such as eco-friendly and "green" industry development and packing is no exception. Nevertheless, application of these concepts must not degenerate its basic purpose and requirements which are product protection and aesthetics (Makower, n.d.). Paperboard and its derivatives have some weak points and usage of various synthetic (mostly polymer) materials in growing in the general use but those materials do have some disadvantages in terms of sustainability and biodegradation (*Allianz, 2021;* Eu, n.d.).The quality factors of printed packaging can be reduced by an outer influence such as UV induced degradation. The UV radiation (from 100 to 380 nm) not only causes inks to fade (Aydemir & Yenidoğan, 2018), but is also responsible for yellowing and the loss of strength of the material (Jiménez-Reyes *et al.*, 2021) (Brokerhof *et al.*, 2017). The ink fading and yellowing will lead to the loss of the visual appearance of printed imprints making them less attractive to the user. Moreover, the fading of ink can result with losing the products information (i.e., barcodes) that endangering the consumer's rights to information and violate the EU's consumers law (*Consumer rights directive | European Commission*, n.d.).

To diminish that phenomenon, one of the solutions is to create a coating that could challenge these issues. The water-based varnish (denominated as WB) is the most "eco-friendly" coating type on the market that has the industrial, technological, and commercial capability since it does not create hazardous vaporization when handling or curing (*3 Oak News*, n.d.). The WB varnish has some downsides when compared to UV varnish for instance in terms of lightfastness, barrier properties etc (Ragauskas & Lucia, 1998a). Some research has been made with incorporation of nano sized compounds in commercial varnishes that have the upgrade potential (Zvekic *et al.*, 2011; Cigula, Hudika & Vukoje, 2021; Hudika, Cigula & Vukoje, 2021). One of those compounds is a metal oxide, TiO_2, well known for its ability to absorb UV radiation and commonly used as part of inks, colours, coatings, sunscreens, etc (Wang *et al.*, 2009; Hudika *et al.*, 2020).

2. MATERIALS AND METHODS

For this research, lithographic offset printed samples were coated with prepared nanocomposites in various nanoparticle's weight ratios (0.25%, 0.5% and 1%). The base of nanocoating was commercial water-based varnish while chosen nanoparticle was titanium dioxide (TiO_2). The printing for the purpose of this research was done in accordance with the ISO 12647-2:2013 standard, i.e., FOGRA PSO (ISO/TC 130 Graphic technology, 2013). The standards sets the CIE L*a*b* values of each primary colour and defines the tolerance level is ΔE_{ab}=5. The sheetfed offset printing was done with industrial printing press KBA 105 PRO-5+L FAPC (Rapida, n.d.). The printing test form was created which included large patches (50 x 200 mm) with full tone of primary colours and tone value (TV) patches (10 x 10 mm) from 0 – 100% with the step of 2% (0 – 10%) step of 5% (10 – 20% and 80 – 100%) and step of 10%. The four colour CYMK offset printing was done with Novavit F918 Supreme Bio inks made by Flint Group (*Flintgrp, n.d.*). The paper used was UPM Finesse white gloss paper WFC (Woodfree coated) grade with gloss coating and grammage of 300g/m^2. Paper was conditioned and stored in environment at temperature of (23 ± 1) °C and (50–55) % relative humidity before the printing process. The nanocomposite's base was water-based varnish (denoted as WB) with production name Terra High Gloss Coating G9/285 by Actega USA, used for flexographic printing (coating) technique (*TERRAWET®*, n.d.). The nanoparticles used in this research were TiO_2 was from Sigma Aldrich with the production code EC 2015-282-2 (International organisation for standardisation, 2011; Titan dioxide, Sigma A., n.d.). Nanoparticles used in the nanocomposite mixture were weighed using Mettler Toledo XS205DU Dual range Analytic Scale. The varnish was weighted in the mixture cup. Due to the increase in viscosity by adding NPs, in the initial WB a 5% wt of deminiralized water was added. All prepared nanocomposites were applicable in flexography, i.e. viscosity was in range of 0.7 Pa*S. The nanocomposites were prepared by homogenization of nanoparticles into water-based varnish using ultrasound dispenser Hirrlscher UP100H from 20 to 40 minutes depending on the nanoparticles weight ratio (%) in the varnish (Table 1). Time-to-weight ratio of homogenization process derived from previous testing and proved to be the most optimum one with this setup. During the course of homogenization process the mixture was cooled down in cooling console that was immersed into a water bath with the temperature of 5°C.

Table 1: Homogenisation time and denomination

Compound	Denomination	Weight ratio (%)	Homogenization time (min.)
Pure WB	*WB*	-	-
TiO_2	*0.25% TI/NC*	0.25	20
TiO_2	*0.5% TI/NC*	0.5	30
TiO_2	*1% TI/NC*	1	35

To apply the prepared nanocomposite coating, IGT F1 printability tester for flexography was used (IGT, n.d.). The anilox used was IGT 402-258 roller with 90 l/cm screen line and 18 ml/m^2 cell volume. The flexographic polymer printing plate used was Kodak Flexcel NX with DigiCap NX patterning. The printing plate had 100% TV coverage, used for varnishing (Workflowhelp, n.d.).

To investigate the lightfastness of the prepared samples, accelerated aging (AcA) via UV radiation was used. To create those conditions Solarbox 1500 e chamber was used with the xenon light exposure in the solar chamber with the indoor filter simulates the sunlight rays hitting the surface through a glass or shop window. In this research, an indoor filter S208/S408 (artificial daylight) was used. This was done to assess the level of visual degradation of the samples which were meant to be kept in an indoor environment during their lifespan. Irradiation in the chamber was set to 550 W/m^2 and the temperature of 50 °C (30h

of AcA, i.e., to electromagnetic energy of 59 MJ/m^2). The experiment was done in accordance with the ISO 4892-2 standard (International organisation for standardisation, 2013).
The colour control was conducted by measuring full tone patches with the use of Techkon SpectroDens spectrophotometer (Techkon, n.d.) (D50, 2° standard observer, no polarisation filetr, M1 with calibration on absolute white). There are two important factors that needs to be addressed when considering coatings in general, first being, would and if so in what measure coating influence the original print and second, did the coating achieved and fulfilled its purpose. To tackle the first issue two colorimetric approaches were considered, the ΔE_{ab} which showed the difference between the coated samples and FOGRA PSO (Table 2) designated colour target and ΔE_{00} which provided the difference between aged and unaged samples (Sharma, Wu & Dalal, 2005; Mokrzycki & Tatol, 2011).

Table 2: Fogra PSO tagret values

Colour	*L**	*a**	*b**
C	55	-34	-52
M	47	74	-5
Y	87	-4	90
K	16	0	0

To measure ink density Techkon SpectroDens spectrophotometer was also used (D50, density status E, no polarization filter and calibarion on the paper sample). The equation (1) to describe ink density (D) is:

$$D = log_{10} 1/R \tag{1}$$

Where is: *R* – reflectance.
The ink density was measured before and after UV exposure to better assess the ink fading.

3. RESULTS AND DISCUSSION

After homogenization of TI/NC, coating and curing (24h), colorimetric analysis was conducted in three directions; first determining the difference between sample and colour target set by FOGRA PSO (ΔE_{ab}); second, the density difference. The third part is where the overall efficiency of the prepared TI/NC is measured between the initial unaged sample and sample after 30h AcA (ΔE_{00}). The comparison of the measured ΔE_{ab} values can be seen in the Table 3.

Table 3: Comparison of ΔEab

Sample	C	M	Y	K
Uncoated	1.97	3.74	4.28	3.05
WB	1.98	4.54	2.61	3.57
0.25% TI/NC	1.15	*5.47*	3.73	2.52
0.5% TI/NC	1.32	*6.95*	3.10	2.15
1% TI/NC	1.81	*6.88*	1.42	4.60

To observe the magenta closely, CIELAB coordinates are presented in Table 4. With increase of TiO_2 nanoparticles, a* values decrease while the b* coordinate's values increase.
From these results it could be noted that introduction of nanoparticles into the coating requests primary colours closer to the target CIE LAB values. One can note that the closest colour difference for black (initial value is not close to the allowed colour difference) was achieved on the sample with highest TiO_2 weight ratio. The ΔE_{ab} values rise with WB coating and this is most evident on magenta. The introduction of TI/NC nanoparticles will excel the values over the standard, but one must bare in mind that the initial $\Delta E_{ab\ i}$of uncoated sample was slightly high (ΔE_{ab}=4.54), although it was in accordance with ISO 12647-2:2013.

Table 4: CIELAB for magenta

Sample	*L**	*a**	*b**
Uncoated	47.49± 0.21	75.81± 0.18	-1.73± 0.21
WB	47.70 ± 0.18	77.01 ± 0.22	-1.64 ± 0.28
0.25% TI/NC	47.53 ± 0.13	76.49 ± 0.11	0.04 ± 0.23
0.5% TI/NC	47.72 ± 0.1	75.90 ± 0.08	2.01 ± 0.17
1% TI/NC	48.06 ± 0.08	74.46 ± 0.16	2.09 ± 0.36

As for the yellow samples coated with TI/NC (Table 5) the values in the b* coordinate rises, i.e. first added weight concentration increased the b* coordinate but further increase of the added nanoparticles caused decrease of the b* coordinate. The overall biggest shift is with the 0.25% TI/NC and with the Hybrid/T. Lowering the b* coordinate can be attributed to the TiO_2's whiteness.

Table 5: CIELAB for yellow

Sample	*L**	*a**	*b**
Uncoated	88.22 ± 0.17	-4.08 ± 0.16	94,44 ± 0.13
WB	88.24 ± 0.18	-4.49 ± 0.43	92.33 ± 1.02
0.25% TI/NC	88.20 ± 0.21	-4.15 ± 0.02	95.23 ± 0.5
0.5% TI/NC	88.56 ± 0.1	-4.49 ± 0.36	92.68 ± 0.46
1% TI/NC	88.15 ± 0.72	-4.26 ± 0.11	90.60 ± 0.31

To get a density value assessment, measurements were performed on the wedge patches of different nominal tone values before and after 30h AcA. The first measurement set was performed on 100% TV and second one on half tones. Tone values (TV) were calculated using Murray-Davies equation (4). In Table 8**Error! Reference source not found.**, density changes of the full tone or ΔD between 0h and 30h AcA are presented for TI/NC, this was done using equation 5. It can be noted that yellow samples have the biggest density difference. Although the difference is notable, it lowers with increase of TiO_2 nanocomposite weight ratio (%). As for the cyan and black samples, they proved to be the stable, i.e., almost no change can be noticed. Densitometry was also used to investigate the dot gain (also known as tone value increase, TVI), which is defined as the difference between the actual printed dot and nominal (ideal) digital dot (%), i.e., a dot could indicate 50% TV, but after printing it measures 65%. For the tone value control Murray-Davies equation (*Cmykhistory*, n.d.) (4) was used to calculate tone values (G). To investigate the density change (ΔD), equation 2 was used:

$$\Delta D = D_b - D_{AcA} \qquad (2)$$

Where are: ΔD – density difference, D_b – density before AcA, D_{AcA} – density after 30h AcA.

Table 6: ΔD between 0h and 30h AcA for TI/NC

Sample	C	M	Y	K
Uncoated	-0.09	0.14	0.38	-0.05
WB	-0.02	0.09	0.31	-0.03
0.25% TI/NC	0.00	0.11	0.32	0.03
0.5% TI/NC	0.01	0.10	0.29	0.04
1% TI/NC	-0.03	0.10	0.22	0.02

To investigate the half-tone values, the results for yellow are presented…. The yellow has proven to be most sensible to change, one for being the brightest process ink and due to its pigment which has the lowest lightfastness from the process inks (Ragauskas & Lucia, 1998b). It can be noted that with increase of nanoparticle weight ratio (%) overall density lowers. The 1% TI/NC proved to be the most resistant to change in the half-tones.

Table 7: ΔTV of yellow for TI/NC sample

Sample	20%	30%	40%	50%	60%
Uncoated	31.46	33.7	27.84	28.61	26.31
WB	24.69	24.26	26.94	22.50	19.32
0.25% TI/NC	20.16	20.15	16.56	14.57	11.27
0.5% TI/NC	5.22	8.25	11.48	11.77	7.14
1% TI/NC	-0.93	3.29	6.14	5.93	5.31

The colorimetric difference, ΔE_{00} between samples non-AcA samples and 30h AcA samples in comparison to WB can be seen in the Table 6. Most notable difference can be seen on the yellow samples. With increase of nanoparticles in the nanocomposite coating, the effect of UV exposure decreases. The TiO_2 nanoparticles can absorb the part of UV radiation. The gap band of TiO_2, is up to 329 nm. This leads to ink samples coated with TiO_2 to appear darker, as less light is reflected (Vukoje et al., 2022).

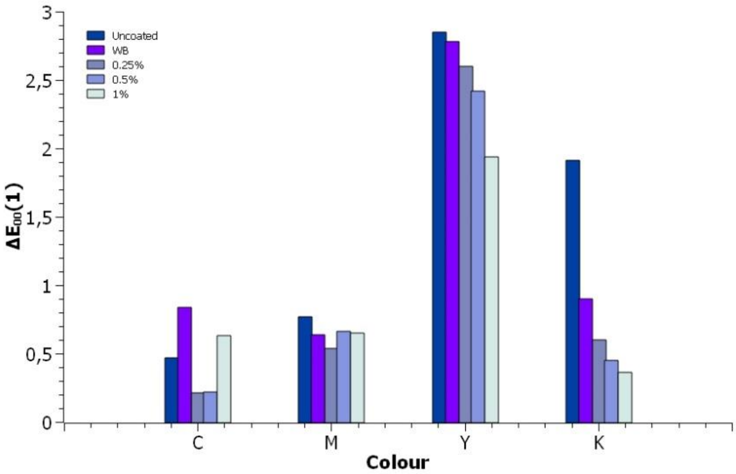

Figure 1: Colour difference (ΔE00) of TI/NC coated samples

The yellow samples had the biggest chromatic change as well as they had on ΔE_{00} (Table 7). This leads to conclusion that with the increase of nanoparticles weight ratio chromatic value difference decreases. Meanwhile, the ΔC for cyan dropped below 1 for 1% od added TiO_2, meaning that the colour became more intensive. This can be attributed to TiO_2 compound's colour of the natural state. TiO_2 as mentioned before is used also as white pigment but in its natural state it is blue (Krishnan & Shriwastav, 2021).

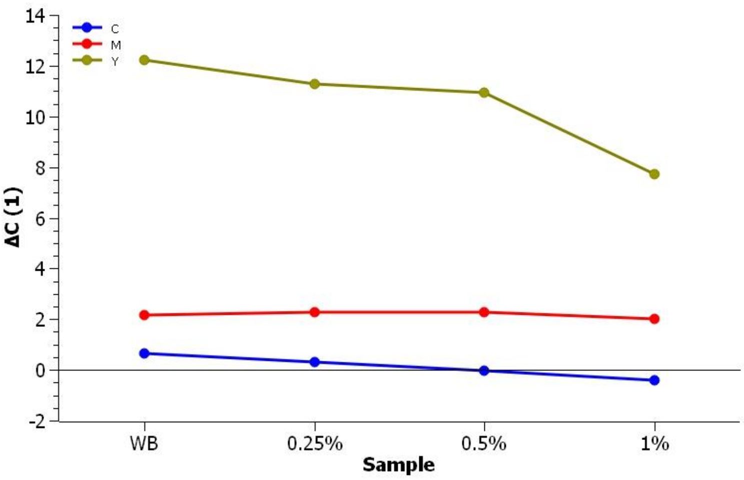

Figure 2: Chroma difference (ΔC) of TI/NC coated samples

4. CONCLUSION

The aim of this research was to compose a nanocomposite coating which will upgrade existing varnish and enable transfer of the visual message and function of the packaging throughout the product's lifespan. To do so, the newly formed nanocomposite compositions was created with commercially available water-based varnish as a base that was enriched with TiO2 and SiO2 nanoparticles in various weight ratios. The research provided the results from it can be concluded that the prepared nanocomposites can protect the printed paperboard packaging, with a relatively small effect on the colour. Although on some samples primary colours caused colour difference to the colour targets set by Fogra PSO above ΔE_{ab}=5, it must be considered that the initial values were close to the tolerance range (i.e., magenta was above ΔE_{ab} 4.5). Nevertheless, that means that usage of the proposed nanocomposites leads to better control of the printing and setting the primary colours closer to the colour targets, if printing in standardized mode. The results proved that TI/NC did increase the resistance to AcA induced by the UV radiation, i.e. reduced ink's fading. After tested for 30h AcA, TI/NC overall showed resistance to UV radiation, and it can be noted that increase of the nanoparticle's weight ratio will increase preservation of colour in the AcA process.

The Hybrid/T nanocomposite did upgrade the WB performance in terms of resistance to the AcA, where it showed great resistance to the lightfastness caused by the UV radiation. For instance, when compared to WB, it upgraded the system substantially, where in terms of magenta and yellow ink Hybrid/T performed 15 and 60% better.

This research provided a new method of possibility of varnish modification via added nanoparticle that can upgrade the protective benefits against outer environmental influence such as UV radiation. The newly formed nanocomposite coatings protected the printed image while having limited effect on the colorimetric values of printed inks.

5. ACKNOWLEDGMENTS

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INFLUENCE OF LIGHT INDUCED ACCELERATED AGEING ON SURFACE PROPERTIES OF CARDBOARD PACKAGING COATED BY TIO_2 NANOCOMPOSITES

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Abstract: *Although the primary role of packaging is to protect its content, it also acts as the carrier of both relevant information and visual identity. To enhance its properties, packaging materials are often coated with material which could provide barrier against chemicals, atmospheric conditions, or electromagnetic radiation. This paper focuses on the change of surface properties, i.e., wetting of a coated cardboard surface when packaging material is exposed to light induced accelerated ageing.*
Prepared printed cardboard was coated with nanocomposites composed of commercial water-based varnish and defined mass concentration of nanosized TiO_2. The prepared samples were subjected to accelerated ageing in a light chamber equipped with Xenon lamp. The characterization of the samples included determining contact angles with liquids of known surface tension and calculating surface free energy, determining water vapour transfer rate and performing burst resistance tests (Mullen burst test).
It can be concluded that the UV radiation influenced the cardboard substrate and varnished samples where AcA made some changes in the polar component due to forming of new oxidation products, which are less polar from its -OH group. However, with the introduction of nanoparticles, the UV influence was lowered in terms of surface parameters. The smallest TiO_2 weight ratio (0.25%) lowers the WVTR by 56%. Moreover, with increase of TiO_2 nanoparticles weight ratio, water permeability decreases significantly where the 0.5% TI/NC provided the best result (decrease of63%). Regarding the mechanical properties, although bursting strength of samples coated with nanocomposites is higher than the one coated by WB, there is no visible dependence between mechanical properties and weight ratio of nanoparticles.
This research showed that addition of TiO_2 nanoparticles will improve commercial varnish and will increase protection against UV radiation in terms of adhesion to the substrate and water vapour barrier.

Keywords*:* Coating, Nanocomposite, Packaging, Titanium dioxide (TiO_2), Accelerated ageing

1. INTRODUCTION

The global packaging industry grew from 843 billion US to 914 billion US from 2015 up to 2019, which is approx. 2%. Due to Covid-19 pandemic in 2020, the industry had a drop of approx. 6% (to 859 billion US), but according to forecasts, the “new dawn” of packaging is yet to come where in period of 2020-2030 is estimated that the industry will reach 1.13 trillion US (Smithers, n.d.). To have the continuous growth and to follow new trends, industry must develop more resistant and more sustainable packaging. In terms of secondary printed packaging application of these concepts must not degenerate its basic purpose and requirements. The basic purposes of the packaging are product protection and aesthetics (Makower, n.d.). Paper and its derivatives are ecologically acceptable materials since the use of single-use plastic is at its final (European Commision, 2021). On the other hand, paper as such, also has some issues, for example relative low resistance to outer influences like UV radiation, moisture or simply the weather in general. With this in mind, some quality factors of printed packaging can be reduced by an outer influence such as UV induced degradation, i.e., UV radiation causes the change in surface morphology and structural properties leading to the overall degradation of material (Hudika, 2022).
To diminish that setback, one of the solutions is to laminate protective layer or coat the printed packaging surface (*The Importance of Secondary Packaging*, n.d.; Soroka, 1999). Due to the limited protective properties of varnishes, further step in enhancing protection is to upgrade the existing varnish by modifying it to meet specific needs (Cigula, Hudika & Vukoje, 2021; Hudika, Cigula & Vukoje, 2021; Hudika, 2022). The water-based varnish (denominated as WB) is the most “eco-friendly” coating type on the market that has the industrial, technological, and commercial capability since it does not create hazardous vaporization when handling or curing, but WB varnish has some downsides when compared to

UV varnish for instance in terms of lightfastness, barrier properties etc. (Kipphan, 2001a; Yam, 2010; *3 Oak News - Why are water based lacquers becoming so popular*, 2015; Moreira *et al.*, 2018). Some research has been made with incorporation of nano sized compounds in commercial varnishes that improved packaging properties (Zvekic *et al.*, 2011; Salla, Pandey & Srinivas, 2012; Cigula, Hudika & Vukoje, 2021; Hudika, Cigula & Vukoje, 2021; Hudika, 2022). One of those compounds is a metal oxide, titanium-dioxide (TiO_2), well known for its ability to absorb UV radiation and commonly used as part of inks, colours, coatings, sunscreens, etc. (Kumar, Verma & Singla, 2012; Hudika *et al.*, 2020; Pfaff, 2021).
The aim of this research was to compose a nanocomposite coating containing TiO_2 (denoted as TI/NC) which will upgrade existing varnish in terms of preservation of printed packaging under influence of UV radiation, therefore preserving the function of the packaging throughout the assumed product's lifespan. In the same time, to implement those particles into a commercially available varnish enables easier implementation of newly formed composite to production workflow.

2. MATERIALS AND METHODS

For this research, lithographic offset printed samples were coated with prepared nanocomposites in various nanoparticle's weight ratios, where the base of nanocoating was commercial water-based varnish while chosen nanoparticle was titanium dioxide (TiO_2).
The printing of the samples for the purpose of this research was done in accordance with the ISO 12647-2:2013 standard, i.e., FOGRA PSO (ISO/TC 130 Graphic technology, 2013). The sheetfed offset printing was conducted using industrial printing press KBA 105 PRO-5+L FAPC. The prints were made in four colour process (CMYK). The printing inks used were Novavit F918 Supreme Bio inks made by Flint Group (*Flintgrp, n.d)*. The printing substrate was UPM Finesse white gloss cardboard WFC (Woodfree coated) grade with gloss coating and grammage of 300g/m^2. Cardboard was conditioned and stored in environment at temperature of (23 ± 1) °C and (50–55) % relative humidity for 48 hours before the printing process.
The nanocomposite's base was water-based varnish (denoted as WB) with production name Terra High Gloss Coating G9/285 by Actega USA. The varnish is to be used in a varnishing unit at lithographic printing press (a flexographic unit) (*TERRAWET®, n.d.*). The nanoparticles were TiO_2 from Sigma Aldrich with the production code EC 2015-282-2 (Titan dioxide, Sigma A., 2012). To determine weight ratios, compounds (base and nanoparticles) were weighed using Mettler Toledo XS205DU Dual range Analytic Scale. Preliminary showed that adding NPs increases viscosity of the composite above boundaries set by coating technology. In flexography, viscosity should not excide 0.7 Pa*s (Kipphan, 2001b). To counter that, initial WB was diluted by adding 5% wt. of demineralized water. The nanocomposites were prepared by homogenization of nanoparticles into water-based varnish using ultrasound dispenser Hielscher UP100H from 20 to 40 minutes depending on the nanoparticles weight ratio (%), as presented in Table 1.

Table 1: Homogenisation time for preparing nanocomposites

Weight ratio of TiO_2 (%)	Homogenization time (min.)
0.25	20
0.5	30
1	35

Time-to-weight ratio of homogenization process derived from previous testing and proved to be the most optimal one using this setup. During the course of homogenization process the mixture was cooled down in cooling bath filled with water at temperature of 5°C.
To apply the prepared nanocomposite coating onto the prepared prints, IGT F1 printability tester for flexography was used (IGT, n.d.). For the coating process, IGT 402-258 anilox roller with 90 l/cm screen line and 18 ml/m^2 cell volume was used. The coating was transferred by the usage of Kodak Flexcel NX with DigiCap NX patterning flexographic polymer printing plate. The printing plate had 100% TV coverage (*Workflowhelp, n.d.*).

To investigate the influence of lightfastness of the prepared samples (packaging material), accelerated aging (AcA) by Xenon lamp chamber was used. To create those conditions Solarbox 1500 e chamber was used. As the packaging is not exposed to the Sunlight, an indoor filter S208/S408 (artificial daylight) was used. Irradiation in the chamber was set to 550 W/m^2 and the temperature of 50 °C (30h of AcA, i.e., to electromagnetic energy of 59 MJ/m^2). The experiment was done in accordance with the ISO 4892-2 standard (International Organization for Standardization, 2013).

To characterise the surface properties before and after 30h AcA, surface free energy (SFE) and adhesion parameters were calculated. The SFE can be also referred to as the surface tension of a solid. The SFE is presented in mN/m in the SI system or dynes/cm in the metric system. In terms of physics, the interaction in the solid-liquid system is important as it determines the adhesion force. This is an important feature in the printing industry as well, as paints, varnishes and must adhere on the printing substrate surface To calculate SFE of solid surfaces, contact angles (CA) of reference liquids (liquids with known surface tension) must be measured.

For the purposes of this paper, contact angles were measured using sessile drop method and Laplace-Young fitting, ten times per sample, at different sample positions. The droplet shape was a spherical cap, and the volume was set to 1 µl. The measurements of the contact angles were performed 2 seconds after the initial contact between liquid and the surface. From the CA results, SFE was calculated. When SFE is high, the solid is easily wetted. To obtain the optimal approximation of the SFE in the Owens, Wendt, Rabel and Kaelble (OWRK) method with the use of Equation 1 (Owens and Wendt, 1969). For this method a minimum of three liquids with known SFE values have to be applied. In order to diminish possible errors, we measured CA of four liquids with known properties: water, diiodomethane, formamide and glycerol. The Surface tension and its dispersive and polar part of known liquids is presented in *Table 2*.

Table 2: Liquids used for contact angle measurements

Liquid	SFT (total)	SFT (disp.)	SFT (polar)
Water (Ström et al.)	72.80	21.80	51.00
Diiodomethane (Ström et al.)	50.80	50.80	0.00
Glycerol (Ström et al.)	63.40	37.00	26.40
Formamide (Van Oss et al.)	58.00	39.00	19.00

The equation used for the calculation of SFE using the OWKR method:

$$\frac{(1+\cos\theta)*\sigma_s}{2\sqrt{\sigma_l^D}} = \sqrt{\sigma_s^P}\sqrt{\frac{\sigma_l^P}{\sigma_l^D}} + \sqrt{\sigma_s^D} \tag{1}$$

Where are: γ_s – surface tension of the solid, γ_l – surface tension of the liquid, γ^d– dispersive part of surface tension, γ^p– polar phase of surface tension, Θ- contact angle.

To determine adhesion between applied coatings and the printing substrate, adhesion parameters were determined. The thermodynamic work of adhesion W_{12} between two phases was calculated using equation (2):

$$W_{12} = \gamma_1 + \gamma_2 + \gamma_{12} \tag{2}$$

Where are: γ_1 – refers to SFE of the first layer, γ_2 – refers to SFE of the second layer, i.e., printed sample and coating, γ_{12} – refers to interfacial tension between first and second solid.

Using the Owens-Wendt model, the SFE of the interface was determined according to the equation (3):

$$\gamma_{12} = \gamma_1 + \gamma_2 - 2(\sqrt{\gamma_1^d * \gamma_2^d} + \sqrt{\gamma_1^p * \gamma_2^p} \qquad (3)$$

Where are: γ^d– dispersive component of surface tension, γ^p– polar component of surface tension, while indexes 1 and 2 mean first and second material.

The adhesion parameter of wetting S_{12} was calculated using equation (4):

$$S_{12} = \gamma_1 - \gamma_2 - \gamma_{12} \qquad (4)$$

Optimal adhesion is achieved if the following conditions of the adhesion parameters are fulfilled: thermodynamic work of adhesion must be maximal, interfacial tension must be minimal and close to zero, and wetting must be equal to or greater than zero (Petković *et al.*, 2019). The SFE calculation and CA measurements were performed using the Data Physics OCA 30 goniometer, with the support of Dataphysics SCA 20 software (*Dataphysics-instruments, n.d.*).

The barrier to the water vapour of the prepared samples was determining by calculating water transfer rate (WVTR). The WVTR test was done via permeability cups made by TQC Sheen with the production name VF 2201 in accordance the ASTM D1653 standard (American Society for Testing and Materials, 2021). Test cup consists of a cup, seal and a cover ring. The seal is designed to prevent turning when closing the cup while the cover ring secures the sample in place. The cup is filled with 25 ml of demineralized water, sealed weighted with analytic weight (the same used as for the weighing of the coatings components). The WVTR was calculated using equation (5):

$$WVTR = \frac{\Delta m}{\Delta t * A} \qquad (5)$$

Where are: *Δm* - change of the container mass in grams, *Δt* - time between sample weighing given in days, *A* - area of the sample in m^2.

The settings for this test were: surroundings temperature 22 ± 1 °C and RH of 60 ± 2%. Weighting of samples was performed at beginning and after 24, 48 and 72 hours after test began.

The bursting strength measurements for this test were conducted by means of Lorentzen & Wettre Bursting Strength Tester. The tested samples were cut to ø=100 mm, while the testing area was ø=50 mm. The rubber diaphragm is ø=33.1 mm. Under the diaphragm, the pressure in the Lorentzen & Wettre burst tester rises from 70 kPa up to 1400 kPa in accordance to the ISO 2759-2001 standard (International Organization for Standardization, 2014).

3. RESULTS AND DISCUSSION

Table 3 presents all calculated SFE values (total/disp./polar) of prepared samples. As mentioned before, for this research four liquids (Table 2), with know SFT were applied onto the solid surface to obtain CAs which were used for SFE calculations. The SFE calculations were conducted using average values of measured CAs.

The presented results indicate that at plain cardboard and ink without any coating the SFE decreases with the AcA. At the cardboard substrate this is due to the increase of the dispersive part of SFE while at the ink the polar part of SFE increases. It can be noted that the plain cardboard after 30h AcA has some change in the polar component due to forming of new oxidation products, which are less polar from its -OH group. Kaolin, also one of the ingredients of the cardboard is a very hydrophilic substance as well (Bundy and Ishley, 1991). The ink contains vegetable oil in its composition, which is influenced by the UV radiation, therefore the ester bounds are destroyed, and the polarity has risen (Erhan &Bagby, 1995).

Table 3: Calculated SFE of samples before and after 30h AcA

Sample	*Before AcA*			*After 30 h AcA*		
	SFE (Total) / (γ)	Dispersive SFE /(γ^d)	Polar SFE/ (γ^p)	SFE (Total) / (γ)	Dispersive SFE /(γ^d)	Polar SFE/ (γ^p)
Cardboard	27.06	20.27	6.81	28.01	22.32	5.69
Ink	32.41	30.83	1.57	35.03	30.58	4.45
WB	33.68	28.61	5.08	30.85	26.45	4.41
0.25% TiO_2	33.59	29.15	4.45	28.82	22.69	6.13
0.5% TiO_2	37.03	34.94	2.09	36.18	33.24	2.94
1% TiO_2	38.08	37.07	1	34.55	28.66	5.89

On the other hand, it is visible that coated samples decreased their SFE due to the AcA mainly due to the change of the dispersive part of SFE. In addition, the SFE of coated samples is higher than of the uncoated ones. The addition of the TiO_2 to the coatings will increase the SFE.

WB samples, after 30h AcA have lower polar component but higher total SFE values. This can be attributed to the acrylic resin that is a common ingredient in water based varnishes and it tends to become more hydrophobic after exposure to UV or ozone (Dou *et al.*, 2021). On the other hand, with the increase of TiO_2 nanoparticle weight ratio (%), the wettability of TiO_2 coated samples also increases but after the AcA it lowers. According to the Stevens et al., with UV exposure, the surface properties in terms of SFE change, increasing the hydrophilic properties of TiO_2 (Stevens *et al.*, 2003).

In Table 4 values of calculated adhesion parameters are presented. To evaluate results, all three parameters (*γ_{12},, and S_{12}*) should be observed together as a whole. From the presented, the best adhesion was achieved adding 0.25% of TiO_2 in the nanocomposite coating.

The highest work of the adhesion was achieved between the print and the coating with 1% TI/NC (70.12 mJ/m^2). Furthermore, the increased concentration of resulted with the increased work of adhesion, pointing to the increased work necessary to separate the two layers and improved adhesion. From SFE of the interphase and wetting coefficients one can also note that SFE of interphase generally lowers as the wetting coefficient increase 0.25% TI/NC / 1% TI/NC (S_1 = - 1.94 mJ/m^2 / S_1 = - 6.04 mJ/m^2). However, SFE of the interphase is close to zero for all samples, which is favourable for the optimal adhesion.

Table 4: Adhesion parameters between the plain print and - nanocomposite coatings

	Adhesion parameters (mJm^{-2})		
Sample	*γ_{12}*	*W_{12}*	*S_{12}*
WB	1.13	66.64	-2.71
0.25% TiO_2	0.75	65.24	-1.94
0.5% TiO_2	0.17	69.26	-4.80
1% TiO_2	0.36	70.12	-6.04

As mentioned before, barrier properties of substrates can be upgraded by lamination or by coating, where introduction of various compounds that could improve surface impregnation is beneficial. Increase of TiO_2 nanoparticles weight ratio, water permeability decreases significantly (Figure 1). The *WVTR* results of 0h remained more or the less unchanged regardless of the NPs weigh ratio (%). After 30h AcA the water permeability lowers for WB, but slightly increases for samples coated with nanocomposites. The TiO_2 is a metal oxide, which is a compound that is found to have good water permeability features in various bulk studies (Nazari & Riahi, 2011; Benkoula *et al.*, 2015; Hegyi *et al.*, 2020).

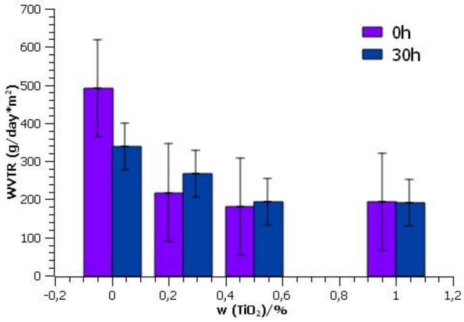

Figure 1: WWTR in dependence to the added TiO_2 in the nanocomposite

In the Figure 2

Figure 2, bursting strength diagram for TI/NC samples is presented. It can be noted that the highest value was achieved on sample coated with nanocomposite containing 0.25% TiO_2 (283.20 kPa) while other samples coated with nanocomposites samples have slightly higher values than the WB in the start (266.25 kPa). The results after 30h AcA show that lower change was noted by samples coated with nanocomposites containing higher weight ratios of TiO_2, which can be attributed to the TiO_2 ability to absorb the UV radiation. The increase of the TiO_2 nanoparticle's weight ratio did not show any significant upgrade to the sample performance. On the 0.25% TI/NC sample, the change is notable before and after 30h AcA (approx. 32 kPa).

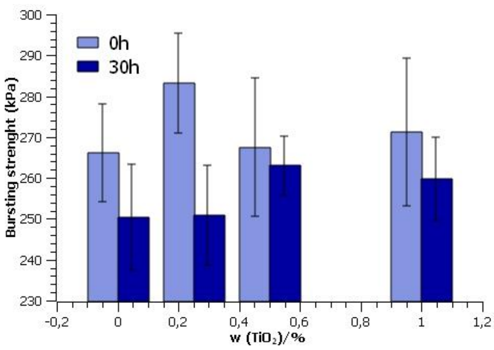

Figure 2: Bursting strength in dependence to the added TiO_2 in the nanocomposite

4. CONCLUSION

The aim of this research was to compose a nanocomposite coating which will upgrade properties of existing varnish in terms of preservation of printed packaging under influence of UV radiation (Sunlight), i.e., preserving the function of the packaging throughout the product's lifespan. To do so, the newly formed nanocomposite compositions were created with commercially available water-based varnish as a base that was enriched with TiO_2 nanoparticles in various weight ratios.

The results showed that SFE of samples coated with nanocomposites will decrease with weight ratio of added TiO_2 due to the increase of the dispersive part of the SFE. The highest work of the adhesion was achieved between the print and the coating with nanocomposite containing 1% TiO_2, but it is visible that even lower weight ratios of the nanoparticles will result in similar values (with exception of the 0.25%), which are higher than the one achieved at WB. Observing all adhesion parameters, it is clear that although adding TiO_2 will increase S_{12} (with the exception of 0.25% TiO_2), the interface tension decreases to 0 and work of adhesion increasing could mean that adhesion will not decrease. The smallest TiO_2 weight ratio (0.25%) lowers the WVTR by 56%. Moreover, with increase of TiO_2 weight ratio, water permeability decreases significantly where the nanocomposite with added 0.5% wt. of TiO_2 provided the best result (63% decrease). Regarding the mechanical properties, although bursting strength of samples coated with nanocomposites is higher than the one coated by WB, there is no visible dependence between mechanical properties and weight ratio of nanoparticles.

This research showed that adding TiO_2 nanoparticles will improve commercial varnish and will provide increased protective benefits against outer environmental influence such as UV radiation in terms of adhesion to the substrate and barrier to the water vapour.

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BACTERIAL NANOCELLULOSE ENHANCED CARDBOARD ADHESION JOINT TESTED WITH Y-PEEL AND T-PEEL TESTING METHODS

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Abstract: *The demands on the adhesive joints for packaging are important during conversion, transport, storage, shelf exposure, and end-of-life operations of paper-based packaging. During this lifecycle, the adhesive joint is under constant loading from environmental conditions (e.g. forces from the surroundings such as other packaging units, dynamical forces from the machines, and/or climate changes such as temperature and relative humidity). The contribution from mechanical bonding can be particularly important for solid boards where the adhesive bonding is achieved through the mechanical interlocking of the adhesive into irregularities and pores of the carton-board surface. The formation of an adhesive joint with dispersion adhesives is affected by the rheological properties of the adhesive layer, the structure and absorption properties of the board surface. There are many test methods intended to determine the strength of an adhesive including peel, shear, cleavage and tension tests. Peel tests are common for tapes, labels, coatings and other bonded materials. The most common methods include T peel, Y peel and angle peel tests using tensile test machines. The cardboard adhesives that are currently in use have a large share of dispersion adhesives (PVAC, EVA, acrylic and PU) which are water-based adhesive systems that form bonds through physical hardening when the water evaporates. Sustainability issues require replacement of these chemicals with bio-based ones. Based on our previous research, bacterial nanocellulose (BNC) can increase the bonding strength of adhesive joints for different kinds of materials. In this study, 3 different cardboards with dispersion adhesive which had the addition of 7% of BNC were used. Zwick multitester with two methods (Y peel and T peel) was used to determine the strength of the cardboard joints. The results indicate differences in force elongation results due to different testing methods, where some of the cardboard properties and BNC had a positive effect on the overall adhesion joint strength.*

Key words: cardboard adhesion, bacterial nanocellulose, Y peel, T peel

1. INTRODUCTION

Gluing is a very important process in the conversion of coated paperboard packaging products, that is used to join paperboard surfaces together, providing a permanent join. It is also used to erect and close cartons and to provide several functions to graphical products. For a predictable and reliable way to adhere the paperboards is by careful choice of the surface sizing system, interlaminar strength and pigment coating. Gluability is especially important for high packaging line efficiency and runnability. The glue seam must withstand forces arising from the package contents during the lifetime of the package. The established way to assess gluability is to examine the tear behaviour of a glue seam between a pigment-coated surface and, usually, the reverse side of a carton flap. When a barrier effect is created at the surface of either substrate, it slows down the dehydration rate of the glue considerably thereby reducing the tendency to tear fibre upon separation. The main criterion in determining successful gluing of packaging products is almost always 100% fibre tear upon separation of the glue joint. Failure to achieve fibre tear along the glue joint is considered a failure in packaging conversion. In a recent study by Dohr and Hirn (2021) different paper properties of the adhesive strength of starch gluing were investigated with surface roughness, wettability and glue penetration measurements. The results suggest that the roughness (macro) played a minor part while the main parameters were fibre wetting and penetration of the glue into the fibres.

Nanocelluloses (i.e., bacterial nanocellulose, cellulose nanocrystals, and cellulose nanofibrils) are cellulose-based materials with at least one dimension in the nanoscale. These materials have unique and useful properties and have been shown to assemble at oil-water interfaces and impart new functionality to emulsion and latex systems (Kedzior, Marway & Cranston, 2020). Cellulose fibres on the nanoscale are divided in four groups: (1) bacterial cellulose nanofibers, (2) cellulose nanofibers prepared by electrospinning, (3) nano fibrillated cellulose plant cell fibres and (4) nanorods or cellulose whiskers. Processing techniques have a significant impact on the adhesion properties of the resulting cellulose nanofibers in composite material applications. Bacterial cellulose structure is more homogeneous than standard cellulose. This property together with a lack of irregularities lead to both superior reinforcement and thermal expansion properties when used with matrix materials. The nanocellulose inter- and intra-molecular binding are accomplished through hydrogen bonding. Bacterial cellulose fibres have normally a degree of polymerization between 2000 and 6000 (Iguchi, Yamanaka, Budhiono, 2000). This relatively low degree of polymerization may limit the adhesion through interpenetrating networks or mechanical interlocking and, for the most part, the adhesion in composite materials is limited to hydrogen bonding through other mechanisms of adhesion that need to be explored.

An overview by Li et al. (Li et al., 2021) based on previous research concluded that the addition of nanocellulose in the pulp, that the surface of NC which is rich with free hydroxyl groups, will be distributed in the gaps between the fibres or on the fibre surface. Nanocellulose is closely combined with the pulp fibres, and therefore it strengthen the adhesion between the fibres, fill the voids in the paper, and achieve the effect of improving the strength of the paper. The research (Kedzior et al., 2020) cellulose and nanocellulose surface issues regarding adhesion conclude that in heterogeneous water-based polymer systems, when BNC, CNCs, and CNFs have been incorporated either by blending with the dispersion of polymer particles post-synthesis, or by adding nanocellulose at the beginning of the polymerization reaction, i.e., in situ incorporation, several interactions occur. The interactions between nanocellulose and monomer droplets/polymer particles are governed by hydrogen bonding, van der Waals forces, surface activity, hydrophobic interactions (if the nanocellulose is surface-modified for compatibility), and they may even be tethered to each other if the polymerization initiator induces some free radical reaction sites on the nanocellulose (Dastjerdi, Cranston & Dube, 2018; Ghosh, Dev & Samanta, 1995; Misra, Mehta & Ketarpal, 1984; Zhou et al., 2011). Due to hydrophilic nature of unmodified nanocellulose, it is generally inferred to be in the aqueous phase (i.e., outside of/between the polymer particles) when blended with latexes or in situ polymerized in the presence of a noninteracting surfactant (that stabilizes the emulsion polymerization) (Kedzior, Marway & Cranston, 2017). As such, the location of nanocellulose relative to the polymer particles and ultimately, their influence on product properties, is a fine balance of the interactions between all components in the polymerization reaction. Despite deep literature review, we have not found a great deal of publication on the topic of using nanocellulose addition in cardboard adhesives as they cover mostly adhesives for wood panels which due to differences in the surface structure have a somewhat different locking mechanism. For example, a recent study of adding nanocellulose components to PVAc adhesives used in cardboard joint gluing showed that replacing parts of the adhesive gave mixed results regarding the z-tensile strength, but almost all concentrations (0.5, 1 and 2 %) were beneficial for the T peel adhesion tests at the room temperature as the average peel force (N/mm) increased for all samples.

The adhesive bonding in general can fail with three different types of failing mechanisms: adhesive failure, cohesive failure or substrate failure. Adhesive failure is mainly caused by improper penetration of the adhesive onto the surface, the substrate failure is connected with the internal bonding of the substrate (in paper packaging the interlocking of fibres and additives or coatings) and the cohesive failure is connected with the insufficient cohesive forces in the adhesive or coating layer itself. To test these failures different kinds of the tests have been developed. The traditional way of analysing the mechanical strength of a hot-melt adhesive joint in the converting industry is to look at the fracture surfaces after manual peeling. The joint is acceptable if there are more than 50% fibres on the fractured adhesive surface; otherwise, it is considered as bad. However, this method is very subjective and based on personal skills and experience (Korin et al., 2007). Peel tests are the most used type of tests for determining adhesion for thin ductile materials because the tests are fast and easy to make and the test rig is simple. The theory behind peel tests is easily derived when the simplifications that the peel arm is infinitely stiff when pulled and flexible in the bending which is made, the total energy to separate the surfaces for these assumptions is known as $G^{\infty E}$. To calculate the energy required for separation, the parameters shown in Figure 1. must be known.

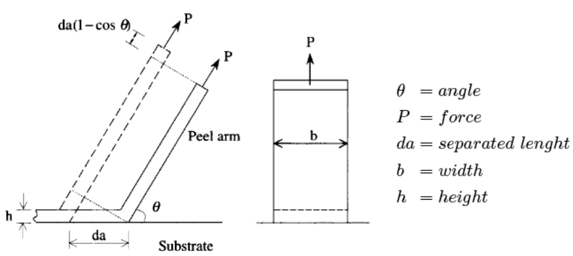

Figure 1: Basic peel testing mechanism (Kinloch & Williams, 2002)

The energy is given by the work done by the force (Eq. 1). The distance of the force is da(1 - cos θ) which gives the energy P × da(1 - cos θ) that is required to separate the area b × da, (Kinloch & Williams, 2002).

$$G^{\infty E} = P \cdot \frac{da(1-\cos\theta)}{b \cdot da} = \frac{P}{b}(1-\cos\theta) \tag{1}$$

This is a very simplified model but it is the basic concept for the peel tests. Effects that come into account when a more advanced model is used are elongation of the peeling arm, bending and plasticity in the peel front, kinetic energy and root rotation (the angle in the peel front) (Kinloch & Williams, 2002).

Different kinds of peel tests have been introduced for fibre-based packaging materials like the T-peel test (Edin, Ödberg & Sterte, 2002), the angle peel test (Kinloch, Lau & Williams, 1994) and Y-peel tests (Korin et al., 2007). In the T-peel test method, the adhesive joint is not fixed relative to the tail and the tail is free to move during the test, while in the other two methods no arbitrary movement is allowed. The Y-peel method is a redesign of the constrained T-peel test.

To completely cover all aspects of the substrate and adhesive failures, a list of an extended set of tests is needed like the surface wettability test, PPS Roughness test, K&N ink stain test, water interference method, SEM microscopy, z-directional or internal bond testing which are covering the substrate side of the adhesion system. In our research, we have used the Bendtsen roughness and porosity for the cardboard surface morphology detection, penetration dynamics analyser for water penetration measurements and contact angle measurements for the wettability of the surfaces. For peel testing we have used two methods: T and Y peel testing and we have calculated the forces of the adhesive joint failure.

2. METHODS AND MATERIALS

In this research three commercial coated cardboards (Sample 3 - MM Excellent TOP 230 g/m^2, Sample 2 - MM Grafopak 250 g/m^2, Sample 1 - Kromopak 230g/m^2) were tested with adhesive EUKALIN 6550-VL-80 water-based dispersion (REF samples) (Brookfield viscosity of 1000 mPas). The adhesive was enhanced with a 7% BNC solution (BNC samples) wich was obtained from an alternative raw material – vinegar mother as described in an article by Lavrič, Medvešček and Skočaj (Lavrič, Medvešček and Skočaj, 2020). The surface roughness of the substrates was evaluated according to ISO 8791-2:2013 standard, and the porosity according to ISO 5636-3:2013. The dynamic contact angle (the wettability of the samples) was evaluated with the Fibrodat 1100 measuring device (Fibro System AB, Gustafs, Sweden) using distilled water drops of 4 µl following Tappi T 588 standard. We have used also ultrasound dynamic penetration measurements using the Emtec PDA measurement device.

The samples were prepared according to the ASTM standard D1876 for the T peel testing and the amount of glue was 0.4 g per sample. To ensure even pressure on the whole surface the samples were pressed with a standardized FINAT 2 kg roller. The measurements of the peel test were done on Zwick multi testing machines using the 10 KN measuring head and adjusted specimen holders.

3. RESULTS

The measurement of the roughness and porosity with the airflow-based method is a standard way of the surface morphology and porosity of different cardboards. The measured results presented in Figure 2. show that there are quite large differences in the coated and uncoated sides of the used cardboards. As the adhesive penetrates both sides when a box is glued on the production line the differences in these parameters can indicate changes in the peel adhesion force. Sample 2 had the largest coated side roughness with a value of 480.55 ml/min and the uncoated side had 2491.9 ml/min. The Bendtsen porosity (Figure 3.) shows that sample 2 again was different from the other two samples, where sample 2 both on the coated and uncoated sample sides had low air permeability (3.54 ml/min for the coated and 2.26 ml/min for the uncoated sides), while sample 1 had the highest air permeability.

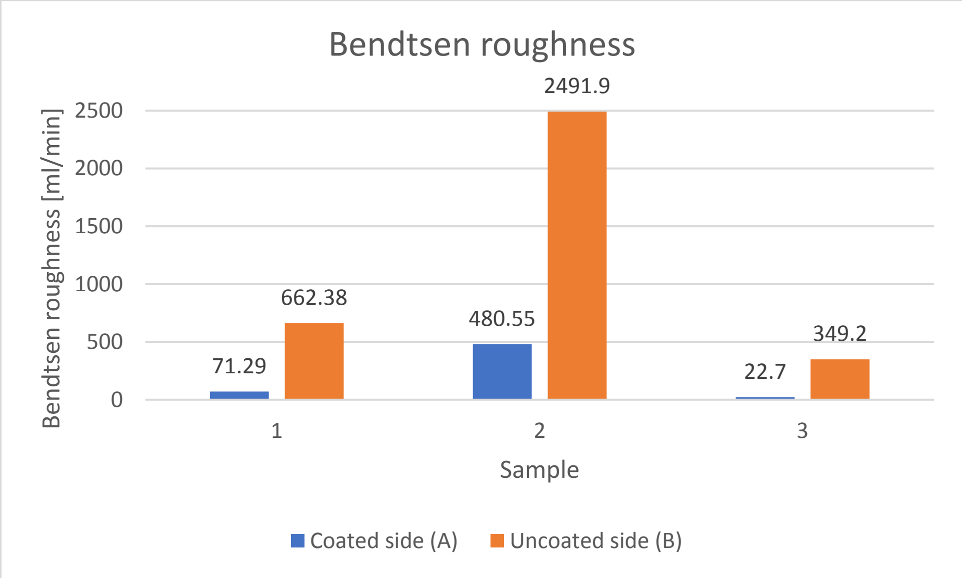

Figure 2: Bendtsen roughness of the sample cardboards

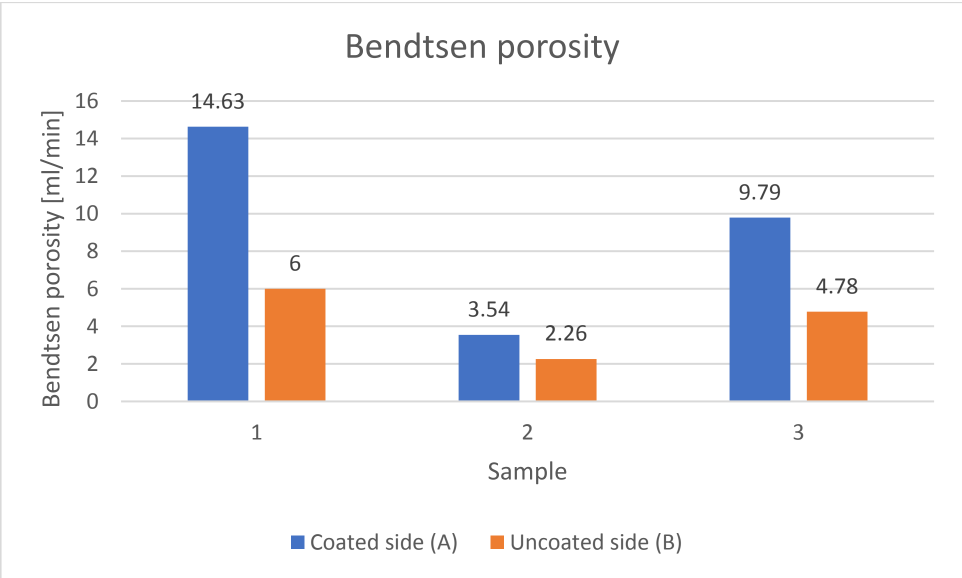

Figure 3: Bendtsen porosity of the sample cardboards

As air and liquids penetrate the surface in different ways we have also tested the samples with the ultrasound method for determining the dynamic penetration of liquids. For the measurements, the Emtec PDA measurement device was used with water and water as the working fluid. Signal intensity decline which indicates the penetration mechanism into the fibrous substrate was measured during 1 minute time. From the absorption curves in Figure 4. one can observe that the surface is quite closed as almost no liquid penetration is happening in the first 2 seconds of the samples exposed to water, except for the coated side of sample 1, which also is similar to the air porosity results. On the other hand for sample 2 (both coated and uncoated)

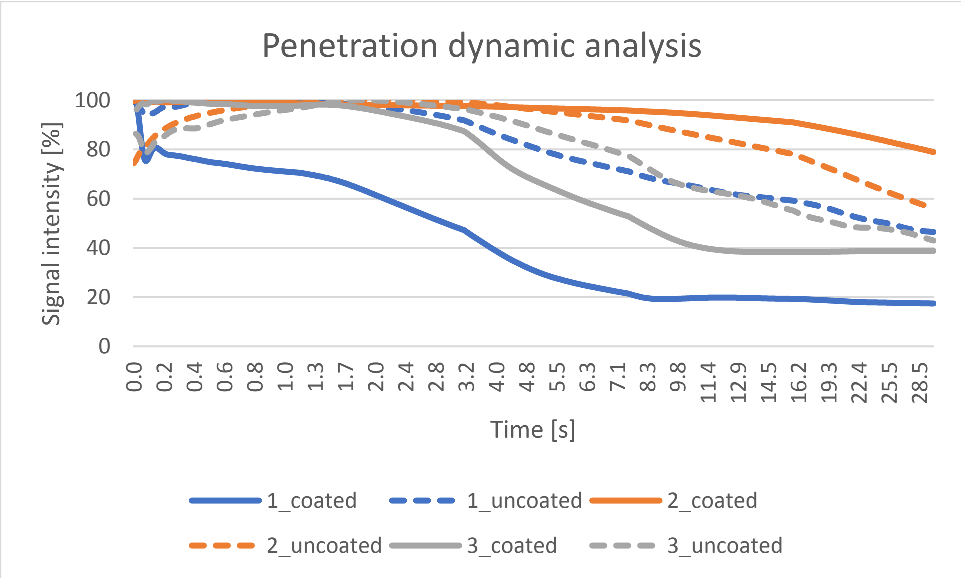

Figure 4: Penetration dynamic analysis of samples with water

The measurement of the dynamic contact angle is presented in Figure 5.

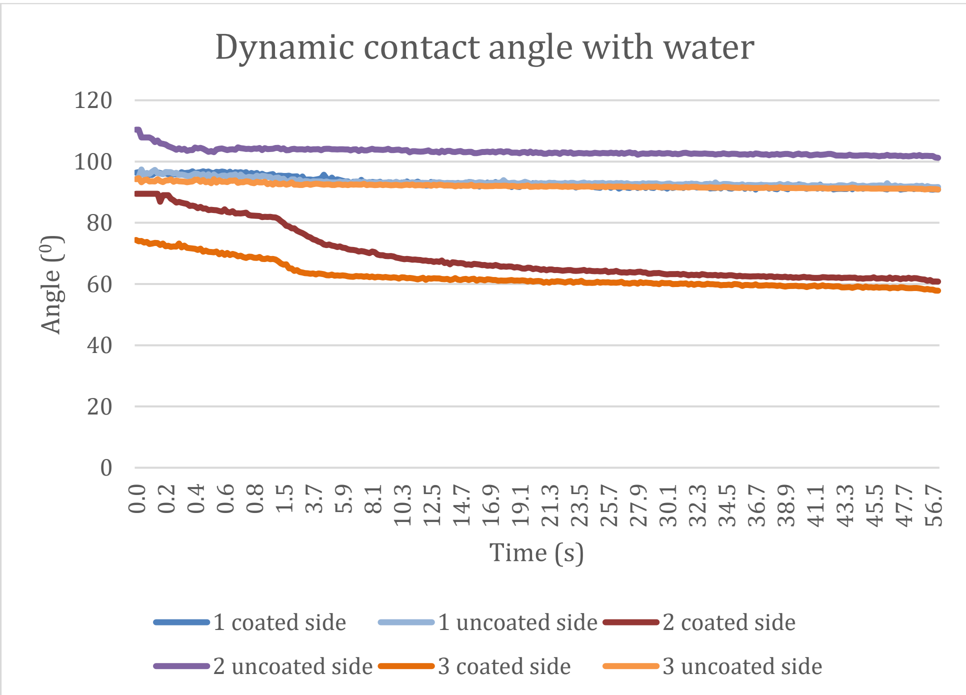

Figure 5: Contact angle measurement of the samples

Before mentioned properties were confirmed again. Sample 2 had the largest contact angle values on the uncoated side and lower value for the coated side (at 1 s 104^0 for the uncoated side of sample 2 and 81.94^0 for the coated side). Sample 1 had the most similar values for both sides at 1s (95.75^0 and 94.95^0) while sample 3 had quite a low contact angle of 68.12^0 for the coated side and 92.93^0 for the uncoated side.

The peel tests were performed with the same speed 254 mm/min. and with a minimal force of 0.1 N. The clamps were also adjusted so the glued cardboard samples were aligned at the same measuring distance. The results of the Y peel are presented in Figure 6 and 7, while the results for the T peel testing is presented in Figure 8 and 9.

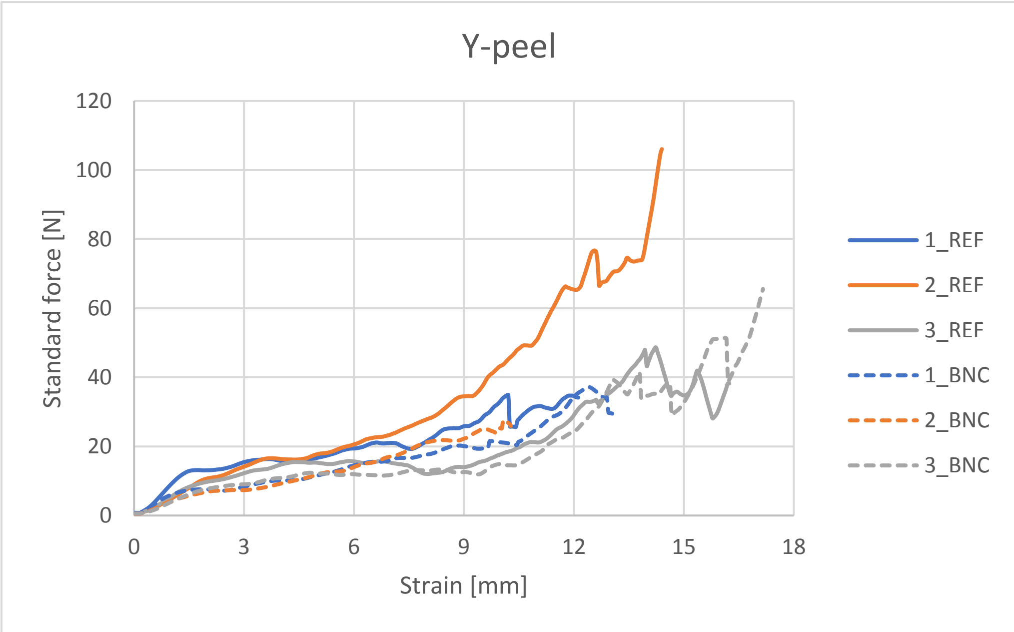

Figure 6: The standard force and strain of the measured samples with the Y peel method

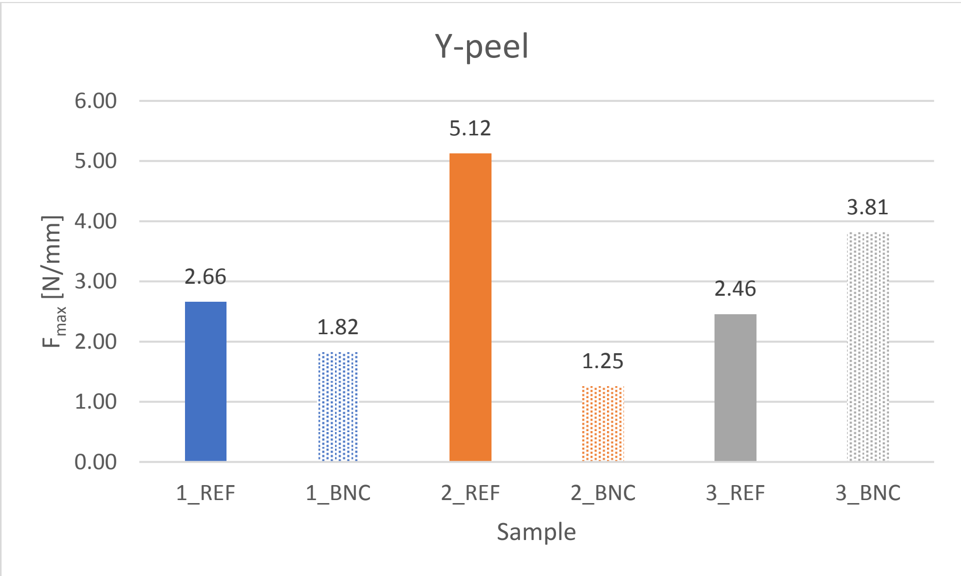

Figure 7: The max force of the measured samples with the Y peel method

From the measurement with the Y peel method, we can observe that the 2_REF sample had the largest force measured. In parallel it was observed, that the same cardboard had the roughest and closed surface and the smallest joint adhesion with the use of BNC. For other samples, the adhesion strength was slightly lower for sample 1 (2.66 N/mm to 1.82 N/mm), but a little bit higher for sample 3 (3.81 N/mm to 2.46 N/mm). It should be noted that for all samples the internal bonding between plies of the cardboard was the main cause of the adhesion joint failure, and the crack propagation was visible in the form of fibre tear. For the T peel testing the results showed some similarities, but opposite results for sample 2.

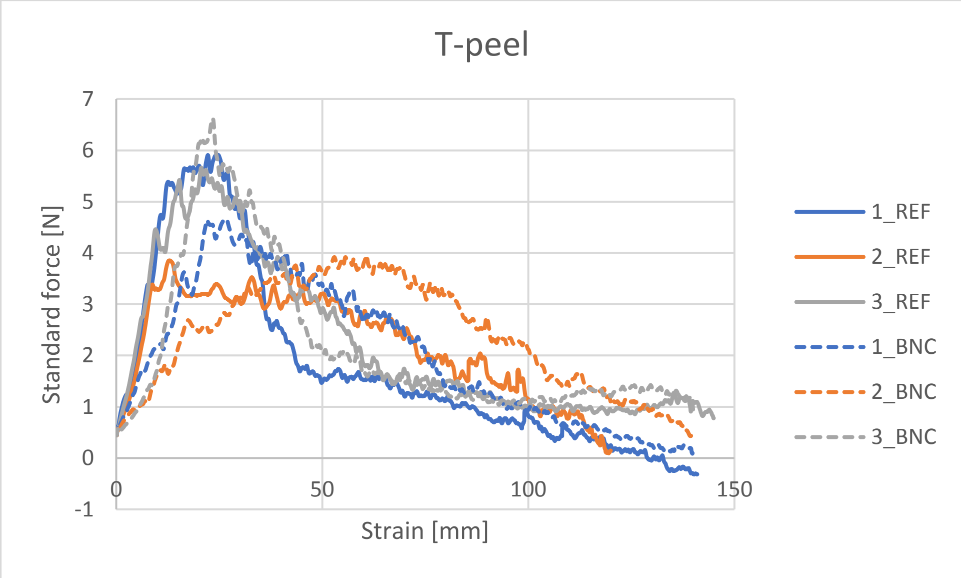

Figure 8: The standard force and strain of the measured samples with the T peel method

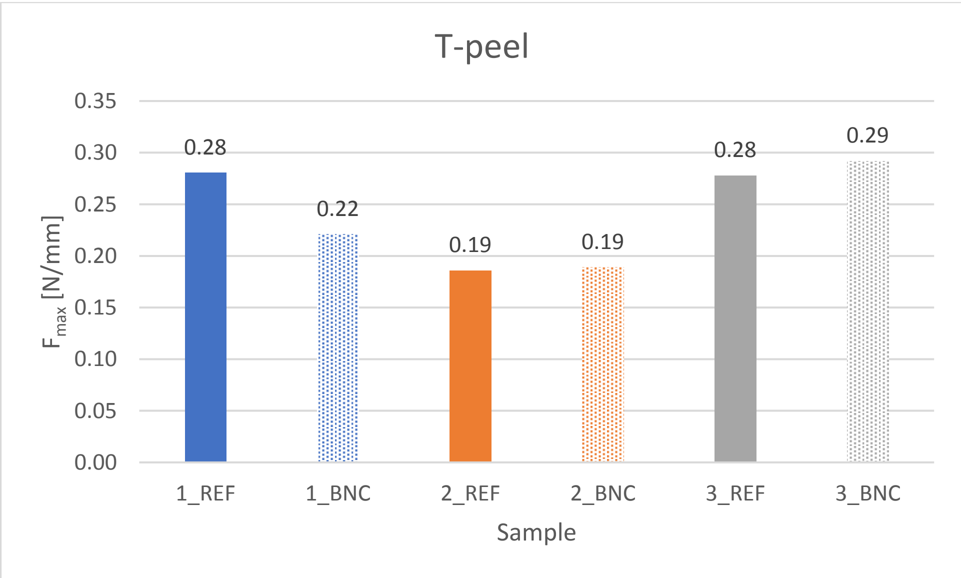

Figure 9: The max force of the measured samples with the T peel method

Sample 1 and sample 4 had similar trends with lower Fmax values in N. For sample 2 this method of peel testing showed no differences but is different from the Y peel method for the reference sample (with no applied BNC). As shown on Figure 8 which indicates larger forces for samples 1 and 3 both for BNC and without which means that the forces applied to the adhesion joint were acting more quickly than in sample 2. As sample 2 had a closed surface and low wettability this can indicate that in the T peel testing the thinner layer of the glue had less elasticity and internal cohesion and the strain on the fibre to coating bonding exerted larger delamination forces. At Y peel as most probably the adhesive stayed on the surface between the 2 plies of the 2_REF sample and the method uses lower angle where the forces have potential effects. As this sample had no BNC (which contains a certain amount of water which can dissolve some of the bonding the fibre network structure and was quite closed regarding the penetrable surface (less chance for mechanical interlocking) the high adhesion separation force is due to strong internal cohesion of the polymer adhesive.

4. CONCLUSIONS

This research tried to indicate some challenges when testing new bio-based materials for use in packaging applications (adhesion joint failure testing). The result indicates that the use of bio-based BNC as a substituting agent of 7% in the water-based polymer matrix can improve slightly the adhesion joint. This value was determined with previous pre-tests, for further values additional testing of BNC compatibility with different water-based polymer solutions needs first to be tested. On the second hand, with the use of different peel tests, one must know the difference in basic cardboard parameters. Our results show that for example the large differences in surface roughness and porosity as well penetration ability are influencing factors if the two peel methods are to be compared. In either Y peel and T peel testing wettability properties as previously tested with other adhesives can be more useful than surface roughness parameters (especially macro roughness). As almost in all samples the fibre tear occurred between the fibre matrix and the surface coating on the coated side of the cardboards additional information needs to be obtained for the internal bonding strength or the z-tensile strength of the base materials. This would show the potential weak points of the fibre layering cohesion failures with the less shallow or deeper penetration of the adhesive and the BNC entangling of the upper layers of this fibre matrix. Further studies will be carried out also on the potential of using also other peel testing angles and the forces applied on the adhesive joints of packaging materials.

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WASTE PAPER MOLDING USING 3D PRINTED TOOLS

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Abstract: *The subject of this paper includes research into the possibility of using different waste paper materials for the production of new graphic packaging, in order to reduce the percentage of paper waste, give new life to waste paper materials, and reduce the production and use of virgin paper packaging materials. The subject of this paper also includes research into the possibility of using the FDM technique of additive manufacturing in the production of molds for casting, that is, the design of future paper packaging. The molding process is used to form the shape of paper pulp, while the forming process is used to form the shape of solid paper materials.*

Keywords: packaging, paper pulp, recycled paper, 3D printing

1. INTRODUCTION

The packaging industry is one of the world economy sectors with the fastest growing trend. For many years, packaging has been the focus of political and consumer campaigns to address environmental issues. Packaging creates significant impacts on the environment at all stages of its life cycle, however, these cannot be isolated from the impact of the product it protects. The life cycle of packaging represents a series of interrelated stages through which packaging as a product goes, from obtaining raw materials to its final disposal as waste. It begins with the production of packaging materials and packaging, continues its life cycle with packaging and storage of products, and ends as discarded packaging (Lazić & Novaković, 2010). Although packaging is crucial for the preservation of packaged products, used and discarded packaging can represent a significant environmental problem. In 2019, the total volume of packaging waste generated was estimated at 79.6 million tons, which is an increase of 2.8% compared to 2018. Over the ten-year period, paper and cardboard were the main packaging waste generated, contributing 32.3 million tons to the total packaging waste generated in 2019. Plastic packaging reached a total of 15.4 million tons as the second most significant material (+26.4% compared to 2009). Glass packaging takes third place with 15.2 million tons (+13.9%), wooden packaging 12.4 million tons (+19.8%) and metal packaging 4 million tons in 2019 (+6.7%) (Eurostat Statistics Explained, 2020). Daily per capita waste generation in high-income countries is projected to increase by 19% by 2050, compared to low- and middle-income countries where it is expected to increase by approximately 40% or more (The World Bank, 2022). Plastics and polymer packaging materials are increasingly used worldwide in a wide range of applications, with global production exceeding 300 million tons per year as of 2014 (Plastic Europe, 2016). Due to their durability, low recycling rate, poor waste management, and widespread use, waste polymer packaging can represent a significant problem. Inadequate disposal of polymer packaging and other polymer products causes many harmful defects, leading to more and more plastic being found in natural aquatic and terrestrial ecosystems (Gvoka et al., 2022). The study found that more than 4.8 million metric tons of plastic waste enter the oceans from land each year, and that figure may be as high as 12.7 million metric tons (Cohen, 2015). If current trends continue, oceans could contain more plastic than fish by 2050 (Horejs, 2020). Moreover, food polymer packaging contains a great number of small particles known as microplastics. Scientists have detected microplastics everywhere they have looked: in deep oceans; in Arctic snow and Antarctic ice; in shellfish, table salt, drinking water, beer, and drifting in the air or falling with rain over mountains and cities. These tiny pieces could take decades or more to degrade fully (Lim, 2021). The solution to this problem certainly lies in replacing polymer packaging, primarily polymer wrapping materials, with paper-based packaging whenever possible. Paper is a composite structure in layers with different porosity, obtained by random arrangement of cellulose fibers (Aydemir et al., 2021). It is a widely available material that can be recycled up to four times without significantly losing its characteristics. Each paper changes its physical, mechanical and chemical properties over time - paper ageing – and the process is irreversible (Boeva et al., 2020). If coated or laminated papers, which are coated with other materials to improve their properties, are not used, paper is a biodegradable alternative that is healthy for humans and the environment, as it takes four to six weeks for its complete decomposition, depending on the depositing conditions.

Today, packaging based on cellulose fibers plays a significant role in the storage and transportation of goods. This packaging is most often made from waste paper material, such as newspapers, used cardboard, and so on. These materials give new life to paper waste and reduce the amount of virgin paper used in packaging to an acceptable minimum. Today, paper pulp is fully recyclable and is considered an environmentally friendly material. It is significantly cheaper to produce, is completely biodegradable, and has no harmful effects on the physical, chemical, and mechanical properties of the product (Gvoka et al., 2022). The quality of the printed image is a function of maintaining the parameters of the printing process within precise limits. Since cast pulp packaging is made from waste paper, it is necessary to use dyes and bleaches in order to improve the optical properties of the material and enable satisfactory print reproduction as substrate whitens is one of the most important parameters in correct colour reproduction (Spiridonov & Shopova, 2013; Spiridonov et al., 2013; Spiridonov et al., 2012; Bozhkova et al., 2017; Spiridonov et al., 2012). Once this is satisfied, it is possible to print elements of the graphic design of the packaging on it, by adding environmentally sustainable inks in the mixture of paper pulp, it is possible to change the colour of the packaging itself, making it more attractive to consumers, and it is also possible to imprint important informative graphic elements directly into the texture of the packaging itself in the process of molding.

2. RESEARCH METHODS

In order to perform the experiment, it was necessary to define the geometry of the tool for forming process. The tool has consisted of two separate mold halves. One half of the mold is designed to form the hollowed-out pattern, while the other half is forming the shape of the sample itself. The overall dimensions of both halves are 50x50 mm, with a draft angle of 2°. It was necessary to design guiding elements that would enable an adequate matching of both halves, without the possibility of shearing, which could later result in an irregular pattern. While modelling the tool, it was necessary to consider a gap of 1.5 mm, which also represents the thickness of the sample material, necessary for the correct forming of the samples. One of the influential factors that needed to be tested was the variable depth, therefore tool pairs were modeled for indentation depths of 1 mm, 3 mm, 5 mm, and 7 mm. These CAD models were created using 3D software Autodesk Inventor Professional 2022, and then converted to an STL document, suitable for further processing in the software Ultimaker Cura 4.11.0. Before 3D printing, imported STL files of the tool model were necessary to be prepared for printing and this preparation included the correct orientation of the model to the printer's platform, adequate scaling of the model to reproduce the realistic values of the given dimensions, and defining parameters of the FDM printing process.

The tool models were printed in the laboratory at the Department of Graphic Engineering and Design, at the Faculty of Technical Sciences in Novi Sad, with an FDM 3D printer Creality 3D CR-10s Pro V2. Each model is printed individually with the addition of the initial layers of the substrate, centered on the platform, to avoid possible printing errors, which has proven to be good practice on this device. Material PET-G 3031 was used for printing, due to its hardness, flexibility, and moisture and gas resistance. In Figure 1 printed models of tools are shown.

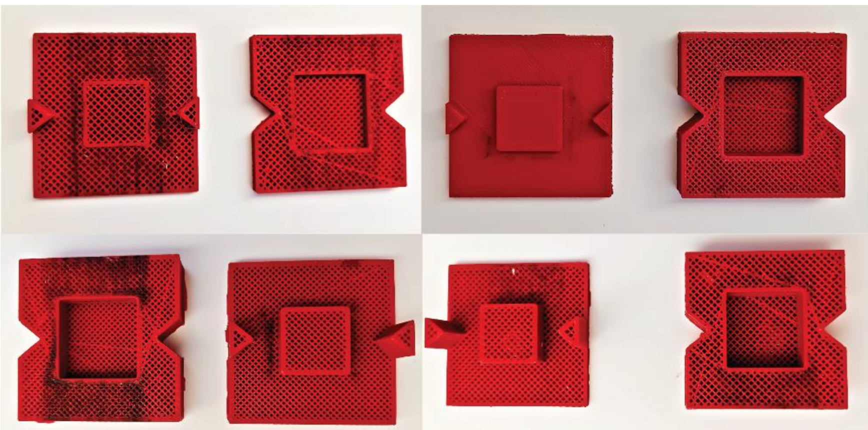


Figure 1: Models of tools printed with FDM 3D printing technology

For the realization of the experiment, it was necessary to prepare two types of samples: (1) paper pulp based samples and (2) samples from waste paper materials in trays. White offset paper with a weight of 80 g/m^2, collected as waste paper material in the laboratory of the Department of Graphic Engineering and Design, was used as the basic material for the production of paper pulp, which was previously cut into pieces whose dimensions are 20x10 mm. The paper was first immersed in a tank filled with a solution of water and dispersion adhesive, and then blended until a thick pasty mixture – the pulp - was obtained. After the pulp was created, it was necessary to press out the excess water through a screen with a weave density of 150 threads, and then create a sample that was 1.5 mm thick, and whose dimensions are 35x60 mm.

The materials that were used in the experiment to create samples represent the most common examples of paper packaging waste and they are: offset paper with a weight of 80 g/m^2, natron paper with a weight of 40 g/m2, newspaper with a weight of 40 g/m^2, tissue paper with a weight of 25 g/m^2, corrugated cardboard (three-layer) weighing 500 g/m^2 and solid grey cardboard weighing 620 g/m^2. These materials are readily available and were collected as waste material in the Department of Graphic Engineering and Design laboratory, except tissue paper. Samples of each material were first cut to dimensions of 35x60 mm in order to fit the molding tool and then stacked according to the sheet-on-sheet principle in layers of 1.5 mm thickness. After preparing the material and forming the stacks, it was necessary to immerse the stacks in a solution of dispersion glue and warm water, so that the paper materials would absorb the water. In contact with water, the fibres swell and the intermolecular forces in the material are released, which makes the paper material flexible for reshaping.

The experiment of pressing the samples and forming the desired shape was performed at the Department of Graphic Engineering and Design, using a Shimadzu Compact Tabletop Testing EZ-LX device, with a measuring cell intended for forces of 2500 N, with a speed of movement of the pressure head of 100 mm/s, at a temperature of 25 ± 2^{o}C and relative humidity of 50 ± 5%. The experiment procedure involved positioning and fixing the tool for forming the shape of the samples on the compressive strength test plates, by taping one half to the lower plate and the other to the upper plate, and then placing the sample on the surface of the mold half. Using Trapezium X software, the device is programmed to apply a pressure force of 2000 N to the sample for each test, in Compression mode, for a duration of 30 seconds. At that moment, the pressure plate, together with the upper molding half, is lowered, squeezing the excess water out of the material through the grid structure of the tool made of polyethylene terephthalate and forming a sample of the material. When the scheduled time expires, the upper pressure plate is lifted manually, by entering the value on the control panel, the formed sample is taken out of the lower half, taken to dry and a new sample is placed in its place for subsequent testing. Testing was performed five times for each material, and it is shown in Figure 2.

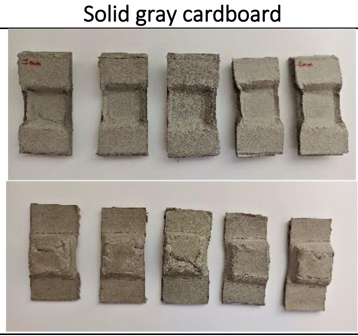
Figure 2: Sample formation on the Shimadzu Compact Tabletop Testing EZ-LX device

3. RESULTS AND DISCUSSION

3.1 Reproducibility of results within the reproduction of the same depth

Table 1 shows the results of samples made from a layer of waste paper materials, whose layer height is 1.5 mm, and which were formed with a 7 mm deep mold and dried at a temperature of 100°C for 20 minutes. The criteria for evaluating samples are the uniform depth of the sample, the clarity of the edges, the reproduced geometry, and material damage.

Table 1: Results of samples made from a layer of waste paper materials produced by molds with a depth of 7 mm

Material	White offset paper	Tissue paper
Picture		
Depth uniformity	The depth is uniform in all five samples	The depth is uniform in all five samples
Clarity of the edge	Satisfactory	Satisfactory
Reproduction of geometry	Satisfactory	Satisfactory
Material damage	Material damage occurs at the bottom of 3 samples	Material damage did not occur
Material	Natron paper	Newspaper
Picture		
Depth uniformity	The depth is uniform in all five samples	The depth is not uniform in all samples
Clarity of the edge	Not so satisfying	Satisfactory
Reproduction of geometry	Not so satisfying	Satisfactory
Material damage	Material damage occurs at the bottom of 4 samples	Material damage occurs in all samples
Material	Corrugated cardboard	Solid gray cardboard
Picture		
Depth uniformity	The depth is uniform in all five samples	The depth is uniform in all five samples
Clarity of the edge	Satisfactory	Satisfactory
Reproduction of geometry	Satisfactory	Not so satisfying
Material damage	Material damage occurs in all samples	Material damage occurs in all samples

Based on the produced samples, it is possible to conclude that the best reproduction of the geometry was observed on samples made of tissue paper and offset paper, while significant damage was observed on samples made of newspaper and solid cardboard. In the case of samples made of natron paper, one can see the vagueness of the edges. The repeatability of the samples can be seen in Figures 3, 4, 5, 6, 7, and 8. Based on these graphs, it is possible to establish that the repeatability of the samples is at an extremely high level and that most materials are characterized by a similar growth trend, except for tissue paper.

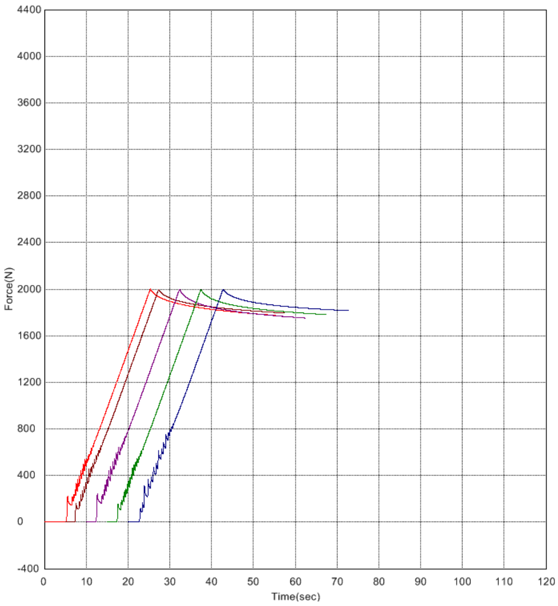


Figure 3: Curve of pressure force in defined pressing time for offset paper samples

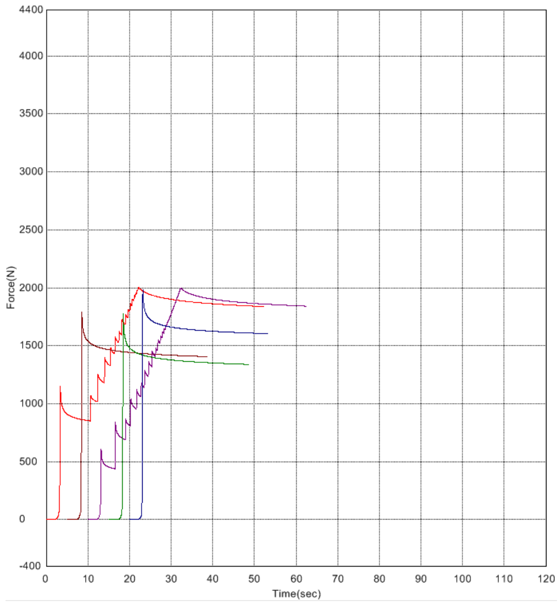


Figure 4: Curve of pressure force in defined pressing time for tissue paper samples

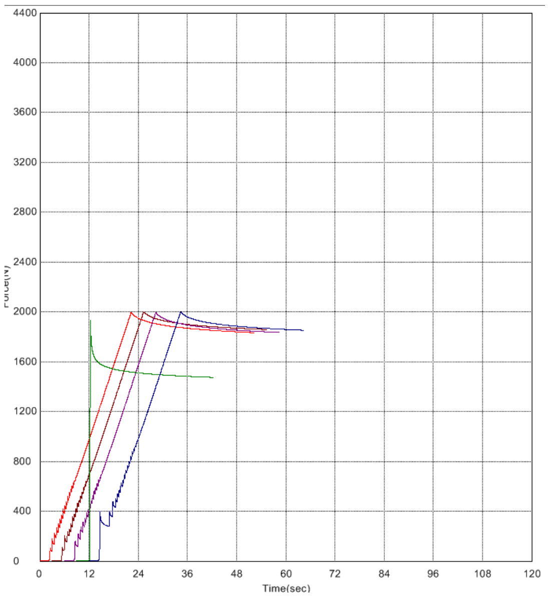


Figure 5: Curve of pressure force in defined pressing time for natron paper samples

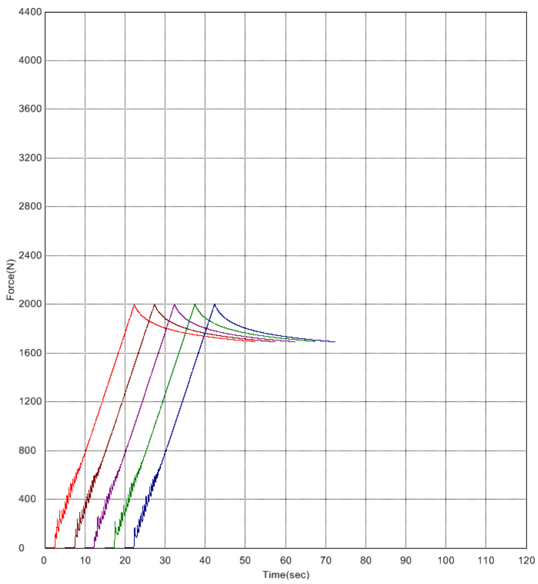


Figure 6: Curve of pressure force in defined pressing time for newspaper samples

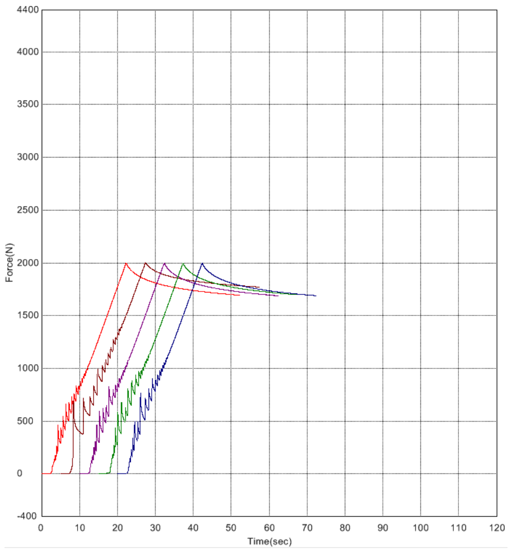


Figure 7: Curve of pressure force in defined pressing time for corrugated cardboard samples

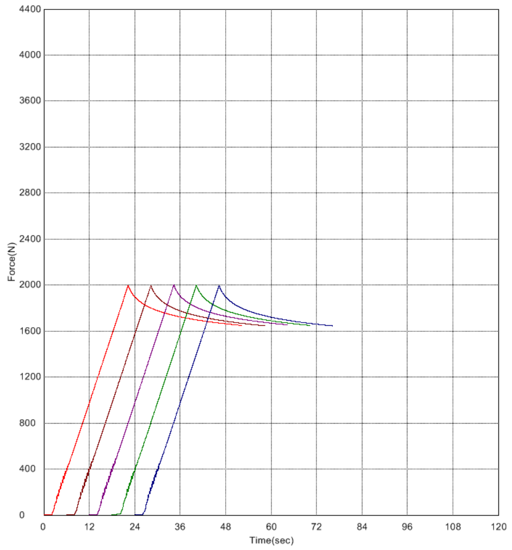
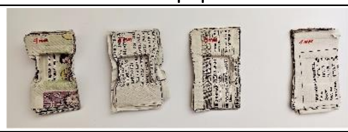


Figure 8: Curve of pressure force in defined pressing time for solid gray cardboard samples

3.2 Evaluation of formed samples of the various depth made of the same materials

Table 2 shows the results of samples made of layers of material, the layer height of which is 1.5 mm, and which were shaped by molds with a depth of 7 mm, 5 mm, 3 mm, and 1 mm. The criteria for evaluating the model are, as in the previous case, the clarity of edges, reproduced geometry, and material damage.

Table 2: Results of samples made from a layer of waste paper materials produced by molds with various depth

Material	White offset paper	Tissue paper
Picture		
Depth uniformity	Uniform in all samples for each depth	Uniform in all samples for each depth
Clarity of the edge	Satisfactory	Satisfactory
Reproduction of geometry	Satisfactory	Satisfactory
Material damage	Material damage occurs in 2 samples	Material damage did not occur
Material	Natron paper	Newspaper
Picture		
Depth uniformity	Not uniform in all samples for each depth	Not uniform in all samples for each depth
Clarity of the edge	Not so satisfying	Satisfactory, except in the 1mm sample
Reproduction of geometry	Satisfactory, except in the 1mm sample	Satisfactory, except in the 1mm sample
Material damage	Material damage occurs in the 7mm sample	Material damage occurs in 3 samples
Material	Corrugated cardboard	Solid gray cardboard
Picture		
Depth uniformity	Uniform in all samples for each depth	Uniform in all samples for each depth
Clarity of the edge	Satisfactory, except in the 1mm sample	Satisfactory, except in the 1mm sample
Reproduction of geometry	Satisfactory, except in the 1mm sample	Satisfactory, except in the 7mm sample
Material damage	Material damage occurs in 3 samples	Material damage occurs in all samples

Based on the produced samples, it is possible to conclude that the best reproduction of the geometry was observed on samples made of tissue paper and offset paper, while significant damage was observed on samples made of newspaper and solid cardboard. In the case of samples made of natron paper, a deviation is observed in the geometry reproduction, which is significantly noticeable in the case of a 1 mm sample. It is also possible to conclude that the best reproduction occurs with 5 mm samples, while reproduction problems were observed mainly with all 1 mm samples. However, with 1 mm samples, there is no noticeable damage to the material. The best clarity of the edges is visible in samples made of solid cardboard and tissue paper for all depths.

3.3 Comparison of samples made from a stack of offset paper and paper pulp based on offset paper

Figure 9 shows the results of samples made from offset paper stacks and the results of samples made from cast paper pulp. Both types of samples were obtained using a tool with a depth of 5 mm and a pressure force of 2000 N for 30 seconds.

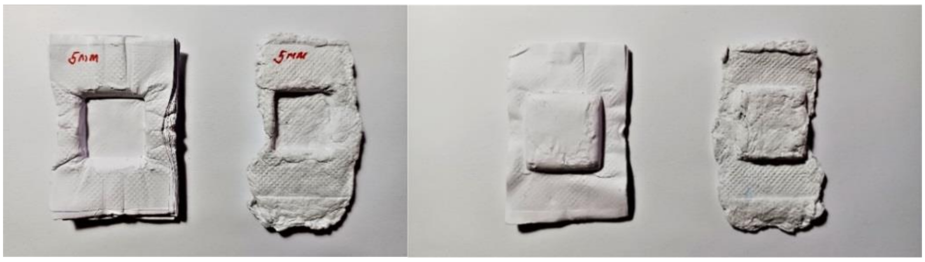


Figure 9: Results of forming samples from offset paper and paper pulp at a depth of 5 mm

After comparing these samples, it was determined by the method of visual quality assessment that the samples made from the offset paper stack proved to be a better choice compared to the paper pulp samples, in terms of the shaping of the material under the influence of pressure force. With paper pulp samples, the reproduction of clear geometry proved problematic due to the intermolecular forces acting within the structure of the material being molded. In terms of resistance to material damage, both materials proved prone to damage to the bottom of the back of the sample. Also, with the sample made of cast paper pulp, the appearance of cracks in the structure of the material was observed, which could pose a problem when using this material for the production of packaging. During the pulp creation process, it was noticed that the production of paper pulp requires the use of a significant amount of water, which, after this process, is contaminated with fibres and other substances such as printing ink, and is released into the effluent. Although the production of paper pulp is considered a good form of recycling waste paper materials, this is a rather dirty process that can have as a negative consequence great amounts of contaminated waste water, which would have to be further purified before being discharged into the effluent. Also, during this experiment, it was determined that the failed pulp can be reused for the production of new pulp, but this results in significantly shortened fibres, which can negatively affect the mechanical and other properties of the samples.

4. CONCLUSIONS

In addition to the obligation that the packaging must fulfil towards the potential customer, it also has an obligation towards health and preservation of the environment. With the increase in the volume of serial production, there is an increasing amount of packaging waste, which, due to improper handling and inadequate disposal, increasingly becomes a polluter of aquatic and terrestrial ecosystems. This is precisely why it is necessary to consider the use of healthy, alternative, environmentally sustainable materials for the production of graphic packaging. Based on the performed experiment, it is possible to conclude that the samples made of waste paper materials, primarily offset paper and corrugated tape, proved to be satisfactory in terms of forming and reproduction of geometry. In the majority of samples made of waste paper material, damage to the material can be seen, especially on the samples made with a 7 mm depth tool, while the samples made with a 5 mm depth tool proved to be the optimal solution. After comparing samples, it was determined by the method of visual quality assessment that the samples made from the offset paper stack proved to be a better choice compared to the paper pulp samples, in terms of the shaping of the material under the influence of pressure force.

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DISPLAY OF INTERACTIVE 3D MODELS IN AUGMENTED REALITY ON MOBILE DEVICES

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Abstract: *This paper study is related to two research areas, namely 3D computer graphics and augmented reality with a combination of their display on mobile devices. It presents the creation of three different interactive 3D models based on a realistically drawn image of domestic animals and can be displayed on mobile devices using augmented reality. The textured animals' models are displayed in the application Augmented animals (slo. Obogatene živali) with a simple user interface. The usability of the application is demonstrated by the detection of the image target, i.e., a printed interactive card, which proves the interaction between the mobile device and the augmented paper. When the mobile device camera recognizes the target, it displays the selected animal on the screen. The result is the enhancement of the real environment with animated 3D characters. By displaying a 3D character on the screen and interacting with the user interface, the presentation of each animal in three different animated movements is enabled.*

The first empirical part of this work was done with the help of the Blender program, in which we created all three animal 3D characters. First, we had to model all the animals from the initial templates into a recognizable 3D mesh, which we then mapped the textures on. This was followed by the construction of a system of bones and animation controls, based on which we could create the animal animations. After this step, we transferred the project to the Unity program. Then it followed the construction of an application that allows the representation of characters in augmented reality. The results of the entire work are appropriately made animal characters in the form of animated 3D models that can be displayed in augmented reality mode on mobile devices using interactive cards. The selected testing parameters showed that there are certain differences in rendering between the two tested mobile devices depending on the selected subdivision level of the 3D character. However, for recognition based on lighting conditions, distance and slope between the image target and the mobile device, the best user experience is obtained when the image target is captured from a distance of 15-20 cm and from a bird's eye view under good lighting conditions.

Keywords: 3D computer graphics, augmented reality, mobile devices, interactive 3D content, augmented paper.

1. INTRODUCTION

Mobile Augmented Reality - MAR stands for the display of augmented reality on mobile devices that adds computer-generated virtual content to the real world using a selected mobile platform. Mobile augmented reality systems usually include programs or applications. The combination of augmented reality and various mobile platforms allows the creation of various new mobile applications that include the use of augmented reality. Nowadays, the use of MAR is very wide, research is mainly focused on its use on devices such as smart glasses, smartphones, tablets, PDAs or even in some cases laptops. Mobile phones are considered the most typical MAR device because they contain a camera, sensors, powerful processors and specialized graphics hardware. This has made them the dominant mobile platform for MAR. Despite rapid advances, their capacity for real-time applications is limited. The most popular examples of MAR usage are Pokemon Go, Archeoguide, ARQuake, BARS, Snapchat, etc. (Kipper & Rampolla, 2012; Furht, 2011; Chatzopoulous et al., 2017; Craig, 2013; Shah, 2018) MAR system programs consist of the following three main components (Chatzopoulous et al., 2017; Shah, 2018):

- Input components that are part of the mobile device and have various sensors attached to them (camera, gyroscope, microphone, GPS) that serve as input for the MAR application;
- Data processing displayed on the mobile device screen, which requires access to data stored locally in the device or in a remote database;

- Output components where augmented reality content is displayed on the screen of a mobile device.

1.1 Examples of displaying 3D graphic content on mobile devices

We present some recent examples of research or market products that address the display of 3D graphics content in augmented reality in the MAR domain, using enhanced paper for the display. In the latter, interactive flashcards are usually used to display 3D models in augmented reality, with certain information on both sides. The main purpose is usually to facilitate familiarisation with the material or objects. Another alternative is various printed media, which are mainly used to facilitate the learning of the material. In addition to the graphic content it contains, the augmented paper also serves as an image target that enables the display of augmented reality on a smart device, such as a 3D model or other multimedia content (Wikipedia, 2021; Dijaya et al., 2018; Chow, & Sharmin, 2020; Subhashin et al., 2020; Andayani et al., 2019). On mobile devices, the thing works best via a developed application where the display is based on the model method of representing data (Kipper & Rampolla, 2012).
We summarize the research findings, focusing on functionality, usability, and user experience. Using medicinal plants as an example, systems for display and recognition were developed (Dijaya et al, 2018), with the goal of the application being to display 3D models using augmented reality technology. Interactive cards containing a graphical image of the plants were used for the display. The whole process was carried out in the Blender, Unity and Vuforia programming environments. The final testing focused on determining how long it took to load a given 3D model, the impact of camera quality on lighting conditions, screen response, receptivity, comparison between different devices, and user responses. The main findings were that the 3D model can be displayed correctly under conditions where the final display is strongly influenced by the quality and lighting of the camera, which has a very large impact on the display of 3D models.
A similar example is the use of interactive cards in an application from AR, designed to facilitate independent learning in neurobiology, cardiology, and structural biochemistry at the University of Alberta. An entire process was developed involving the display of 3D models in real time, and all of this required high levels of computer literacy, programming, and design (Chow & Sharmin, 2020).
Education is considered one of the most common application areas of augmented reality, since most of the content in books and textbooks is not interactive. Therefore, one of the research papers focuses on how to reduce the use of digital media during the pandemic and use traditional print media instead. As a solution, they propose the use of interactive books based on augmented reality, where the books would offer more interesting use through a AR application. Each page of the book would reflect certain rich content regardless of the type of graphic representation. So the goal is to understand the content of the book without needing further help from other electronic media. The whole thing is based on a mobile smartphone app created in Blender, Unity and Vuforia. The application on the smartphone ensures the connection with the classic book and helps in easier understanding of the content, testing different ways of displaying it more concretely (Subhashin et al., 2020).
The last example from the field of research is the 3D representation of models using the example of the digestive organs, which augment the content of the anatomy book. Based on the selected data from the book, the creators first selected images from which the corresponding pixels and 3D models with textures were created. This was followed by the design of the entire augmented system for the application in the Android environment, where everything was developed by showing the markers of the intestinal anatomy in detail. In addition to the content, the application also included a suitable user interface, where the opening menu includes the options Play AR, How to Play and Exit. The first option allows viewing the 3D scene and organ, while the second option informs about the full use of the platform. The tests in this research tested distance detection, which involves determining the image plane of a marker from a given distance. This type of testing is concerned with how far the camera can detect the image target in centimetres. A stable display is estimated to be possible between 15 and 45 cm. The test also included tilt detection to determine the distance with a camera tilt test. Research has confirmed that the most stable detection angle is between 45 and 150 degrees (Subhashin et al., 2020; Andayani et al., 2019).
There are many examples in the market where augmented reality is used on augmented paper to display various 3D models. The main purpose is to show the appearance or movement of various objects, and they are primarily intended as learning aids. Most often, content creators sell everything together via a mobile application and with the physical content of printed interactive cards or a book collection. First, we will highlight foreign examples, such as representations of animal images, cartoon characters, the

solar system, historical images, learning the alphabet, etc. Such examples are Talking Cards (AR Talking Cards, 2021), Paparmali AR (Paparmali, 2021), Monopril Interactive, Experience Real History Alamo, Animal and Food, Shifu Space (Miller, 2018), Digoo Education Card AR Kaka (Digoo, 2021), the Red Chimpz series which offers a rich collection of different kinds of animals (RedChimpz, 2016), etc. We can also point to a self-learning project for Arabic letters, created using tools such as Blender, Illustrator, Unity and Vuforia, which includes different types of animation, such as outdoor animation, action animation and fun animation (Expose Academy, 2016).

On the Slovenian market, we can highlight the example of the retailer Lidl, which, in cooperation with the Dutch company BrandLoyalty, offers an example of wildlife presentation through its Incredible animals brand. The application works with the help of special interactive cards on which augmented reality can be used to show nine different wild animals in a 3D model in their natural habitat along with sound. The whole system is equipped with a simple user interface that also allows playing simple games (Lidl, 2021; BrandLoyalty, 2021).

The purpose of this paper is to present the manufacturing process and the final result of the properly produced animal figures in the form of animated 3D models that can be displayed in the application with the help of augmented reality on mobile devices using printed interactive cards, and to present the main final results of the tests according to various selected parameters performed on two selected mobile devices.

2. METHODS

The working methodology included idea generation, development of initial images with sketches and 2D illustrations of 3D animal models, and final applications. Based on 2D illustrations and sketches, we performed the first part of the task in the Blender program, where we fully created all three interactive 3D models of a cat, a horse, and a duck. The animal figures were designed in a non-photorealistic and stylized way, based on cartoon photos. For research and final performance testing on mobile devices, the animals were designed with a varying number of polygons and body anatomy. In Blender, we performed all steps from 3D modelling to texturing to placement of bones and controls. As part of the animation, we created three different movements for each animal. We created movements in a stationary state (idle), an example of walking, and an action state where we have a walking mode for a cat and a horse, and a flying mode for a duck. The augmented reality model method was used to represent the creatures in augmented reality mode. For this reason, it was also necessary to create physical interactive cards on paper for display, which the augmented reality application can use to recognize them, allowing the display of 3D models.

In the following, we also planned the design of the whole platform called Augmented Animals, talking about the appearance of the application on mobile devices. We carried out the preparation process in the Unity program, where we used prepared interactive cards and created 3D animal figures to set up the entire application platform, which allows it to be displayed in augmented reality mode. Another step was the preparation of the test parameters according to different criteria, which allowed us to confirm or refute the hypotheses established at the beginning of the task. We tested according to the following parameters:

- Playback according to the different degree of subdivision on both mobile devices,
- Display from the viewpoint of the camera and the image target in five different lighting conditions,
- Character recognition based on the distance between the mobile device and the image target according to different recognition ranges in two different ways,
- Character recognition based on the detection angle between the image target and the mobile device.

The following mobile devices, namely the Huawei Mate 10 Lite smartphone (year 2017) and the Samsung Galaxy A32 (year 2021), were the most helpful in the tests. Finally, a final analysis was performed. Figure 1 shows the entire work cycle from the idea to the final product.

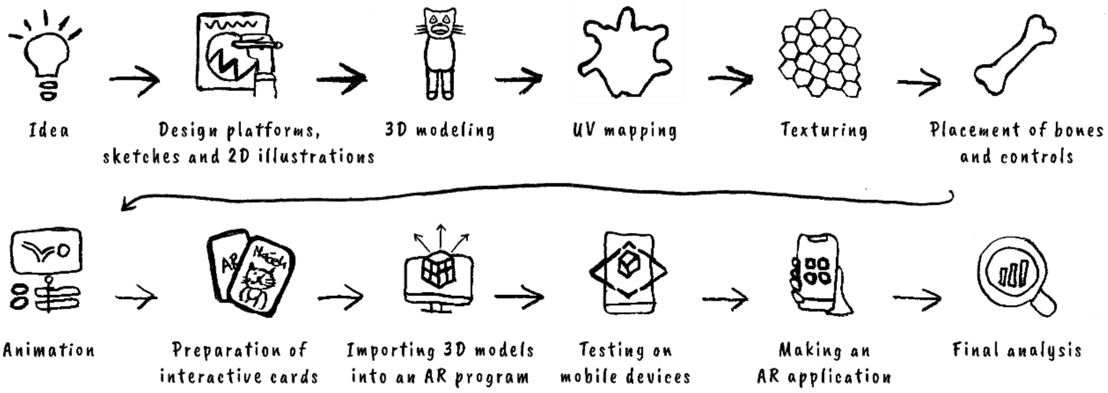

Figure 1: Showing the execution scope of production from idea to finished product

3. RESULTS

3.1 Presentation of the final results

The final result of the work is a mobile application called Augmented Animals, through which 3D animal models are displayed in augmented reality mode. After launching the platform from the desktop of the mobile device, it first takes us to the start menu, where we have the platform's trademark at the top and three buttons at the bottom, which are Start, Information and Exit. When you click on the Start button, the platform takes you to the application scene, where selected animal characters are shown in augmented reality mode with the help of image targets. In this mode, the user is greeted by three game buttons, which allow switching between three different animations when the selected character is displayed. Figure 2 shows the final result with all three animal models displayed on a mobile device.

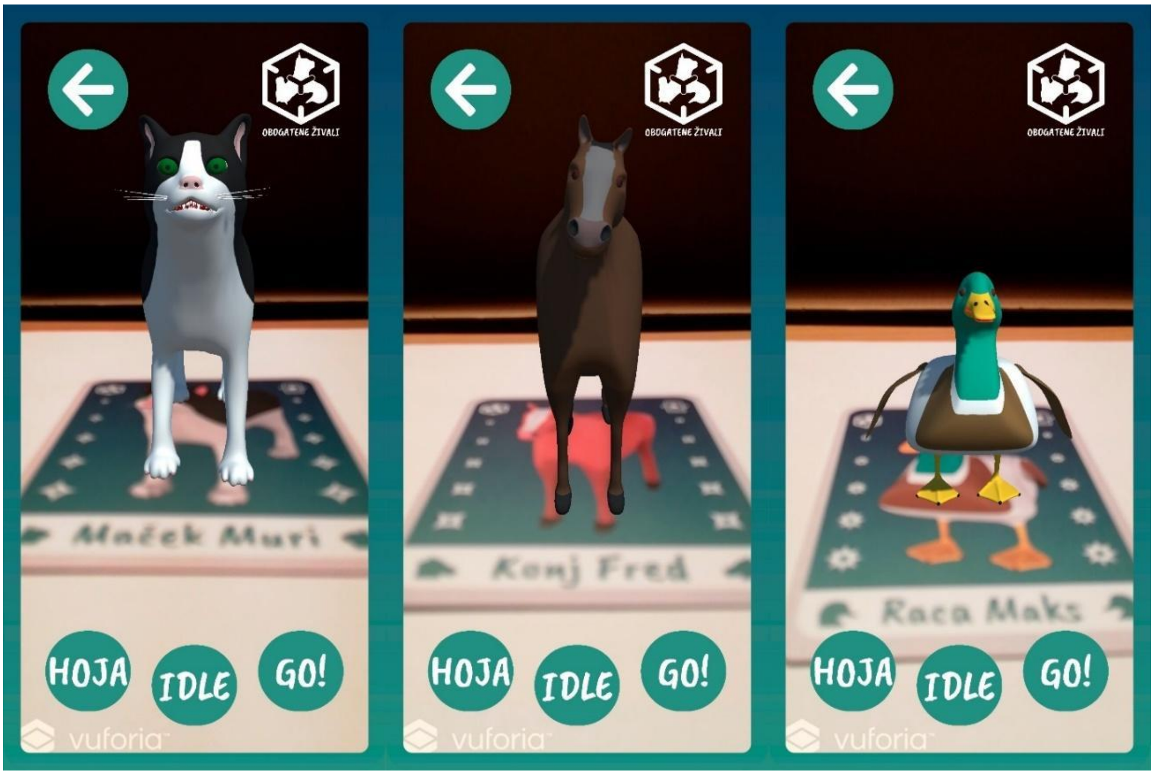

Figure 2: Display of all three animal characters on the image target from a mobile device screenshot

3.2 Final results regarding selected testing parameters

First, we analysed how animal characters play on two selected mobile devices according to different sharing levels (levels 0-3). Table 1 presents the playback performance results based on the degree of sharing between the two devices.

Table 1: Comparison of animal character playback by the level of subdivision between the two devices.

		Huawei Mate 10 Lite	Samsung Galaxy A32
Level 0	Static animation	There is no difference.	
	Dynamic animation		
Level 1	Static animation	There is no difference.	
	Dynamic animation		
Level 2	Static animation	No particular difference when playback animal characters. Playback quality looks better on a newer device.	
	Dynamic animation	Slightly slower playback, slight stuttering and less fluid playback.	Faster, better quality and smoother playback for a certain part.
Level 3	Static animation	No particular difference when playback animal characters. Playback quality looks better on a newer device.	
	Dynamic animation	Lower quality and slower playback.	Faster, better and smoother playback of action animations.

We also analysed the display of animal 3D models under different lighting conditions. Table 2 shows the final test results according to the lighting conditions.

Table 2: Test results according to lighting conditions.

	Image target	Character display
Sunny	Fast and successful recognition	
Cloud		
Artificial		
Light from another mobile device		
Darkness	Without success	

We also checked the detection according to different distances of the mobile device camera from the image target. In the first part, we checked detection when we did not have an animal character on the screen of the mobile device. Table 3 shows the final results of object detection according to the distance between the image target and the mobile device when starting the augmented reality mode in the application.

Table 3: Comparison of object detection by distance when launching augmented reality mode.

	Both mobile devices
Less than 10 cm	● Detection is rather difficult, as the camera is too close to the image target and consequently is not able to focus the card well enough. ● At a distance of 10 cm, it takes more time to detect than at a distance of 15 cm.
15–60 cm	● The light sensors of the camera quickly, qualitatively and successfully recognize the image target and display the selected animal character. ● The optimal distance for the best end-user experience is a detection range between 15 and 20 cm.
65 cm and more	● Due to the excessive distance, the mobile device camera is no longer able to detect all the details of the image target and does not display the character.

In the second part, we also checked how the animal figure is preserved depending on the distance of the image target from the mobile device. Table 4 shows the final results of described according to the distance between the image target and the mobile device.

Table 4: Comparison of keeping the animal character on the screen according to the distance between the image target and the mobile device.

	Both mobile devices
5 cm or less	● At a distance of 5 cm, the character remains visible, but we no longer see him in full, the character begins to shake. ● At an even smaller distance, the character disappears as expected.
5 cm or more	● The animal character remains visible even at a distance of more than 100 cm. ● However, the greater the distance between the device and the image target, the worse the final user experience is due to the lower visibility of the character on the screen. ● The ideal area of final use is a distance between 15 and 20 cm.

We ended the testing with an analysis that covers the recognition of the image target according to the inclination of the mobile device. Table 5 shows the test results in terms of the angle of capture between the imaging target and the mobile device.

Table 5: Results according to the angle of capture between the image target and the mobile device.

	Both mobile devices
Bird's perspective	● Fastest rendering, but we only see the character's back.
Sharp angle	● Still effective and fast rendering of the character, an intermediate level between the first and third views.
Right angle	● Characters did not want to appear in most cases. ● If we want to see the animal from the front, we have to put the mobile device in this kind of position, because it offers us the best end-user experience.

4. DISCUSSION

The following is a short commentary on all the results from the table of the previous point. First, we analysed how the animal characters are played on the two selected mobile devices according to the different levels of subdivision, namely 0 and 1. We noticed that animal characters and animations run equally well on both selected mobile devices. At Subdivision level 2, it has already been shown that the newer mobile device plays the action movements better and more fluidly when playing dynamic animations. While the tracking speed itself was still even between the two mobile devices. The difference was ultimately most noticeable at the Subdivision 3 level. It was shown that the processor of a newer mobile device plays selected action animations faster for a certain fraction of a second. Regarding the evaluation of static animation playback at a higher topology level, we can conclude that the differences were minimal, however, the playback quality was better performed on the newer mobile device. Subdivision testing has shown that animal 3D models with higher polygon count are considered more challenging to render on mobile devices. The main reason lies mainly in the more complex characters. The difference was most noticeable when playing dynamic movements.

We will continue with a comment regarding the analysis of perception under different lighting conditions, in which the influence of the choice of the mobile device had no particular effect on the final results. Perception analysis was performed under five lighting conditions. In very good lighting conditions, such as detection under sunlight, cloudy light or artificial light with the help of a table lamp, the camera recognized the interactive card very quickly and successfully displayed the selected animal model. When detecting in darker conditions, the latter is somewhat more demanding, as the camera's light sensors need a longer time to detect the image target and display animal characters. In this case, we tried displaying it against the light of the screen of another mobile device, where, surprisingly, the device displayed the animal character on the screen quite successfully and qualitatively. While the mobile device was not able to display the selected animal model in complete darkness as expected.

In addition to brightness, we also checked detection according to different distances of the mobile device camera from the image target. In the first part, we checked detection when we did not have an animal character on the screen of the mobile device. When detecting when the application is launched in augmented reality mode, the detection can be divided into three detection areas according to the distance. In the first class, we consider the detection of the image target at a very small distance, where we are talking about a distance of less than 5 cm and up to 10 cm. In this case, capture and detection are quite difficult. The reason lies in the fact that at a distance of less than 5 cm, the camera is not able to focus the interactive card well enough due to being too close. While at a distance of 10 cm, we can say that the light sensors of the camera manage to focus the image with sufficient quality to show the animal figure, for which they need a little more time. The most successful and appropriate way is to capture an image target at a distance of 15 to 50 cm, in which the mobile device recognizes the image target qualitatively and quickly and displays the associated selected animal character. While at a distance of 60 cm and more, the camera of the mobile device is no longer able to detect all the details on the interactive card and, as a result, it is not able to show the animal character. The most ideal detection distance is thus foreseen in the range between 15 and 20 cm.

In the second part, we also checked how the animal figure is preserved depending on the distance of the image target from the mobile device. It can be noted that during the testing of this part, problems appeared only in the part if we approached the image target to a distance of about 5 cm or less. At a distance of 5 cm, the animal figure is still present on the image target, but it is no longer visible to its full extent. A special feature when approaching is also the noticeable shaking, e.g., in animal legs. At an even smaller distance than 5 cm, the character always disappears, because the mobile device's camera is no longer able to recognize the details on the interactive card. When moving away from the character by more than 50 cm, the result surprised us, as the character remained visible even at a distance of up to 100 cm and more from the image target. Of course, the final quality and user experience at such a distance are useless or bad, because the selected animal character can only be seen as a single dot on the picture target.

We ended the testing with an analysis that covers the recognition of the image target according to the inclination of the mobile device. Perception of the interactive card from a bird's eye view was by far the most effective, as regardless of the lighting conditions, the animal character appeared the fastest in this view. Relatively fast rendering was also possible at a sharp 45-degree angle, which represents an intermediate angle between a bird's eye view and a right angle. There were more problems in detecting the characters at the right 90-degree angle, as the characters in the vast majority did not want to appear. The problem with this position is mainly in the fact that if we want to see the animal figure frontally, we have to set the position of the camera of the mobile device in this position most of the time.

5. CONCLUSIONS

At the end of this article, we can confirm that the main purpose has been successfully achieved, namely the creation of three different interactive 3D animal models that can be displayed on a mobile device using augmented reality technology. In the entire article, a short introduction and the methodology of the entire work are successfully presented, with the final results of the animal characters created and the final results of the tests carried out according to various selected parameters.

Finally, we will highlight the most important points of this article. When playing 3D models on mobile devices, we could see that animal characters with a higher level of subdivision or the number of polygons is considered more demanding when playing on mobile devices. The difference was best illustrated by the example between an older and a newer mobile device. The results of our tests also showed that the most successful detection between the image target and the mobile device is in the distance between 15 and 20 cm and from a bird's-eye angle position in good lighting conditions. The perception is worse at a smaller or greater distance outside this area and at a slope outside the bird's eye view. However, detection of an image target on a mobile device is also possible in much worse lighting conditions. To fulfil the detection conditions, only a small presence of light is sufficient for the mobile device to recognize the image target very quickly and efficiently and display the selected animal character. As an example, we will cite a successful detection attempt, where we illuminated the image target with the light of only another mobile device. Finally, we will evaluate the content playback according to the hardware. It turns out that a newer mobile device with better hardware and software OS equipment enables better playback of dynamic animations than an older mobile device. We can also mention that the newer mobile device allows better and higher quality use of animal characters. Regarding the playback of static animation on both devices, we can estimate that due to the small number of operations required by the animated character, the difference did not particularly affect the two mobile devices.

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COMMUNICATING A GLOBAL PANDEMIC WITH WHATSAPP AND HEALTHBOT IN CROATIA

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Abstract: *The Covid-19 pandemic has caused a series of hasty changes and spurred the digital transformation of various services. The pandemic itself has the greatest impact on the health system, which faces several challenges. Health-focused chatbots ("healthbots") and apps have more and more important role in collecting quality information about health from credible sources and by doing so, they contribute to quality healthcare. Chatbots, which were used exclusively in connection with the pandemic, were used in more than thirty countries in the world. But there is limited evidence on how such healthbots are perceived in public. This paper is a contribution to this field of research – it deals with the analysis of media presentation of the healthbot Andrija, which was developed and used in Croatia during the Covid-19 pandemic. Using the research matrix from the paper "Chatbot use cases in the Covid-19 public health response" by P. Amiri and E. Karahanna published in Journal of the American Medical Informatics Association, we analysed the health chatbot used in Croatia, with the emphasis on its design features and also media presentation of the project, which was crucial in popularization of the healthbot. Because of the need for a quick response to crisis, this chatbot was developed very quickly. As such, design is relatively simple, using system-directed initiatives and it is focused on a narrow set of simple tasks. In conclusion, the ease of use, and fast information dissemination provide complementary functionality which can potentially reduce the pressure on health workers in situations of increased need for access to primary health care. The use of health chatbots is confronting with many obstacles both at the level of the social system (consumers' acceptability) as well as the technical system (design and usability). More sophisticated chatbot designs and opportunities for synergies with machine learning should be explored in the future in combination with more developed and sophisticated methods of media presentation.*

Key words: chatbot, design, visual information, health system

1. INTRODUCTION

New information technologies have enabled greater interactivity and greater degree of democracy and the level of participation in the creation of media content. Modern ways of communication have become such powerful communication tools not only for content management, but they have also become a new battlefield for individual, group, technological and social conflicts, and compromises (Plenković & Mustić, 2016). Holistic approach to media communication as a cultural phenomenon is a professional and social preoccupation of every communication scientist, graphic and media designer, author and distributor of visual messages, marketing and design agencies, creative media and educational institutions, advertising and propaganda institutions, economy and party entities, civil society, government, and non-governmental institutions. (Plenković & Mustić, 2020). A holistic approach to the design of media campaigns should be used in crisis communication, which was also necessary in the recent health crisis of global proportions. A holistic approach also implies the use of knowledge from different fields (social and technical) to shape messages using advanced information and communication technologies and knowledge while respecting cultural, educational, sociological and all other differences that each human community has. Visual aids are usually the most effective when transparent – when their elements are well defined and if they accurately and clearly represent relevant information making the relation with data, partially or completely, visually accessible (Garcia-Retamero & Cokely, 2013). An efficient, attractive, and excellent graphic language/communication is a product of joint efforts and integrated planning. The images are used to describe and communicate medical procedures, discoveries, and diseases throughout history and as such have the potential to clarify what is invisible to the naked eye, processes appearing internally, those occurring at long intervals or anywhere on the atomic to solar scale (Scheltema, Reay & Piper, 2018). The use and appropriate design of medical illustrations is becoming increasingly important with advances in technology and the increasing scope and complexity of information about the human body. At the same time, new technologies make it possible to produce anything from simple schemes to hyper realistic ones that cannot be distinguished from photographs. With increasing medical specialization and increasing audience diversity that requires medical information one of the challenges for medical illustrators is to establish the reality or interpretation of the illustration (Scheltema, Reay & Piper, 2018). Krakov (2017) describes the connection between graphic narratives and health communication on the example of prevention of oncological disease. She says that graphic narratives have a growing trend in health communication, attracting adult reading audiences with convincing visual and textual images of health and disease (Krakov, 2017). In their work, the authors Garcia-Retamero & Cokely (2013) discussed a set of studies researching the advantages of visual aids in communicating health risks with different vulnerable persons (e.g. different abilities, age, risk characteristics and cultural background) and stated that studies have shown that appropriately designed visual aids are often very effective, transparent and ethically desirable means to improve decision making, change attitudes and reduce risky behaviour (Garcia-Retamero & Cokely, 2013). Scheltema, Reay & Piper (2018) stated in their paper that the existing literature on visual communication tends to the theory that simple representations are better for communication and that the use of visuals improves patient understanding of the medical topics (Scheltema, Reay & Piper, 2018). Medical information is complex, therefore a design that contributes to the simplification and better understanding of complex information is increasingly being used, which also contributes to a better understanding of medical topics among the general population. Likewise, the use of information and communication technologies that enable quick, simple, clear and unambiguous access to health information also contribute to the quality of health services. But, the focus of public health is very different from the individualized practice of clinical medicine, and as such public health values and ethics have several justifiable challenges that differ from medical or bioethical ones. Public health is aimed at the population, not individuals, and because of its nature it is interested in public good (Couch, Fried & Komesaroff, 2017).

1.1 Chatbot use in health crisis and public health response

A new, highly contagious disease has put a lot of pressure on healthcare systems around the world. On December 31, 2019, the World Health Organization Office in the People's Republic of China picked up a press statement from the Wuhan Municipal Health Commission from its website on cases of 'viral pneumonia' in Wuhan, People's Republic of China (World Health Organization, 2020b). In March, the World Health Organization reported the rapid escalation of COVID-19 in the European region, placing it at the centre of a pandemic (World Health Organization, 2020b). In the same month, WHO launched a messaging service with partners WhatsApp and Facebook, with the potential to reach 2 billion people. From government leaders to health workers, this messaging service was able to provide the latest news and information on coronavirus including details on symptoms and how people can protect themselves and others. It also provided the users with the latest situation reports and numbers in real time to help government decision-makers protect the health of their populations (World Health Organization, 2020a). Chatbots, in contrast to newspapers and online information sources, can often hear and respond in natural language, improving access for people who cannot read or have difficulty using the internet. They can be available any time of the day to answer questions with up-to-date information, and unlike human experts, can concurrently speak with millions of people at the same time in local languages and dialects (Miner, Laranjo & Kocaballi, 2020). During the Covid-19 crisis, health chatbots were used in more than 30 countries (Amiri & Karahanna, 2022). The purposes of use were different: education of citizens, surveillance and detection of contacts, risk assessment, dissemination of information etc. In Croatia, The Prime Minister Andrej Plenković informed the public about the first confirmed case of a coronavirus patient in Croatia at the end of February 2020 at a press conference (Ministry of Health, 2020b.). The requirement for social distancing made normal face-to-face communication with health professionals impossible, which made the usual health services more difficult to access. Along with the fight against the virus, there was a constant need to prevent misinformation and fake news, so solutions that offered fast, accurate and reliable information while respecting the requirements for social distancing became very attractive. To raise this cooperation to a higher-level technology, a project "Andrija" was created – the first digital assistant in the fight against coronavirus (Ministry of Health, 2020a). The digital assistant Andrija was intended for civil society and uses artificial intelligence to be connected at the same time with millions of citizens and all relevant institutions in the fight against coronavirus. (Ministry of Health, 2020a). Smartphone users were able to self-evaluate their health condition through chatbot on the koronavirus.hr platform and the WhatsApp business API platform, using the global communication platform of the Croatian IT company Infobip (Ministry of Health, 2020b; Government of Croatia, 2020). The project "Andrija, digital assistant" was made with the idea to help health professionals, doctors and epidemiologists in controlling the development of the Covid-19 epidemic (Government of Croatia, 2020), and as a communication tool of the Ministry of Health of the Republic of Croatia that will help answer citizens' inquiries about coronavirus with reliable and timely health advice, all in order to make citizens feel safe (Ministry of Health, 2020b). Its purpose is education, proper assistance, and information, emphasizing the reliability, cooperation, community, involvement and accountability of citizens and relief of the health care system (Ministry of Health, 2020b; Government of Croatia, 2020). The project leader is the Ministry of Administration and a team of experts led by epidemiologist experts, with the technical and IT support of the joint forces of domestic companies Mindsmiths, Neos and Oracle Croatia, which are, along with Infobip, members of the Croatian Association for Artificial Intelligence CroAI. All Croatian companies involved decided to give their contribution generously and to participate together in a national effort to combat the new coronavirus epidemic free of charge (Ministry of Health, 2020b). Already on the first day there were about 30,000 users on the "Andrija" system, and over 75% of them said that they were satisfied with Andrija (Government of Croatia, 2020).

1.2 Purpose and goal

The purpose and goal of this paper is to present a case of digitalization in the health system on the example of Andrija, digital assistant, healthbot of the Ministry of Health and analysis of the media campaign whose goal was to popularize the digital assistant and motivate the population to use it.

2.METHODS

The review paper "Chatbot use cases in the Covid-19 public health response", in which the authors collected data on the use of healthbots during the Covid-19 crisis, was taken as the basis for the analysis of Andrija digital assistant, what was the first part of our research. Amiri and Karahanna analysed 61 chatbots from more than thirty countries, including 33 chatbots that used 45 languages other than English (Amiri & Karahanna, 2022). They created a research matrix for health chatbot analysis, which was also used in this paper. They determined through analysis that the use of chatbots can be divided into six basic categories within 15 different answers/purposes/instructions in public health can be identified. More than half of the analysed chatbots were used for risk assessment. Using the same categories, the Croatian version of the chatbot was also evaluated. In the field of design, the categories offered by these authors are multipurpose versus single purpose; chatbot platform; anonymity; anthropomorphism; interface design; and follow-up and recurring conversation. The purpose of first part of our research was to determine whether the health chatbot used in Croatia has the same characteristics as in other countries or whether there are still some specifics. For preparing this paper we also used the official website of the Government of the Republic of Croatia and the official website of the Ministry of Health of the Republic of Croatia and chatbot on WhatsApp. On the official website, the search engine was given a search under the keyword "Andrija" in the period from 31 December 2019 to 14th of February 2021. For the purposes of SWOT analysis, the official website of Andrija was used. In the analysis of media campaign with special emphasis on visual communication, the research matrix for analysis of media campaign was created.

3. RESULTS

3.1 Chatbot evaluation based on Amiri-Karahanna model

Six basic categories defined by Amiri & Karahanna (2022) are Risk assessment; Surveillance; Information dissemination; Post-Covid 19 eligibility screening; Distributed coordination and Vaccine scheduler.
Andrija, like most previously analysed chatbot (Miner, Laranjo & Kocaballi, 2020; Amiri & Karahanna, 2022), was focused on risk assessment and providing only basic information and guidelines about the new disease (Table 1). During a pandemic, people do not know what to do, so reliable information sources are crucial to prevent a "misinfodemic": the spread of a disease facilitated by viral misinformation. Unfortunately, Andrija did not have that function in wide manner.

Table 1: Andrija chatbot use cases and definitions

Use-case category and associated use cases	Use-case description	Benefits
Risk assessment	Triage users based on their Covid-19 symptoms and exposure risk and recommend a course of action.	Social distancing, capacity expansion, efficient capacity utilization, prevent virus transmission
Surveillance	/	/
Information dissemination	Virus and vaccine education	
	Misinformation/disinformation debunking	
	Proactive misinformation/disinformation debunking	
	Nonpharmaceutical interventions (NPI) promotion	
	Virus transmission data reporting	
	Available public resources awareness	
	Encouragement of activities (other than NPIs) to fight the pandemic	
Post-Covid-19 eligibility screening	/	/
Distributed coordination	/	
Vaccine scheduler	/	/

3.2 Andrija chatbot design analysis based on Amiri-Karahanna model

Amiri and Karahanna used few categories to define elements of design used in chatbots. First element is multipurpose versus single purpose. Andrija provides risk assessment and very limited information dissemination. Under the category information dissemination seven sub-categories were detected, but Andrija provided just three of them. Nevertheless, Andrija falls in the category of multipurpose chatbots. Amiri & Karahanna (2022) detected that the most common categories to be combined were risk assessment (22 cases) and information dissemination (21 cases), with the most common multipurpose chatbot combination being these 2 categories (18 co-occurrences). Chatbots were deployed on a variety of platforms, the most common being web-based (34 cases) and social media (22 cases). Andrija used official government webpage for Covid-19 informing – koronavirus.hr and the access was possible on WhatsApp. The chatbot was not embedded within a high-traffic platform what would enhance its visibility and discoverability. Some chatbots required user identifying information like telephone number, national identification number, social media account or. Institutional credentials. Andrija asks to save the number in the phonebook before establishing communication and is activated by sending the word “Greetings”. Most chatbots (70%) lacked anthropomorphism (Amiri & Karahanna, 2022), but Andrija chatbot was presented as male (Figure 1). The official presentation of the digital assistant Andrija was held on April 14th at a press conference of the Government of the Republic of Croatia where the choice of the name Andrija but not the visual presentation of the Andrija character was explained (Government of Croatia, 2020). Andrija was named after the father of preventive dr Andrija Štampar, who set the basic principles of public health applied all over the world.

Figure 1: Andrija (e-Građani, 2020)

Like the vast majority of chatbots analysed in the Amiri-Karahanna paper, Andrija is also text-based chatbot. It interacted via predetermined choice and response options (i.e., use system-directed initiative) and interactions were primarily designed to be user-initiated. Andrija, like the vast majority of other chatbots used for this purpose, does not have the follow-up and recurring conversation option implemented. Table 2 summarizes the chatbot design features for Andrija chatbot.

Table 2: Andrija chatbot design characteristics

	Andrija
Multipurpose versus single purpose	multipurpose
Chatbot platform	WhatsApp
Anonymity	does not enquire additional user identifying information
Anthropomorphism	male
Interface design	text-based
Follow-up and recurring conversation	no follow-up option

3.3 Analysis of media communication using official government channel

The use of chatbots in public health communication is a completely new venture, therefore the use of chatbots had to be accompanied by strong media promotion for the purpose of familiarizing the public with the product and motivating the population to use it. For this reason, we included in the research the analysis of official communication channels that were used in public communication and from which the media often took information. Of course, for a complete overview, it would be necessary to analyse a larger number of media sources, but we were primarily interested in how the government used its official channels to promote Andrija. A search has been entered in the search engine on the official website of the Government of the Republic of Croatia: "Andrija". Of the total number of searches (a total of nineteen (19) pages found), in the period from 31 December 2019 to 14 February 2021, three pages related, or are mentioned, Andrija, digital assistant of the Ministry of Health (Government of Croatia, 2020). The search on the official website of the Ministry of Health of the Republic of Croatia includes a search: "Andrija". Out of the total number of searches (a total of eight (8) pages found), in the period from 31 December 2019 to 14 February 2021, one (1) page referred to, or is mentioned, Andrija, digital assistant of the Ministry of Health (Ministry of Health, 2020a). The search results are shown in Table 3.

Table 3: Search results

Website name	Total number of pages found under the filter: "Andrija"	The total number of pages referring to or mentioning Andrew, digital assistant of the Ministry of Health
	Period: from December 31, 2019 to February 14, 2021.	
Croatian Government	19	3
Ministry of Health of the Republic of Croatia	8	1

There are no further publications on the official Government website on the topic of Andrew, digital assistant, while on the official website of Andrija - How I am developing - there are seven publications after the official presentation by April 14, 2020 to September 14, 2020 shown in Table 2. Thirty-three (33) publications are recorded in the media on the part of Andrija's website, i.e., a link in the media with the publishing dates from 13 April 2020 to 27 April 2020, as shown in Table 4.

Table 4: Display the date of publication and content in the part of the page "Andrija — How I develop"

No.	Date of publication	Content
1.	April 14, 2020	Andrija was officially presented at the press conference of the Government of the Republic of Croatia.
2.	April 14, 2020	Andrija reached 10 thousand users in the first 2 hours.
3.	April 15, 2020	Andrija reached 50,000 users in the first 24 hours.
4.	April 20, 2020	Andrija has a new opportunity to list active measures in the fight against Covid-19.
5.	May 08, 2020	From now on, Andrija provides information on crossing borders and traveling abroad.
6.	September 4, 2020	Andrija's algorithm for schools was tested by the profession under the guidance of prof. Branko Kolarić. Based on the feedback, the algorithm was further refined.
7.	September 06, 2020	Andrija can help parents decide whether to send their child to school, given his health condition and contacts.
8.	September 14, 2020	Andrija reports the daily number of new patients and the total number of patients with a graphic presentation.

Table 5 (part 1): Display of links on the page "Andrija in the media"

No.	Date of publication	Website
1.	April 16, 2020	YouTube
2.	April 15, 2020	24 sata
3.	Private video	YouTube
4.	Video removed	YouTube
5.	April 14, 2020	Tweeter
6.	April 21, 2020	24 sata
7.	April 15, 2020	Hercegovina.info
8.	April 15, 2020	IndexHR
9.	April 14, 2020	Peticija24.com
10.	April 27, 2020	Soundcloud
11.	April 14, 2020	Telegram
12.	April 14, 2020	Jutarnji.hr
13.	April 14, 2020	YouTube
14.	April 14, 2020.	YouTube
15.	April 13, 2020.	Netokracija.com
16.	April 17, 2020	Poslovni dnevnik
17.	Official site	Andrija.ai
18.	April 14, 2020	Tportal.hr
19.	April 14, 2020.	Večernji list
20.	May 4, 2020	Telegram
21.	April 14, 2020	Zimo.dnevnik.hr
22.	Page does not exist	hr.n1info.co
23.	Front page	vijesti.hrt.hr
24.	April 14, 2020	Lider Media
25.	April 15, 2020	Bjelovar.info
26.	April 13, 2020	Slobodna Dalmacija
27.	April 13, 2020	Direktno.hr
28.	April 15, 2020	Evaraždin.hr
29.	April 14, 2020	studentski.hr
30.	April 14, 2020	balkans.aljazeera.net
31.	April 14, 2020	www.antenazadar.hr

Table 5 (part 2): Display of links on the page "Andrija in the media"

32.	April 15, 2020	www.zgportal.com
33.	April 14, 2020	www.bug.hr

4. DISCUSSION

When we compare the characteristics of Andrija with other chatbots used for the same purposes, we can see that the purpose of use is dominantly the same for the vast majority of chatbots, namely risk assessment and information. Andrija did not go a step further and enabled users to get more information in one place. For example, for surveillance and contact tracing, and for vaccinations appointment, other products were developed with major problems in use, which is why they received a lot of negative media coverage, and their use did not take off on a large scale. During the observed period, the official website of the Government of the Republic of Croatia under the given search “Andrija” only three pages refer to or are mentioned in Andrija, the digital assistant of the Ministry of Health, while on official website of the Ministry of Health of the Republic of Croatia, in the same observed period and the same technique, only one page refers to Andrija, a digital assistant. Presenting the project at a press conference in front of the Government of the Republic of Croatia achieved the goal of legitimacy and credibility of the project itself. The selection of project presentation methods enabled the transfer of information according to epidemiological measures. High state officials and renowned experts from various fields such as health care, artificial intelligence, etc. participated in the presentation of the project. The symbolism of choosing the name “Andrija” in the introductory presentation is explained, but not the very selection of the official icon. The press conference was used as a means of disseminating information about the project. The contents of the press conference were broadcast by various portals presented in Table 3 whose contents can be easily accessed through a link. Certain videos show the application of Andrew on their own example. Out of 33 links, there are difficulties in three links, one leads to the official website of Andrija, while one leads to the cover of the portal itself. After 27 April 2020, there are no links.

Although the creation of a chatbot was an extremely quick reaction to the new challenging circumstances, top experts participated in its development, it had the support of high-ranking government officials, it could potentially enable a reduction of pressure on healthcare workers, when we compare it with the categories that Amiri & Karahanna (2022) observed in other chatbots, we see that Andrija has had simplest possible functions, design and services.

Observed advantages and disadvantages of Andrija chatbot are listed in the SWOT analysis in Table 6.

Table 6: SWOT analysis of Andrija, digital assistant

Strengths - Availability to all smartphone users - simplicity in need - expertise and innovation - support from senior officials and experts	Weaknesses - lack of media campaign strategies - lack of promotion - unclearly defined visual communication figures - lack of use of auxiliary used funds
Opportunities - free individual health risk assessment - Education of Citizens - relief of the health care system - epidemiological measures - government presentation of the project	Threats - loss of civic interest - increasing the query by health care system - shortcomings of the project itself

5. CONCLUSIONS

Over the last two decades, a solid body of evidence has shown the potential benefits of using embodied conversational agents for health-related purposes. Chatbots have the potential to play an increasingly important role in health and medical care and their use in this pandemic could potentially speed up the public's habituation to new forms of communication in healthcare. Because of the need for a quick response, chatbot Andrija was developed very quickly. As such, its design is relatively simple using decision-tree structures, system-directed initiatives, and it focused on a narrow set of simple tasks. More

sophisticated designs based on machine learning and sensor data are possible future direction for new or enhanced public health communication.
The coronavirus pandemic has caused a unique crisis that has stopped or changed the normal way of functioning, and in each country, there has been a choice of an effective and efficient combat strategy. During the digitalization of public administration, the Government of the Republic of Croatia presented the project of Andrija - the first digital assistant of the Ministry of Health in the fight against coronavirus. In conclusion, we can say that Andrija, digital assistant, introduced an innovation in health communication, presented a good example of public and private sector cooperation, but its application remained limited due to the relatively small amount of information that can be obtained through it, and insufficient media promotion. This paper presents the results of the analysis conducted on the official websites of the Government of the Republic of Croatia, the Ministry of Health of the Republic of Croatia, and the official website of the digital assistant project Andrija.ai. The results of the conducted analysis show that the project itself has defined goals, which were presented at the Government's presentation of the project to the public. The presentation of the project was performed by high state officials as well as renowned experts from various fields such as health, artificial intelligence, etc., which achieved the legitimacy and credibility of the project itself. In the presentation of the project, the purpose and role of the project, financing, availability, expertise were explained. However, further analysis of the official website of the project showed that there is very little activity on the project itself - only eight announcements about the development of the project. The project presented by the Government of the Republic of Croatia, as a fighter against coronavirus, records only one graphic on its official website - the icon of the project itself without explaining it and there is no clearly defined media campaign of the project. This paper provides an opportunity for further research of the project itself through the prism of the media campaign and its impact on the outcome of the project as a model for future projects of similar content.

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ANALYSIS OF ANSWER TIMES IN RECOGNITION OF FACIAL IMAGES

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Abstract: *In visual interaction between people, faces are the element that most attracts observers, so facial images are also an important element of communication between people. The aspect of observing and memorizing facial images has often been the subject of research. When observing facial images, there are two important parameters: the dimensions of the facial images and the observation time. Both of them have a great influence on recognition performance. In our research, we set three different dimensions of face images (small, medium, and large) and four observation times for the observation test (1, 2, 4, and 8 seconds). Since the results of face image recognition success in terms of these parameters have already been reported in other studies, we focused on the observation times for face images in the recognition process. We hypothesized that when participants looked the facial image quickly (short answer times), they were more likely to be convinced of the correctness of the answer and, consequently, fewer false recognitions would occur. In contrast, when participants looked at the face image for a longer time during the recognition process, they hesitated more, and the rate of incorrect recognition was higher because they were not completely sure of their answer. We found that in all 12 cases, the average duration of correct answers was shorter than that of incorrect answers. According to the time distribution of the duration of all answers, we set two limits (2 and 3 seconds) and analyzed the wrong answers according to these time limits. We found that with longer answer times, the proportion of incorrect recognition increased strongly. This is particularly noticeable in the tests where participants observed the facial images for a longer time (8 seconds) and could therefore memorize them better.*

Key words: facial images, observation test, recognition test, incorrect recognition, eye tracking

1. INTRODUCTION

Two parameters are important for memorizing and recognizing face images: observation time and the dimensions of the facial images. These are all controlled conditions for observing facial images. However, the question is how well we remember these faces and how well we recognize them. Memory and recognition tests are performed according to the well-established method of memory tests (YES / NO tests) (Gillund & Shiffrin, 1984; Snodgrass & Corwin, 1998). These are essentially tests that consist of two parts: an observation test and a recognition test. The observation tests contain a series of facial images that participants view under controlled conditions (the display time of the facial images is fixed). In the recognition test, new facial images are added to the facial images and the observation test, the number of which must be equal to that of the observation test. Thus, in the recognition there are twice as many images as in the observation. In the recognition process, participants had free control over the recognition responses. The success of facial image recognition can be measured by the correctness of the participants' answers to the question whether the face they see in the recognition test was also shown in the observation test (i.e. answers YES / NO).

We were interested in the time of the answers and whether we could establish a relationship between the times of the answers and their correctness (basically incorrect answers). We assumed that a participant who is sure of his answer will give it quickly. If a participant takes longer to give his answer, it means that he is not sure of his correctness and therefore makes more incorrect recognitions. This would be useful in identifying criminals in various crimes (robberies, burglaries, murders, traffic accidents) (Senior & Bolle, 2002).

Since we wanted to find out the influence of the two above-mentioned parameters on the recognition success, we determined four different presentation times of facial images (1 second, 2 seconds, 4 seconds, 8 seconds) and three different dimensions of the images ("small", "medium" and "large"). Thus, we obtained 12 different tests. So, we measured the percentage of incorrect answers for all 12 tests.

2. METHODS

2.1 Participants

As mentioned above, we conducted 12 tests. Every test was done for 6 participants, so all together we recruited 72 participants (26 male and 46 female). They were our students and had normal vision. Average age was 20,6 years (SD = 1,02).

2.2 Stimuli

We took the images from the Minear and Park Face Database (Minear & Park, 2000). We prepared them in three different dimensions ("small" (320 px × 240 px), "medium" (640 px × 480 px), and "large" (1280 px × 960 px)). Thus, the size has increased by a factor of 2.

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. The distance between the test subjects and the screen with the facial images was 60 cm. Analysis were done in Tobii Studio 3.4.8 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 Studio, 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 1.

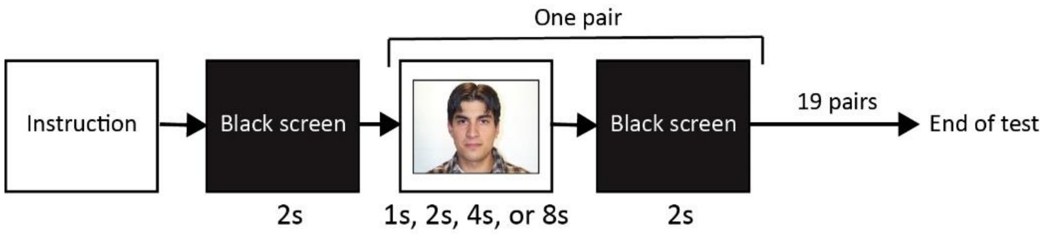

Figure 1: Procedure of the observation test

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 2).

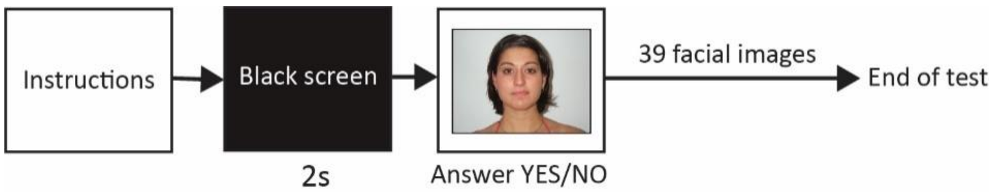

Figure 2: Procedure of the recognition test

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. Correct responses were those in which the participant answered correctly that the face image was included in the observation test or answered correctly that it was not included in the observation test. Incorrect responses were those in which the facial image was not present in the observation test but in recognition test, participant said it was, and vice versa (the facial image was present in the observation test, but the participant did not confirm this in the recognition test).

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 (IA) answers for each of the 12 tests. Here we wanted to confirm the assumption that the times for correct answers are shorter than the times for incorrect answers.
In the second part of the study, we were interested in the percentage of incorrect answers in relation to the duration of the answer. We assumed that for answers that took longer than a certain amount of time, the percentage of incorrect answers would be greater than the percentage of incorrect answers for all answers. To determine the time limit for the responses, we first distributed all answers according to their time duration. Figure 3 shows the time intervals, the number of responses in each time interval and distribution of the number of responses according to time intervals.

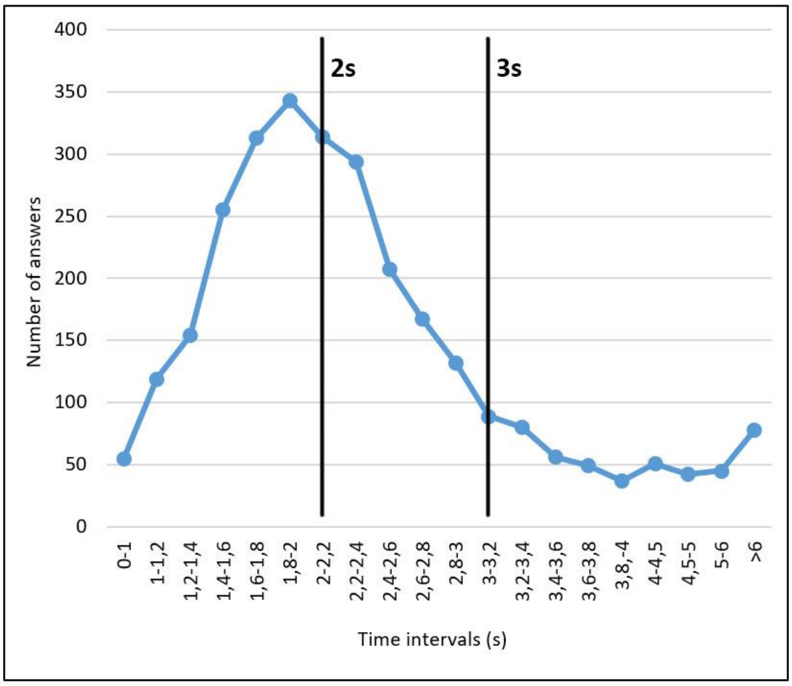

Figure 3: Time intervals, number of answers and distribution of the number of responses according to time intervals

The time intervals were set according to the duration of the answers. Where there were a lot of answers (answers duration between one and four seconds), the time interval was 0.2 seconds. For answers that lasted between four and five seconds, there were two intervals of 0.5 seconds, while for the other answers the interval was one second. Finally, all answers that lasted longer than six seconds were grouped together. In total, there were 2880 answers (72 participants, each had 40 answers).
Based on this distribution, we wanted to set two time limits for the duration of answers, for which we calculated the percentage of incorrect answers. Based on this distribution and the earlier finding that incorrect answers take longer than correct ones, we set these two time limits (two and three seconds). Thus, for each test, we were interested in the percentage of incorrect answers if they lasted longer than two seconds or longer than three seconds.

3. RESULTS

The results of the first part of our research are shown in Table 1. The average times of correct and incorrect answers for all 12 tests are given.

Table 1: Time of correct answers (CA) and incorrect answers (IA).

Average time of answers [s]			Time of observation tests			
			1s	**2s**	**4s**	**8s**
Dimensions of facial images	**small**	**CA**	2,27	2,49	2,56	2,35
		IA	2,54	3,09	3,06	4,02
	medium	**CA**	2,66	2,39	2,29	2,02
		IA	3,38	3,38	4,16	3,14
	large	**CA**	1,93	2,29	2,59	2,19
		IA	2,52	3,79	4,42	3,90

As mentioned earlier the second part of the study, we were interested in the percentage of incorrect answers in relation to the duration of the answer. Figure 4-7 shows the percentage of incorrect answers for three categories: all answers, answers lasting longer than 2 seconds, and answers lasting longer than 3 seconds. The graphs are shown for different presentation times of the facial image in the observation test (1s, 2s, 4s, and 8s).

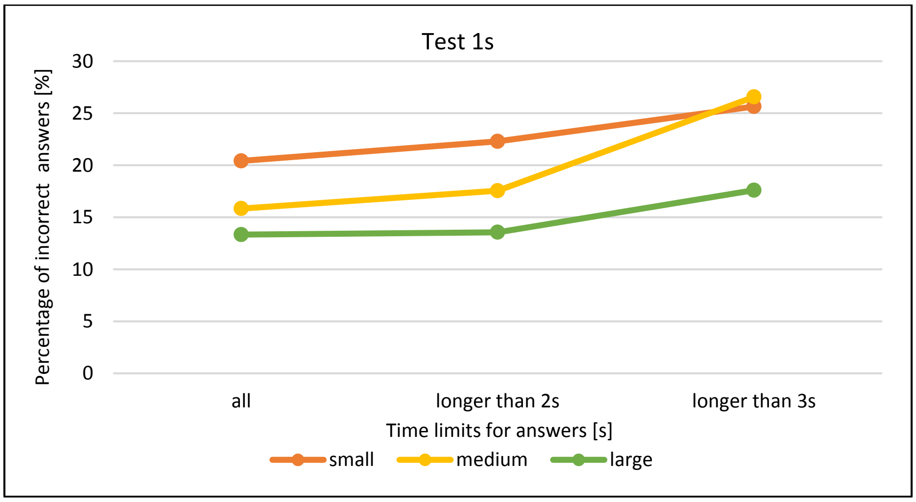

Figure 4: Incorrect recognition for all answers and two time limits for 1 second observation test

Figure 5: Incorrect recognition for all answers and two time limits for 2 second observation test

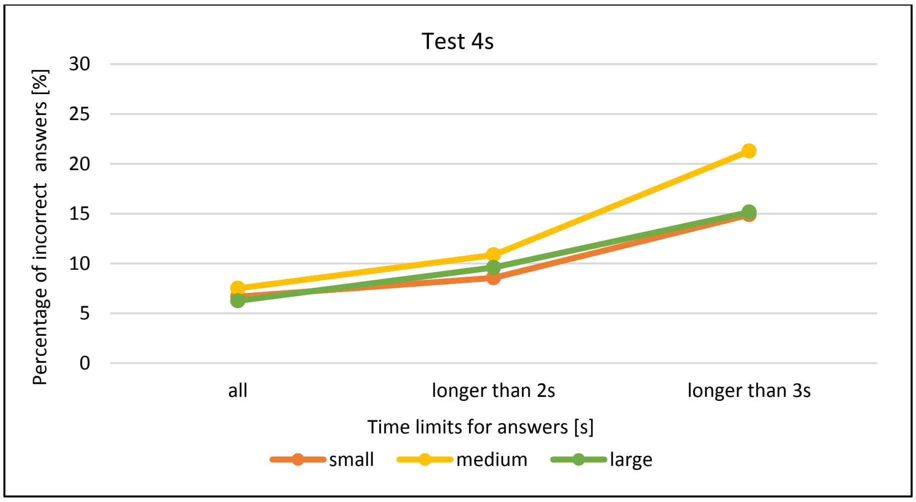

Figure 6: Incorrect recognition for all answers and two time limits for 4 second observation test

Figure 7: Incorrect recognition for all answers and two time limits for 8 second observation test

4. DISCUSSION

As we assumed, all tests confirmed that responses took longer with incorrect recognition than with correct recognition, which was also found out in the study by Liu and Chaudhuri (Liu & Chaudhuri, 2002).
The difference between the times for correct and incorrect answers is greatest for the 4s and 8s tests. Thus, the times for correct answers were very short (2.02 to 2.59 seconds) when participants had enough time to look at the facial image in the observation test and consequently remembered it better, whereas for incorrect answers they usually hesitated a lot and the times were much longer (3.06 to 4.42 seconds).
During the tests themselves, we found that participants made more incorrect recognitions if they hesitated to answer (which, of course, meant a longer response time). When they were confident of the correctness of their recognition response, response times were generally short.
In all the different time tests, we find that the percentage of incorrect answers is higher for longer answer times. This is due to our observations where we found that the participant answered quickly when he was sure of the answer. The longer he thought, the more often he recognized incorrectly. The differences between the percentages of incorrect answers as a function of answer time are largest for the 8-second test, where the percentage of incorrect answers among all answers is very low, regardless of the dimension of the facial images. It is also relatively low for all answers longer than two seconds. However, it increases rapidly for answers longer than three seconds (for medium-sized images, there are as many as 22.2% incorrect responses for responses longer than three seconds answers compared to 3.8% incorrect answers among all answers). The smallest increase in this trend is, of course, in the 1-second observation test, where the percentage of incorrect answers among all answers is quite high regardless of

the size of the face images (small 20.4%, medium 15.8%, and large 13.3%). Again, the percentage of incorrect answers increases with increasing response time (answers longer than three seconds: small 25.6%, medium 26.6%, and large 17.6%), but to much less than in other tests. All these numbers support the assumption that a longer answer time significantly increases the probability of incorrect facial recognition. The reason for this, in our opinion, is the uncertainty of the participants about the correctness of the answer.

5. CONCLUSIONS

In our study, we wanted to find out the relationship between the duration of answers and their correctness in recognizing facial images. We used the well-established method of the memory test. Since we wanted to cover a broader aspect of the test, we included images in three different dimensions and used four different presentation times of facial images (1, 2, 4, and 8 seconds) in the observation test. For all tests, the average times for correct answers were shorter than the average times for incorrect answers. In addition, the percentage of incorrect responses as a function of duration of answers was determined even more precisely. Here, for all 12 tests, the percentage of all incorrect answers, the percentage of incorrect answers lasting longer than 2 seconds, and the percentage of incorrect answers lasting longer than 3 seconds were determined. Again, for the 4s and 8s tests, it is very clear that for answers that take longer than 3 seconds, this percentage increased significantly compared to all answers (from about 5% to 15-20%), indicating very clearly that participants answered incorrectly in the recognition test much more often when they hesitated than when they answered quickly.

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ANALYSIS OF EMOTION EXPRESSION ON FRONTAL AND PROFILE FACIAL IMAGES

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Abstract: *Expressions of emotions are often found in facial images. In addition to the neutral facial expression, we know six basic expressions of emotion: joy, anger, sadness, fear, surprise, and disgust. The similarity of some emotion expressions sometimes leads to incorrect recognition or confusion of two emotions. In our study, we tried to find out how these substitutions manifest in the recognition of emotions on frontal and profile face images. The results of the substitutions in emotion recognition were presented with a substitution matrix. The second part of the study focused on confirming these results with the analysis of facial feature observation and fixation duration. In the analysis of facial features, the three main facial features (eyes, mouth, and forehead with nasal) that attract the most attention were considered. Fixation duration was also measured for these facial features. The basis of the research equipment was an eye tracker, which we used to define the areas of interest (AOI) for the analysis. The results of the observational proportions of facial features confirmed a relatively large scale of substitutions of the emotions fear and surprise, anger and disgust, and partial fear and disgust in frontal facial images. In profile facial images, the most frequent incorrect recognition were the emotions happiness and surprise, anger and disgust, fear and disgust, and anger and sadness. Since there is less information about the face in the profile facial image than in the frontal facial images, the results also confirmed a higher proportion of incorrect recognition in the profile face images and thus a more difficult recognition of emotions in the profile face images. The greater extent of incorrect recognition was also confirmed by the fixation duration results. Both results (observation proportions of facial features and fixation duration) were also presented in a graph.*

Key words: frontal facial images, profile facial images emotion expression, internal facial features, fixation duration, eye tracking

1. INTRODUCTION

Every day we deal with situations where we cannot can not always see people's faces in the front view. When recognising faces that cannot be seen in frontal view, most research has been done with profile facial images. In addition to frontal and profile views of faces, faces are usually shown at a 45^{o} angle (mid-profile view), which is called a ¾-view. This represents the face between the frontal and profile views. Research (Blatz, Tarr & Bulthoff, 1999) has shown that when given a choice between faces at different angles, users chose the ¾-view as the most appropriate view that combined information about the frontal and profile views.
Most studies dealt with frontal, ¾ and profile views. Research (Edelman, 1995) has shown that when the objects of observation are highly similar, recognition is largely influenced by. Since faces are a group where the similarity between the elements of the group is very high, the viewing angle also plays an important role in the recognition of faces. In all this research, the designers and face databases also consider the researchers' requests and take pictures of the faces from different angles.
In our study, we used only two groups of facial images: frontal and profile. With these images, we aimed to identify emotions based on facial features. In general, facial features are divided into inner and outer facial features (Moore, 1985). Inner facial features include the eyes, nose, and mouth, while outer facial features include the forehead, cheeks, ears, and chin (Buchan, Pare & Munhall, 2007). Otherwise, facial features can be further subdivided (eyebrows, eyelids, lips). Figure 1 shows the basic classification.

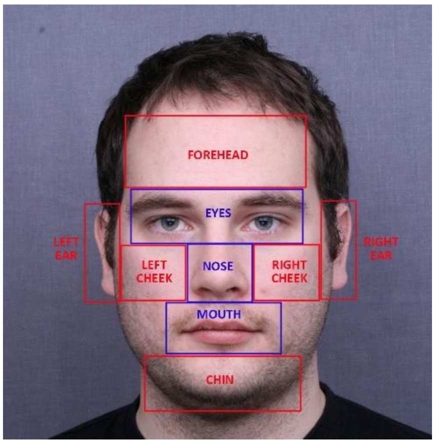


Figure 1: Inner (blue) and outer (red) facial features

When emotions are shown, three parts of the face change the most (eyes, mouth, and forehead). We have therefore based our research on the analysis of the proportions of observing these facial features.

2. METHODS

2.1 Participants

As mentioned above, we conducted two tests, one for frontal facial images and one for profile facial images. For each test we recruited 20 participants among our students. Average age for frontal facial images was 20,3 years (SD = 0,78), and for profile facial images 20,5 years (SD = 0,81). All participants volunteered and had normal vision.

2.2 Stimuli

We took the images from the Stirling/ESRC 3D Face Database (Hancock, n.d.), which contains a good representation of facial images of all emotions in both frontal and profile face images. The dimensions of the images were again adjusted to the set resolution and natural observation conditions (Henderson, Williams, & Falk 2005) and reduced from 800 × 800 px to 480 × 480 px. Three face images were selected for six facial emotions of each gender. Thus, we had 36 (3 × 6 × 2 = 36) frontal face images and 36 profile face images. Subjects in both groups were identical. Figure 2 shows surprise emotion expression of frontal facial image (a) and anger emotion expression of profile facial image (b).

(a) *(b)*

Figure 2: Surprise emotion expression of frontal facial image (a) and anger emotion expression of profile facial image (b) (5)

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. When setting up the environmental and testing system we followed the standards and recommendations.

We performed the test with the Tobii X-120 eye tracking system. The distance between the test subjects and the screen with the facial images was 60 cm. The setting of the test environment and the test subject is shown in Figure 3.

Figure 3: Testing setup

Analysis were done in Tobii Studio 3.4.8 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 studio, 2016).

2.4 Procedure

The test was designed based on the real-time response of emotion recognition. In planning the test procedure, we helped each other with similar tests (Guo & Shaw, 2005; Green & Guo, 2018). After the initial instructions and a two-second of dark screen, a facial image showing an emotion expression is displayed for four seconds. The duration of the presentation of the facial image varied between researchers. For some, the image was viewed freely (after the image was shown, the subject quickly clicked the emotion response button); for others, this time ranged from half a second to five seconds. We determined this time based on our previous tests (Iskra & Gabrijelič, 2019), and it was four seconds. It is important that the time be long enough so that we can perform a good analysis of the proportions of observation of the areas of interest which were based on previously mentioned facial features. After the facial image was shown, a list of six emotions followed, and the subject answered which emotion was shown. After the response, a new face image was displayed with a mouse click. The procedure of emotion expression recognition test for frontal face images is shown in Figure 4. The procedure for profile face images was the same.

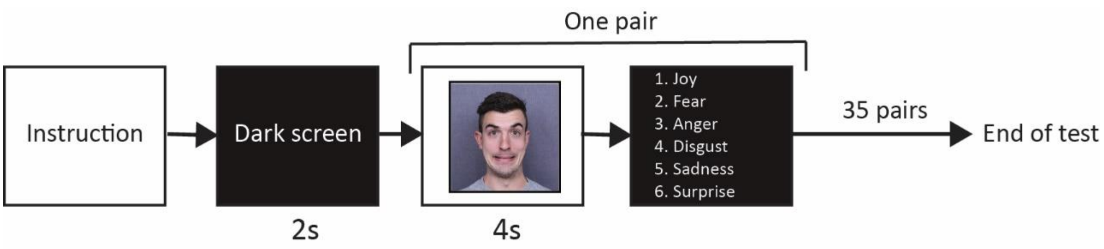
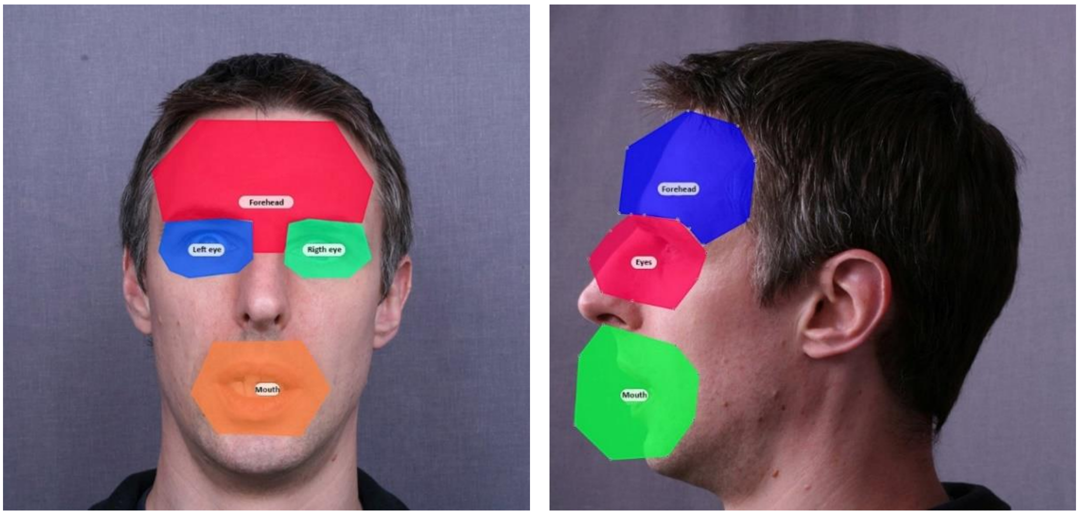


Figure 4: Procedure of emotion expression recognition test

2.5 Analysis of results

In recognizing emotion expressions, participants' responses were recorded manually. As mentioned earlier, we had 20 participants in each test. There were 36 images in each test, so we obtained 720 emotion recognition responses for frontal facial images and the same number for prifile facial images. These results were presented in a substitution matrix, which was also used in by other researchers (Guo & Shaw, 2005; Iskra & Gabrijelič, 2019). One direction of the matrix represents the facial emotion expression presented, and the other direction represents the participants' responses. In this way, false recognitions can be quickly detected (one emotion expression is shown, the test participant recognizes it as a different emotion expression).

In analyzing the observation of facial features, we wanted to find out in what proportion the three parts of the face that change the most when emotions are expressed (eyes, mouth, and forehead) are observed. To obtain these results, we determined the area of interest (AOI) and used the fixation duration setting in the Tobii Studio Pro program. When extracting the data, we were only interested in the total time spent visiting a particular AOI. The creation of these areas was done manually. An example of the AOI for frontal and profile face images is shown in Figure 5.



(a) (b)

Figure 5: AOI for frontal (a) and profile (b) facial images

As mentioned above, the average fixation duration was obtained directly from Tobii Studio Pro and the use of AOI.

3. RESULTS

3.1 Frontal facial images

Table 1 shows the results of emotion expression recognition in frontal facial images. The results of correct recognition are coloured green. These are, of course, the higher results because participants generally recognised the emotion expression correctly. The results of incorrect recognition between 5% and 10% are coloured yellow, and the results above 10% are coloured red.

Table 1: Results of recognition of emotion expression for frontal facial images

		Presented emotion expression					
	Recognition [%]	**disgust**	**anger**	**sadness**	**fear**	**surprise**	**joy**
Participants' response	**disgust**	84,2	6,7	1,7	10,8	2,5	0,0
	anger	7,5	75,0	3,3	3,3	0,0	0,0
	sadness	4,2	2,5	77,5	2,5	0,8	0,0
	fear	0,8	7,5	15,0	63,3	11,7	0,0
	surprise	3,3	8,3	2,5	20,0	85,0	0,0
	joy	0,0	0,0	0,0	0,0	0,0	100,0

The results of the proportion of observation of three facial features for all six emotion expressions are presented in Figure 6. Participants spent about half of the observation time observing the eyes, about a quarter of the time observing the mouth, and a small proportion of the total time observing the forehead.

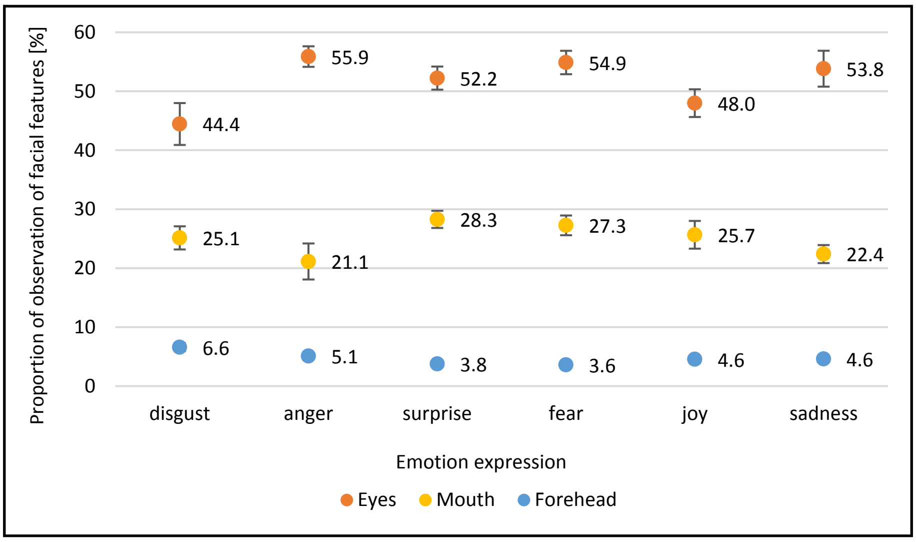


Figure 6: Proportion of observation time for eyes, mouth, and forehead for frontal facial images

The results of fixation duration of three facial feature for all six emotion expressions are shown in Figure 7. In general, the longest fixation durations are for the mouth and the shortest for the forehead.

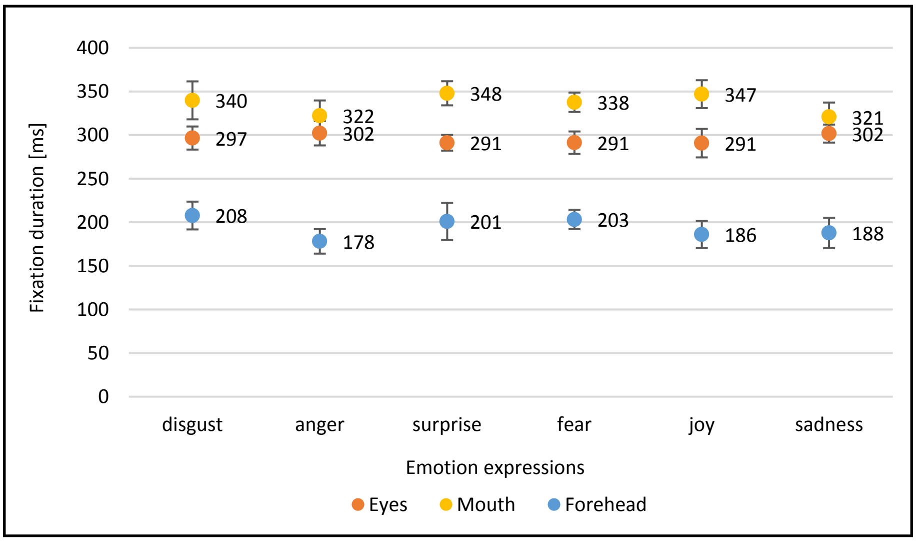


Figure 7: Fixation duration time for eyes, mouth, and forehead for frontal facial images

3.2 Profile facial images

Table 2 shows the results of emotion expression recognition in frontal facial images. All coloured fields are indicated as for frontal facial images.

Table 2: Results of recognition of emotion expression for profile facial images

		Presented emotion expression					
	Recognition [%]	disgust	anger	sadness	fear	surprise	joy
Participants' response	disgust	73,3	9,2	2,5	7,5	2,5	0,0
	anger	10,8	75,8	9,2	0,0	0,8	0,0
	sadness	1,7	5,8	71,7	0,0	0,0	0,0
	fear	11,7	6,7	8,3	59,2	16,7	0,0
	surprise	2,5	2,5	8,3	33,3	80,0	0,0
	joy	0,0	0,0	0,0	0,0	0,0	100,0

Same way as for the frontal facial images, the results of the proportion of observation of three facial features for all six emotion expressions are presented in Figure 8. Participants spent about half of the observation time observing the eyes, about a quarter of the time observing the mouth, and a small proportion of the total time observing the forehead (even less than for frontal facial images).

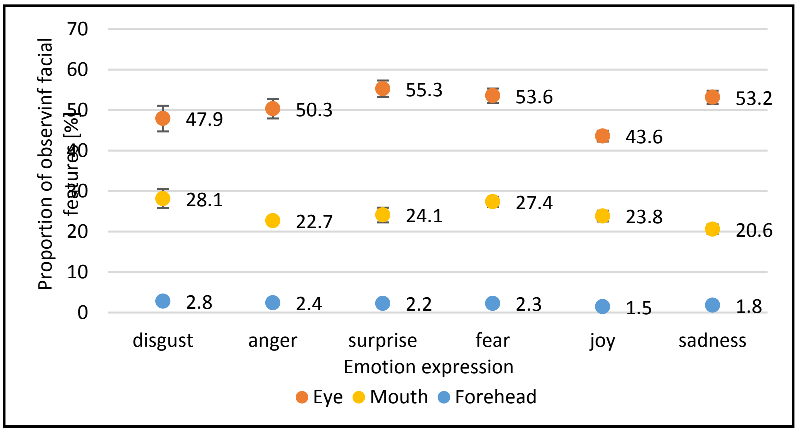


Figure 8: Proportion of observation time for eyes, mouth, and forehead for profile facial images

The results of fixation duration of three facial feature for all six emotion expressions are shown in Figure 9. In contrast to frontal facial images, fixation duration for profile face images is longest for the eyes and shortest for the forehead.

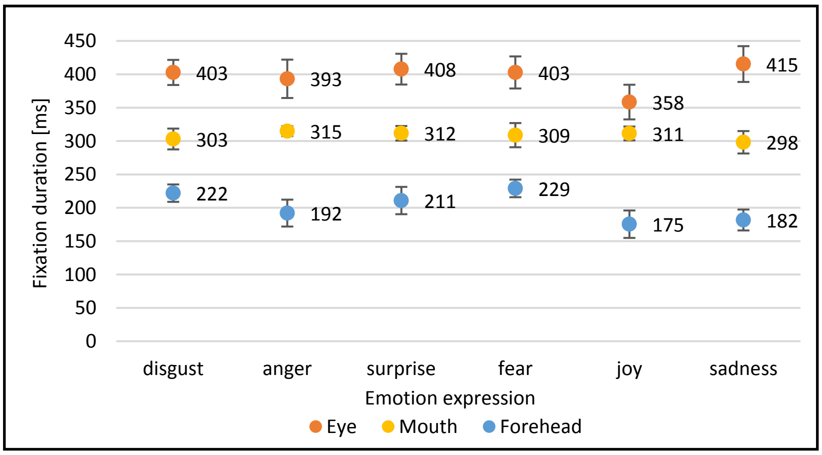


Figure 9: Fixation duration time for eyes, mouth, and forehead for profile facial images

4. DISCUSSION

The results in table 1 shows that participants made the most wrong recognitions of the facial emotion exoression of fear that it showed surprise (20.0%). The reverse case (when surprise was shown, they answered fear) was shown in a lower percentage of substitutions, although the percentage was still quite high (11.7%). When expressing fear, participants also answered that it was an emotion of disgust in a considerable percentage (10.8%). The reason for this, in our opinion, is the similar mouth expressions for these two emotions. There was also a relatively large number (15%) of wrong recognition between the representation of sadness and the participants' responses that fear was represented. We believe that the reason for this is that fear was not clearly expressed in some of the facial images in the selected face database. For example, the facial images of the emotion fear had some similarity with the facial images of the emotion sadness (drooping lips, eyebrows at the edges also downward). In terms of correct recognition, the emotion Fear had the lowest recognition rate (63.3%), followed by anger (75.0%) and sadness (77.5%). Well recognized were the emotions disgust (84.2%) and surprise (85%), and completely successful (100%) was the recognition of joy. Significant level of wrong recognition was for the combination of disgust/fear (7.5%), anger/disgust (6.7%), anger/fear (7.5%), and anger/surprise (8.3%). These results confirm some of the earlier research (Guo & Shaw, 2005; Green & Guo, 2018).

Our main question was whether these results could also be confirmed by the percentages of observation of facial parts shown in Figure 8. There we see that for the emotions fear and surprise there is a high percentage of observations of the mouth (fear 27.3%, surprise 28.3%). The reason for this is that in these two emotions, the mouth changes a lot compared to the neutral facial expression, thus attracting attention. Since their shape is also similar, these two emotions are often wrong recognized. These two emotions also have a high proportion of eye observation (fear 54.9%, surprise 52.2%), which means that they also attract participants' attention, and since the eye expression is similar (the eyes are wide open), they are also more often misrecognized. The emotion disgust also has a relatively large proportion of the observation of the mouth (25.1%). Again, it can be concluded that the similar shape and large proportion of observation of the mouth is the reason for the frequent confusion between the emotions fear and disgust. Wrong recognition between the emotions anger and disgust can be confirmed by the results of the observation of the forehead, as we can see that these two emotions attract the attention of the test participants much more than the other four emotions (disgust 6.6%, anger 5.1%). Basically, both emotion expressions have a similar shape for the area between the eyes that contracts and frowns.

In terms of fixation duration, the results are most likely to be interpreted as indicating that participants' gaze stayed longer on facial features that attract attention, and thus fixation duration is longer. This is even most evident in the area of the mouth, which changed significantly for the emotions fear, disgust, surprise and joy, and thus fixation duration was longer (from 338 ms to 348 ms). For the emotions anger and sadness, the mouth changes only slightly, i.e., it attracts little attention (sadness 22.4%, anger 21.1%), and accordingly the duration of fixations is shorter (sadness 321 ms, anger 322 ms). All six emotion expressions, where you can see similarities in the facial features are shown in Figure 10.

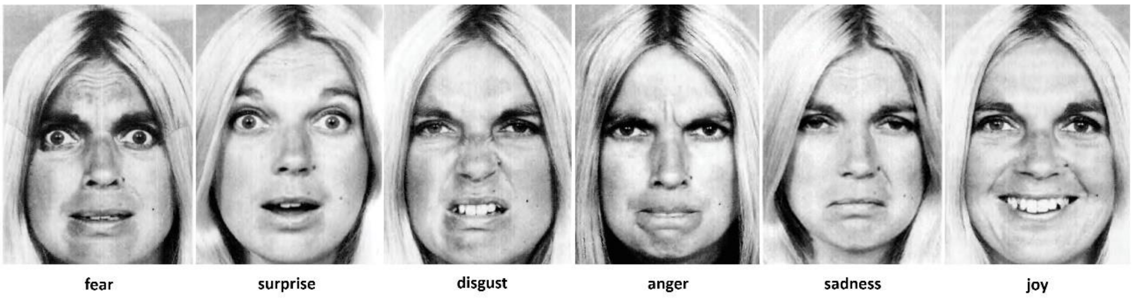


Figure 10: All six emotion expressions (Ekman & Friesen, 2003)

Similar findings can be made for profile facial images, as observation of facial features can be used to confirm incorrect recognition of certain emotion expressions. The most incorrect recognitions were between the emotions of fear and surprise (33.3% and 16.7%). These two emotions have the highest percentage of observations (fear 53.6%, surprise 55.3%), which means that they attract a lot of attention and are similar to each other (eyes wide open). A large percentage of wrong recognition is also between fear and disgust (11.7% and 7.5%). In Figure 8 we see that these two emotions stand out in terms of percentage of mouth observations (fear 27.4%, disgust 28.1%) and are also similar (open lips and

clenched teeth). In the case of wrong recognitions of anger and sadness (9.2% and 5.8%), we see a low proportion of mouth observations (anger 22.7%, sadness 20.6%), where we can also note the similarities in mouth shape (pursed lips). The main difference between these two emotions is the eyes, but since we see only one eye from the side in profile images, wrong recognition occurred much more frequent than in frontal facial images (3.3% and 2.5%), where we see both eyes, which are quite different for the emotion expression of sadness and anger. A large percentage of wrong recognitions between the emotions of anger and disgust (10.8% and 9.2%) can be partially explained by the highest values when observing the forehead (anger 2.4% and disgust 2.8%), which look similar (furrowed brow) but their values differ only slightly from those of the other emotions. As with the frontal facial images, the emotion of joy is perfectly correctly recognized (100%), as it is otherwise very different from the other five. On the other hand, it is difficult to explain wrong recognition of certain emotion expressions in terms of fixation duration results, because the results do not differ sufficiently to draw the same relevant conclusions.
In general, it can be said that the recognition of emotions is significantly better in frontal facial images than in profile facial images, mainly because the depicted faces contain more information in the frontal view than in the side view.

5. CONCLUSIONS

In our research, we focused on retrieving the expressions of six basic emotions for two types of facial images: frontal and profile. In the first part, we obtained the correctness of emotion recognition and, as a result, incorrect recognition or emotion interchanges, the results of which were presented in the confusion matrix. As expected, the emotion recognition results are better for frontal facial images, since only these, contain more information about the face itself compared to profile images. We aimed to confirm the results of incorrect recognition of emotions by analyzing the proportion of observation of facial features and by analyzing the fixation durations. The first proved to be very effective, as we were able to detect some of the most common misidentifications (e.g., fear/surprise, anger/disgust, disgust/fear, sadness/anger) by observing the same proportions of three facial features (either eyes, mouth, or forehead).The analysis of fixation durations was somewhat less effective, as here the results of fixation durations on specific facial features were very similar for all emotions, and only in the case of the misidentifications of anger and sadness was a correlation found between their misidentifications and fixation durations on the mouth.
However, a test of the heatmap-based surface method is currently underway, and we are trying to confirm the results incorrect recognition of emotions.

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VISUAL BRAND COMMUNICATION DURING THE COVID-19 PANDEMIC

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Abstract: *COVID-19 has brought a number of changes in people's lifestyles as well as in business strategies. The consumers are moving towards social media and brands are forced to adjust their positioning strategies to retain existing and attract new customers. In generating the customer engagement, the brand content must match the visual preferences of its target group. This paper reviews a relevant literature of visual communication in the context of branding focusing on changes in terms of redesign and rebranding imposed by a crisis. The aim is to identify how companies successfully developed memorable, contextually-relevant and public-educational visual brand communication and strategies during the COVID-19 pandemic. The content analysis method was used in order to create a synthesized overview of brands' visual communication and their creative solutions during the pandemic. The results of this study highlight the importance of visual communication that can be taken by brands in dealing with crisis situations such as pandemic, and its effects on consumer behaviour in the new-normal era.*

Key words: visual communication, branding, covid-19 pandemic

1. INTRODUCTION

The Covid-19 pandemic has had a significant (negative) impact on the business and economic sectors. The marketing and communication strategies also evolved, particularly after the imposition of social distancing and the territorial lockdown. To survive in the midst of the corona virus pandemic, marketers must develop an adapted brand strategy to promote their products or services to consumers (Hadi & Rachmaniar, 2020). Business people optimize digital branding and online marketing communication as channels for reaching their target audiences (Hermanto et al., 2021).

In pandemic marketing, especially in branding activities, creativity and inventiveness is absolutely essential. The branding initiatives used during the Covid-19 pandemic range from CSR initiatives linked to the corona virus pandemic, home shopping campaigns, branding via online media, social media and official websites, to setting up online festivals with exclusive discounts etc. (Hermanto, 2020). A company can employ a number of measures to ensure that its brand and product positions will survive an unknowable pandemic.

The focus of this research is on creative strategies in the context of marketing communications of global brands during the pandemic. The aim is to identify how companies successfully developed visual brand communication and adapted creative strategies during the Covid-19 pandemic in order to create a memorable, contextually-relevant and public-educational content. The result of this research is reflected in the analysis of redesigned visible elements of the brand that communicate certain values that are socially responsible and important for crisis communication.

2. THEORETICAL BACKGROUND

In order to understand the practical communication strategies that brands implemented during the pandemic, it is important to analyse the theory of visual brand communication and marketing strategies. The authors highlight the specifics of pandemic marketing in the context of consumer behaviour (Mitrović, Novaković & Spajić, 2021). Therefore, the need for research into the communication challenges imposed by this new era is increasing. This paper reviews the body of academic research on visual brand communication in relation to pandemic re-branding focusing on social media communication.

2.1 Visual brand communication

The rapid development of communication technologies has changed how people live. The consumers are moving towards social media and brands are forced to adjust their positioning strategies to attract new customers. The brand must differentiate itself by emphasizing the importance of its content to comprehend the visual preferences that their intended audience requires (Khamis et al., 2021).

The usage of *social media* in brand building and other interactive media emerge as platform in modern marketplace. With a two-way communication possibility, consumers are not only interested in the functions, price, and location of a specific product, but they also pay much more attention to the story, personality, and lifestyle behind a brand (The Pew Research Centre, 2020). Considering media functionality and user motivation, there are two major types of social media: relation-based and visually-based (Chen, 2011). The primary use of relation-based social media is to build and maintain interpersonal relationships and connections with other users (for example, *Facebook, LinkedIn, Yelp* etc.). Visual-based social media is more about self-expression, visual representation, multimedia storytelling, aesthetic communication and so on (e.g., *Instagram, Pinterest* and increasingly *TikTok*).

Visual branding involves successfully creating a memorable experience for consumers that makes them trust the company, which drives brand referrals, customer loyalty and positive word-of-mouth if the experience was great (Sardovski, 2022). Visual branding is one of the best tools companies have to communicate with their customers.

A *brand identity* is comprised of characteristics and attributes that form a unique set of associations that a company seeks to establish and maintain (Esch, 2008). Brand identity is a concept that creates relationships between the company and consumers, and from the customer's perspective it forms the brand image and lead to perceptions of brand personality (Aaker, 1997; Nikolić, Stanković, & Dejanović, 2015). When consumers interact with brands, they are exposed to visual stimuli such as logos, colors, shapes, typefaces, characters, styles, and other brand-image elements (McQuarrie & Phillips, 2008). Any of these visual elements may come to be associated with the brand and serve to identify it.

A study that explored the understanding of visual brand identity (VBI) from the art directors' perspective indicates that VBI is "the holistic look and feel of a brand, manifest as consistency among the brand, its strategy, and all its individual visual elements, ongoing over time" (Phillips, McQuarrie, & Griffin, 2014). For a broader understanding of the importance of this topic, it is important to acknowledge that brand advertising is created in a large group of professionals (marketing/brand manager, copywriter/art director team, creative director, account managers, media planners, research specialists, graphic designers). The visual elements identified as of primary importance for visual brand communication include the *brand's logo, typography, colour, and layout* (Phillips, McQuarrie, & Griffin, 2014). These elements are similar to those identified in the wide branding literature (e.g. Nikolić, Stanković, & Dejanović, 2015).

In the context of *visual brand communication*, some dimensions are of particular importance (Khamis, et al., 2021):

- *Visual literacy*. The Toledo Museum of Art states that visual literacy is the ability to read, comprehend, and write visual language (Toledo Museum of Art, 2016). It is centred on the notion that pictures, and videos can be read, and that message can be passed through a process of reading (Fahmy, Bock, & Wanta, 2015). This skill equips viewers (or content users) to comprehend and evaluate the contextual, cultural, ethical, aesthetic, intellectual, and technical components in a visual element (Association of College and Research Libraries, 2011). People are constantly exposed to images and other multimedia information from various sources, such as social media, television, and street billboard screens (Choon-Lee, 2019). Companies frequently use images in their offline and online marketing communication because they have a much greater impact on customers than text does. Therefore, visual brand communication was crucial during the Covid-19 pandemic in order to send effective and socially responsible messages to their target audiences.
- *Digital visual engagement*. According to Dhanesh (2017) and Muntinga et al. (2011), digital engagement represents an active online behaviour that is defined by intense personal participation with the information, organizations, brands, or causes that are promoted in online public spaces. In addition to liking and commenting, there are distinct levels of users' involvement with branded digital content that are categorized into three types of active online behaviour: contributing, creating, and consuming (Muntinga et al., 2011). Companies are increasingly interested in enhancing their digital communications through visual content that is engaging. Visual brand communication can contribute to positive corporate reputations and purchase intentions (Zerfass, 2017). Powerful images and multimedia with evoking emotions and cultural meanings have a persuasive impact on consumers and influences digital users' decision making (Dhanesh, 2017). Thus, visual brand communication during the pandemic had to use specific codes of colour, tone and public context to convey and evoke emotions of safety, care and necessary social distance.

- *Social media.* Social media represent a very effective and efficient tool for brand to use to create, communicate, deliver value, and exchange offerings to its stakeholders (Kohli, Suri, & Kapoor, 2015). Different social media platforms are available and different content of visual communication can be presented by the brands depending on what the company is aiming to achieve. More than a half respondents of *Edelman* research believed corona virus information from brand social media and 84% used social media channels to facilitate a sense of community and offer social support to people during the pandemic (Edelman, 2020). People were spending a lot of time on social media during the Covid-19 pandemic, thus visuals were very important part of grabbing users first attention to the content and communicating specific values for particular global crisis.

Studies in visual communication and graphic design often use experiments to observe visual components like colour, shape, or view perspective then analyse the changes in branding influences induced by visual variables (Krause, North, & Heritage, 2014). Media and advertising studies frequently examine how the symbolic significance and representation of visual branding affect brand building (Smock, et al., 2011). This paper highlights the creative visual and communication solutions of global brands during the pandemic, which managed to convey a strong message in times of crisis and strengthened their brand image.

2.2 Marketing challenges during the Covid-19 pandemic

The Covid-19 pandemic is being used as a new marketing strategy (White, Nieto, & Barqera, 2020). The new scenario should be seen as an opportunity to observe changes in consumer behaviour and virtually get in touch with them in new ways (Khare & Singh, 2020). Brands use the data they have about their consumers and listen carefully to recognize new demands and succeed in personalizing their brand (Salah, et al., 2020). The key to success in these situations lies in understanding what value means to customers as they establish new buying routines (Knowles, et al., 2020).

Consumers expect brands to explain their larger purpose and how each serves the greater good. A consistent branding strategy fosters familiarity, maintains loyalty, and demonstrates to consumers that their trust is earned (Harvey, n.d.). However, branding efforts must be adapted to match the current context and environment. With those changes in the marketing environment comes the need to develop strategic agility before, during, and after the pandemic (He & Harris, 2020). As critical as thinking about immediate, short-term survival needs is, it is equally important to anticipate the outlook for brands in the new normal market (Roggeveen & Sethuraman, 2020).

Social media are becoming the primary source of information, news, but also the primary tool for promotion (Palupi & Svalov, 2020). Consumers demand different communication during the crisis caused by Covid-19, as well as presentation adapted to the situation. Thus, almost two-thirds of the respondents (65%) of the *Edelman Trust Barometer* research claim that "the way in which brands respond to the pandemic will have a huge impact on the likelihood of buying their products" (Edelman, 2020). This research states that 1 of 3 respondents have punished brands that did not respond well during the pandemic, while 84% of respondents consider that brands should serve as information source, use their power to educate and bring people together. In uncertain times, success will be achieved by those brands that show a willingness to put their consumer first. Brands need to communicate with emotion, compassion and facts.

3. RESEARCH OVERVIEW

In order to create an overview of brands' visual communication and their creative solutions during the pandemic, the content analysis method was used. Images that brands posted as visuals on social media during the pandemic were analysed. Visual analysis is an important step in evaluating an image and understanding its meaning (Campus Library, University of Washington Bothell & Cascadia College, 2022). The results of this paper highlight the importance of visual communication that can be taken by brands in dealing with crisis situations such as pandemic, as well as the significance of creative and symbolic brand refresh.

A brand refresh relies more on visual changes and is more a tactical manoeuvre unlike re-branding which represent a long-term marketing strategy. The level of complexity of brand refresh process depends on the extent to which company needs to change its image (Sardovski, 2022). Realizing that the crisis is an unpredictable situation and that the business response must be quick and agile, it requires a tactical marketing solution such as brand refresh. By changing a brand voice, visual branding or customer service, brand refresh should have a distinct impact on the way that brand feels, sounds, and looks to target customers.

3.1 The research method

Content analysis is a research tool used to determine the presence of certain words, themes, or concepts within some given qualitative data (i.e., text, images, news etc.). Using content analysis, researchers can quantify and analyse the presence, meanings, and relationships of such certain words, themes, or concepts. It is "a research technique for the objective, systematic and quantitative description of the manifest content of communication "(Berelson, 1952).

There are two general types of content analysis: conceptual analysis and relational analysis (Columbia Public Health, 2022). Conceptual analysis determines the existence and frequency of concepts in a text. The main goal is to examine the occurrence of selected terms in the data. Relational analysis develops the conceptual analysis further by examining the relationships among concepts in a text. Each type of analysis may lead to different results, conclusions, interpretations and meanings.

Given that the focus of this research is on the visual elements of brand identity, visual content analysis is used in evaluating the concept of changed VBI elements and understanding their meaning.

3.2 The research results

Governments, companies and consumers have implemented measures to curb the spread of the corona virus and mitigate the impact. Large companies and global brands tried to communicate the important message of social distancing. The brand response to crisis such as pandemic most often involved encouraging people to act or adopt a state that reflects consideration and empathy, and social responsibility with social distancing was the focus. Visual communication was crucial, because it is the most effective on people. In addition to the successful ones, there were also campaigns that were considered to be unacceptable. The subject of the analysis in this paper is only cases that had positive reactions both among users and among experts in the business world (e.g. CNN Business, 2020; Lundstrom, 2020; Graphic Design Forum, 2020; Marketing Interactive, 2020).

Logos are sacrosanct for brands but during the pandemic these were increasingly becoming tools to promote social distancing amid the corona virus outbreak. The reaction of brands implied a change in the tone of communication, special efforts towards building an emotional connection with consumers and strengthening social engagement; and all this within a creative visual. Table 1 provides an overview of changes and pandemic communication in VBI in times of crisis and how some of the most iconic brand identities have been modified to get the word out.

Table 1 (part 1): Brands' refresh communication during the Covid-19 pandemic

Brand	Pandemic VBI	Modification in VBI	Key messages
Nike	JUST DON'T DO IT.	Changed tagline.	*If you ever dreamed of playing for millions around the world, now is your chance. Play inside, play for the world*
Audi		Changed graphics.	*Keep distance.*
McDonalds		Changed graphics.	*A little distance can unite us all.*
Volkswagen		Changed graphics.	*Thanks for keeping your social distance.*
Coca-Cola		Changed typography.	*Staying apart is the best way to stay united.*
Corona Extra	Need new name Extra	Changed name.	*No one wants a corona.*

Table 1 (part 2): Brands' refresh communication during the Covid-19 pandemic

Starbucks		Changed graphics.	*Keep safe, wear a mask.*
Olympics		Changed graphics.	*Physical distancing is a must. If the five continents can do it, you can do it too.*
NBA	NBA	Changed graphics.	*Take a break, stay home.*
US Open	us closed	Changed name.	*Just like everyone, US Open is now closed.*
MasterCard	master card.	Changed graphics.	*Physical distancing helps limit the spread of COVID-19, and hopefully limit our credit and expenses too.*
LinkedIn	Locked in	Changed name.	*Polish that LinkedIn profile of yours that you created for years ago but never used.*
Good Year	BAD YEAR	Changed name.	*This is definitely not a good year for Goodyear and everyone.*
Intel	stay inside	Changed tagline.	*Stay inside where you are safe from the virus.*
YouTube	YouTube	Changed graphics.	*COVID-19 has stopped virtually everything… even the play button in the YouTube logo.*

Physical distancing helped limit the spread of COVID-19, and hopefully brands did the same by separating the visual elements within their logos. *McDonald's* have separated their golden arches within the logo and posted to its social media. The ad agency explained that despite the temporary separation between its customers and the company caused by closures of some of its restaurants, they "can always be together" through Mc-delivery and drive-thru. Two automotive companies that share ownership, *Audi* and *Volkswagen*, tweaked their logos for their social media accounts. *Audi* separated its four rings in a short video telling people to stay at home and keep their distance. *Volkswagen* also promoted a similar video with inspirational messages and separated the V and W. *The Olympic* logo design represents the union of the "five continents" of the world; however, physical distancing is a must, so *The Olympic Games* have separated their circles. *MasterCard* have separated two coloured circles, as well.

Coca-Cola has the most recognizable textual logo in the world, which has not been changed for decades. The brand typically celebrates togetherness and love in its ads, thus this visual change in typography with strong message has had a powerful impact on people.

Face mask was one of the most important items during this pandemic and everyone should wear on. *Starbucks* has transformed this potential problem while drinking a Starbucks coffee into a creative solution on their logo mermaid. The silhouette of *Lakers* great and Hall of Famer *Jerry West* has been standing and dribbling for over 50 years on *NBA's* logo. During the pandemic, this silhouette took a break and stayed home. *YouTube's* changed play button on its logo had a strong public impact as well, considering that people were watching more than ever before (since that's all they can do at the time).

Some of the brands like *Nike* didn't tweak its logo, but it launched a large social media campaign with its global roster of star athletes including *NBA* player LeBron James and golfer Tiger Woods. Sports grounded to a halt because of social distancing rules and the ban on large gatherings, like in stadiums. The campaign has encouraged people to play inside. Instead of going outside, *Nike* said: "just don't do it". *Nike* has created very powerful and meaningful message by modifying its tagline. *Intel* did the same: instead of their recognizable message "intel inside" the company has communicated key message "stay inside".

Self-isolation was crucial during this pandemic, and *LinkedIn* thought that it was the right time to polish the *LinkedIn* profile. With a word play, they conveyed a message about the importance of the lockdown, again fulfilling their purpose of networking people online. *US Open* and *Good Year* applied the same logic and came up with creative solutions as well. *Us Open* become *US Closed* and *Good Year* has changed its name and logo to a symbolical *Bad Year*. The brand *Corona Extra* faced a unique dilemma at the start of the pandemic due to consumer reluctance around the virus and brand's similar-sounding names (Gartner, 2021). The label has had to re-jigger its entire marketing strategy and tap into less-typical methods of innovation, like brewing up its own *Giphy* library and marketing its entire portfolio of beverages.

3.3 The research discussion

Several conclusions can be drawn from this research. First, people have a fear of the corona virus, which reduced their purchasing power and inevitably had an impact on producers and marketers. In order to brand remains popular in the community during the crisis, companies were implementing different strategies and tactics for handling the circumstance while following health regulations.

The Covid-19 disaster has encouraged the formation of what call *giving society* (Hadi & Rachmaniar, 2020). It forms a society that cares, full of love, empathy, compassion. A brand is also a corporate citizen that must care and be responsible for people who are in distress (Hermanto et al., 2021).

The communication brand strategy during the pandemic was threefold: taking advantage of the digital world, using resources efficiently and creatively and making an affirmative movement.

The crisis has imposed a new trend: the brand needs to be careful and offer a solution. Every brand must be an empathetic brand. This is a new commitment to consumers and a new normal. The tone of communication was changed, adapted to the crisis situation. It was communicated cautiously, with respect of newly created norms, adapted to current consumer requirements. Many brands have focused their communication on messages of gratitude to healthcare workers and all those who are unable to stay at home. Communication embodied a general "we're all in this together" vibe.

In a survey conducted by the *Edelman Trust Barometer*, 57% of respondents pointed out that they are against advertising or excessive communications that are humorous or cheerful tones (Edelman, 2020). Brands have recognized this, by communicating action, information or support. Advertising campaigns avoided showing human contact, and scenes of hugging, kissing or touching were absent. All this was accompanied by modified visual brand identities.

The creativity, passion, and thought that go into wanting to help, educate, and be a part of the physical distancing movement, represent the common denominator of the analysed cases of modified VBI in this paper.

4. CONCLUSIONS

The Covid-19 pandemic has conditioned brands to make a special effort to maintain relevance. A specific approach to communication and an effort not to hurt any of the consumer's feelings come into focus. Most brands have adopted a positive tone by highlighting gratitude, motivation and support through its visual content, and the main communication has moved to digital platforms and social media. Special efforts were noticed in building an emotional connection with consumers and strengthening social engagement, given that crisis situations like pandemic require a customized approach and placing marketing goals in a more socially responsible framework. The period of new normality will be successful for those brands that have shown a willingness to put their consumers first in such uncertain times.

The role that visual element plays in brand communication suggests that this strategy has a great deal of potential to strengthen the brand's reputation. With social media as a platform, brand content can reach a wide audience of potential customers. Popular brands have a strong influence towards their customers and followers, and through a logo redesign they could easily engage everyone to stay at home, wear a face mask, practice social distancing, and follow all the safety guidelines to make people safe.

To be successful, brand familiarity on brand content must take into account the visual component in order to capture viewers' attention and maintain customer loyalty.

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CREATING A 2D ANIMATED SHORT FILM WITH SOUND AND IMAGE SYNCHRONISATION

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Abstract: *Animation is a method, in which still images create the illusion of movement on the screen. We manipulate the viewer with fast-moving pictures to make them look as if they can move. This article intends to make a 2D animated film based on a screenplay template with synchronized sound. In the article, we had to provide different Software: Adobe Illustrator, Adobe Animate, Adobe After Effects, Adobe Premier Pro, Reaper (Digital Audio Workstation), and Sketchbook. In addition to the software and, of course, the computer, we also used a graphics tablet, a microphone, and a sound card During writing the article, we get to know the workflow of the creation of animation, from the design to the final product. We tested ourselves in the role of all important members of production houses to get the most realistic insight into the creation of such a project. The final product of the article is a short cartoon with a synchronization of speech and sound.*

Keywords: animation, 2D, cartoon, lip sync, synchronized sound

1. INTRODUCTION

Animation is the result of a sequence of still images that together create the illusion of motion in the real world. The word animation itself comes from Latin, where the ancient Romans knew the word anima for soul. Artists use animation to give characters a soul or bring them to life. Animated films are about bringing cartoon characters and objects to life by moving them around, by "giving" animated characters a soul. And so, these characters can be good or evil, honest, villainous, naive, funny, deadly serious, oblivious, and so on. For this reason, some of them have always remained in our memory, because cartoons were part of our childhood. We had fun watching them, we identified with the cartoon characters, and finally we could learn something from their good and bad qualities. When we grow up, most people stop watching cartoons. But few go beyond the level where not only the body language of the characters and the visual action of the story are important, but where they also notice and learn the hidden qualities of cartoons that we mostly overlooked as children. Some want even more: they want to be involved in the process of creating animated films. They want to create new heroes to entertain new generations and provide them with new learning opportunities.

The goal of the project was to create a short-animated film that would be educational and interesting for all generations, and to overcome the preconception that animated films are childish and only for children. We also spent a lot of time expressing ourselves artistically to make a project where we could bring our love of drawing to the screen. Our work was about learning about the process of creating a cartoon with dubbed sound, and experiencing all sorts of problems we encountered along the way. We wanted to learn how to reduce these problems and, most importantly, how to supplement the knowledge we gained at the university with additional research and put it into practice to realize the project we wanted.

2. METHODS

Through the production of an animated film, we learned about the role of the scriptwriter to the producer of such a project, giving us an insight into the work of an individual on a professional project for a large production company using amateur equipment.

2.1 Creating a story and its screenplay

We began our creative process by coming up with a story, and we had to make sure it had enough speech, which was the only way we could learn animation and sound synchronization. First, we read existing literature, then we had the idea of our own story, which allowed us to create the story, the characters and the images in our own style, and to try a different artistic style, which was an additional challenge. Once we had our story well fleshed out, we began writing the script. Since we had decided to animate with speech, the elaboration of the script was especially important, because without a well-defined dialogue it is not possible to start animating the characters. When writing the script, we had to pay attention to the audience we were writing for. In our case, when we were putting together the animation for the kids, we had to be extremely careful with words they might not understand, and there were a lot of those in our case. We spent a lot of time on the problem of how to explain to children in the simplest way what cubism means.

2.2 Creating a visual image of the protagonist and other characters

Since our story is divided into two realities or two different worlds, we have adjusted our drawing style accordingly. In the story, we have one main character who makes two different appearances throughout the story. Our protagonist switches from one reality to the other, changing his appearance, and at the end of the animation he returns to his original form.
Our creative journey began with sketching in Sketchbook software, which we used to get as close as possible to the characters in the story. We focused on our main character first and later developed the other characters in the same way. For the first part of the story, we mainly used the line drawing technique that we had the most practice within previous projects. The work continued with a slightly more difficult challenge - drawing a character in a cubist world. To do realistic dialogues in the script, we wanted our character to have more mouths and retain the main features of his character from the "real" world in "cubism".

2.3 Creating a storyboard

A storyboard is a sequence of images that represent the visual content of a story based on a script. A storyboard can consist of simple sketches on paper or fully developed colored and shaded drawings or even photographs. Storyboards save a lot of time in project development and can alleviate many financial problems (White, 2005).
In our case, we visually defined the story with sketches in Sketchbook and added the appropriate dialog into the scene. In this way, we thought like a cinematographer and defined the camera position in each scene, which gave us a more detailed view of the spaces we would use in the animation and where we would place our cartoon characters. We took the drawing style from our sketches into the storyboard. We started with a black and white drawing and continued with a color representation as the two worlds transitioned.

2.4 Recording the dialogues

In this step, the actors lent their voice to a particular character in the cartoon. We needed some test recordings to find the right sound without any background noise. We covered the entire studio with pillows and various blankets to dampen unnecessary vibrations in the room. In any case, we recorded many of the same recordings with different voices to have more choices later. All the material was saved directly in Reaper software, where we also removed the noise that was still present despite our careful layout and exported to files that Adobe Animate software can read.

2.5 Animation of the walk and run cycle

Animating a walking cycle (Figure 1) is one of the most basic and important animation processes, but also one of the most difficult. Both drawn characters and real people differ in the way they walk. This depends on the shape of the body, the mood, the personality of the character, etc. (Roberts, 2011). The sad character will walk slowly and hunched over, while the happy character will bounce around the stage. When creating the cartoon, we paid a lot of attention to what mood the character is in at a particular moment. The most important element of the walking cycle animation is the illusion of gravity. When walking, one foot is always on the ground, regardless of whether they are alternating. However, when we have a cycle where both legs can be in the air for a moment, it is no longer walking, but running. As with walking, we animate running with the same key elements, but we need at least one frame where we take both feet off the ground. The number of frames used is critical to the animation of running. If we want the character to run or sprint very fast, we only need three frames, but if we want the character to run and jump slowly, we add more frames in between for that effect. Running cycle in shown in Figure 2.

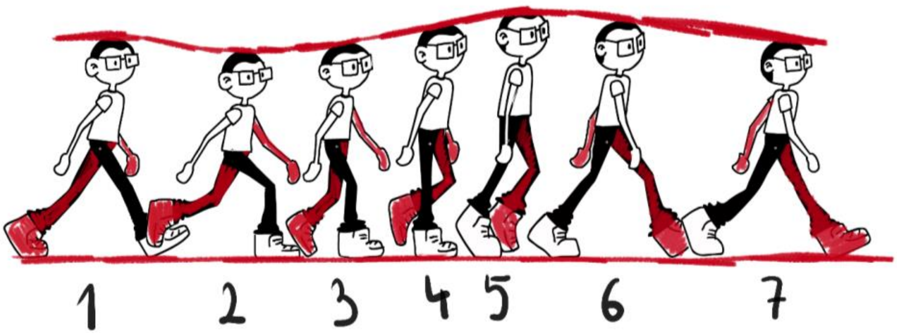


Figure 1: Representation of protagonist's walk cycle

Figure 2: Representation of character's run cycle

2.6 Speech animation

After creating the animation of the character's body movements, we started animating the mouth and facial expressions. We spent some time studying the method of lip synchronization, which led us to the realization that we needed to do some of the intermediate steps ourselves. Like various literary sources, the Internet is full of tips on lip-syncing the English language, which of course differs in alphabet from ours. Even some of the letters we have in common in the alphabet are not pronounced the same way as in their language. Since we decided to make our animation in Slovenian, we started by creating the mouth positions for the phonemes ourselves. We began the study by photographing the lips next to each letter of the alphabet, and the images were compiled into a table (Table 1) containing the alphabet and the viseme corresponding to each syllable. We searched the table for the letters where the differences in the shape of the lips were insignificant, so that we could group them together.

The more time we are willing to invest in animating a character's mouth and matching the image with the sound, the better he will look when he speaks, and the speech will be more understandable, making the animation more successful (Breen, 2016).

The vowels are the most important part of the synchronization, and since they are not similar enough to any other letter of the alphabet, we have drawn a shape for each syllable. They are also the only ones in the table that are not colored since they do not have to have a common shape. All other letters or consonants were grouped by color, as were the common shapes we then assigned to them. This way, we were able to consolidate our collection of lip shapes that we used in the animation, and the final product was a smoother and more efficient synchronization.

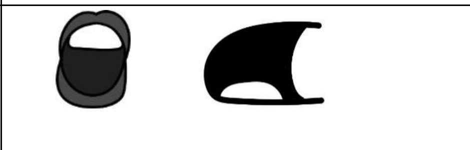
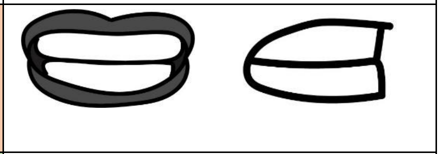
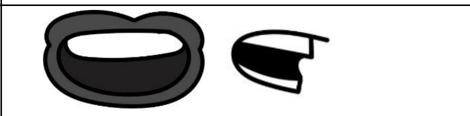
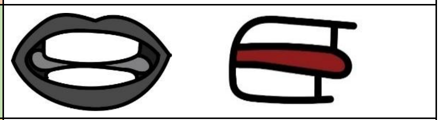
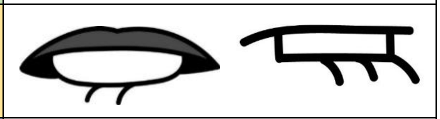
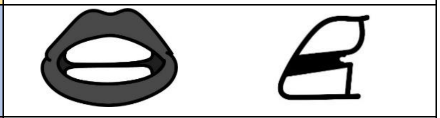
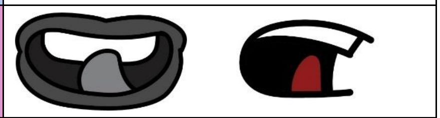
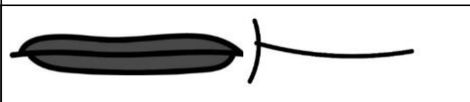
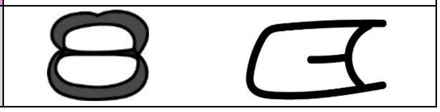
One of the basic principles of animation is exaggeration, and that's what we followed in our lip design. We exaggerated the position of the lips when we took the photo to make them more visible, and even more when we designed them for animation. To create the profile of the lips, in addition to our reference photos, we also looked at popular cartoons that use the side view, such as Family Guy, American Dad, Disenchantment, etc. Table 2 shows all the necessary lip positions to make our animation realistic enough. The common visages are divided by the same colors as in the previous Table 1.

Table 1: Photos of the shape of the lips when pronouncing the whole alphabet

LETTER	PRONUNCIATION	LETTER	PRONUNCIATION	LETTER	PRONUNCIATION
A		B		C	
Č		D		E	
F		G		H	
I		J		K	
L		M		N	
O		P		R	
S		Š		T	
U		V		Z	
Ž					

Once all the characters' movements were animated, we could begin the actual speech synchronization. To animate the lips, we used Adobe Animate's automatic speech synchronization feature. To properly animate the lips, we first had to draw them in Adobe Illustrator and import them back in, assigning each illustration its own keyframe in the software. We also gave each keyframe a name to make it easier to figure out which frames belonged to a particular audio clip at a particular time. In the next step, we imported the frames into the timeline and tried out the lip sync, which surprised us in a positive way. Since the program is written in English, we did not expect it to be compatible with Slovenian. But surprisingly, it split the audio track into the correct timing of the different syllables. Of course, there were some errors, but nothing significant that could not be replaced or even added by other lip shapes.

Table 2: Depiction of all the necessary letters for correct synchronization and their corresponding illustrations

LETTER	LIP SHAPE ILLUSTRATION	LETTER	LIP SHAPE ILLUSTRATION
A		C, J, S, Z	
E		D, N, R	
I		F,V	
O		H, K	
U		L, T	
B, M, P		Č, G, Š,Ž	

3. RESULTS

The result of our work is a short-animated film with synchronized sound and speech. The animated film follows the protagonist who, during an art excursion in a gallery, accidentally falls into a painting and finds himself in a fantasy world where he searches for ways to return to the real world. During his visit to the world of painting, he learns about the artistic style of cubism, in which he changes his image when he comes over from the previous, real world. The animation is educational and can be used for educational purposes in art classes for children. Our idea or desire for future projects is to create a series of short animated films where our protagonist can dive into the imaginary worlds of different paintings and learn about artistic styles. The idea for the animated film came from our childhood imagination. We wanted to show in a metaphorical and informative way the moments when someone stands in front of a painting and looks at it forever, and then his parents tell him that he just lost track of time and "totally fell into the painting." The animated film "Hop into Reality" was created with great love for art and different forms of artistic expression.

4. DISCUSSION

We were aware from the beginning that a project like this would not be easy, but we must admit that we never thought it would be so time-consuming. However, we learned a lot during our research and gained a real insight into how a project like this works. If we could start the project again with the knowledge we have so far, we would do a lot of things differently because the work did not always go as we had imagined. During our creative journey, we encountered all kinds of difficulties. These started at the very beginning of the animation because we wanted to use the same drawing style in the animation as in the sketches, where we used simulated pencil strokes as tools. Since we had not thought carefully enough about the fact that our sketching software - Sketchbook - is a raster software, while Adobe Animate is a vector-based software, we were a bit disappointed when we realized that the drawing tools offered did not match those of the sketches.

We realized quite quickly that time would be a major problem in our case. We realized that we would have to leave out some details that would not make much difference, hoping that we could add them at the end of the project, but unfortunately, we did not succeed. A big problem arose in the design of the

visemes for speech synchronization. Our first thought was that we would use similar lip shapes to those in the various instructional videos on the Internet that we had watched extensively before starting the project, but we had not considered that we had chosen a completely different language for synchronization. Although creating and studying our own viseme was a lengthy process, we are glad we undertook it because we spent more time studying our facial expressions and perhaps helping someone doing a similar project with our research. We would also like to point out a problem we encountered during the animation process when we realized we did not have a good idea of the timing of the animation. Frames were limited to speech, meaning scenes with dialog or monologs took as long as the soundtrack. However, since we created the storyboard before recording the speech, we did not have a good enough idea of the timing of the shots. Therefore, for the first page of the storyboard, we unfortunately had to remove or change some scenes that were already drawn. However, since the storyboard is created at the beginning of the creative process, we did not change it later because we did not need it.
If we could start again, we would leave more time for sound effects and music in the animation. We would have spent most of post-production choosing the sound effects or recording them ourselves. That way, it would be easier to synchronize them with the reference we had already made, and later, thanks to the same recording equipment, it would be nicer and easier to mix the sound together. Despite our sometimes poorly organized workflow, we are extremely satisfied with the final product. We believe that we managed to fix all the problems to a large extent, or at least mitigate them to the point where they are not so visible anymore.

5. CONCLUSIONS

We set out to create a short 2D film with synchronized sound and image, and we succeeded with the final product. Our creative journey was not easy, as we kept encountering various difficulties during our work. But every clever solution gave us the motivation we needed to finish the work. Every time we look at the finished product, we are truly grateful that we did not give up.
At the end of the day, we are not only proud of our finished product, but also very satisfied with the knowledge and experience we gained during the production process. We learned all kinds of new software, the history of animation and finally different drawing techniques. During the creating of the animation, we learned the main elements of the creative process used in the professional world of animation. And what is really encouraging is the fact that with the knowledge we have gained, we are now more confident and therefore ready for new projects.
Creation an animated film is a time-consuming process that most people do not realize when they see it. We hope that our article has given a realistic picture of the working process and the dedication we put into each step.

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INSTAGRAM INFLUENCERS' RESPONSIVENESS TO A SMALL BUSINESS COLLABORATION OUTREACH

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Abstract: *Collaborations between social media influencers (SMIs) and brands have become increasingly popular in recent years, so many marketers and brands either start implementing influencers or intensify SMI use in their marketing strategies. Influencer marketing is the practice of compensating influencers for posting about a product or a service on their social media profiles. Influencers usually specialize in a particular niche area and possess highly devoted follower bases of different sizes. Their incentivized brand-related messages are very effective and achieve increased engagement because of their personal manner, subtlety, and authentic advertising approach. One of the first steps in the influencer marketing process is to reach out to the right influencer with the aim of partnering up and collaborating in order to engage new potential customers and consequently grow a business. Therefore, influencer marketing basically starts with an influencer's positive response to a brand's outreach and collaboration consent.*

This research study aims to determine the responsiveness of Instagram influencers to a small business outreach offering an unpaid collaboration (a free product in exchange for a feed post). It was also analysed how different Instagram influencer categories, in terms of follower count, responded to the selected small business' outreach (and consequently collaborated) and which Instagram influencer category is more likely to accept this kind of collaboration proposal. In addition, several practical recommendations are made regarding how small businesses should focus their efforts to make their Instagram influencer outreach marketing strategy more successful.

Keywords: social media influencer (SMI), Instagram influencer marketing, influencer outreach and collaboration responsiveness, influencer outreach strategy, small business

1. INTRODUCTION

Using influencers as a part of marketing strategy is not a novelty. However, the emergence of various social media platforms, such as Facebook, Twitter, Instagram, and Tik Tok, has increased the use of influencers in marketing, and also democratized their use immensely (McMullan, Laurell & Pitt, 2022). Advertising in online environments is exceptionally competitive, so social media influencer marketing was formulated as a more refined advertising method than traditional ones, offering less overt, more subtle and authentic advertising (Campbell & Rapp Farrell, 2020).

Social media influencers (SMIs) are notable social media users who specialized in particular niche areas and successfully gathered a highly devoted follower base by making an authentic online persona (Casalo et al., 2020; Lou et al., 2019; Sokolova and Kefi, 2020, as cited in Tafesse & Wood, 2021; Campbell & Rapp Farrell, 2020). Influencers differ in branding and focus, follower count, engagement rates, collaboration requirements, and skill sets they possess (Campbell & Rapp Farrell, 2020). By generating and sharing highly personal content focused on their interests and lifestyle, this new type of opinion leader builds closer and deeper psychological relationships with their followers, which are based on shared values, ideas, and preferences (Audrezet et al., 2018; Ki et al., 2020; Ladhari et al., 2020, as cited in Tafesse & Wood, 2021; Casal´o et al., 2020 as cited in Belanche, et al., 2021). Based on influencer follower counts, but also considering their perceived authenticity, accessibility, expertise, and cultural capital, we can distinguish five different influencer categories: 1) nano-influencers (up to 10K followers), 2) micro-influencers (10K – 100K followers), 3) macro-influencers (100K – 1M+ followers), 4) mega-influencers (1M+ followers), and 5) celebrity influencers (1M+ followers) (Campbell & Rapp Farrell, 2020). Influencers are generally positively perceived by consumers and are considered to share similar traits, to be personal, authentic, credible, attractive and down-to-earth information sources which makes their incentivized messages very effective (Jin et al., 2019; Ki et al., 2020; Schouten et al., 2020; Sokolova and Kefi, 2020;

Djarafova and Rushworth et al., 2017; Lou and Yuan, 2019, as cited in Tafesse & Wood, 2021; Kim & Kim, 2021). Their influence depends on their credibility and trustworthiness (Schouten et al., 2019, as cited in Belanche et al., 2021). At the fundamental level, influencers aim to provide value to their community through content creation and engagement, and consequently grow the followers they have influence over (Backaler, 2018). Followers are individuals who subscribe to the content of influencers on Instagram, which enables them to receive updates from accounts they subscribe to (Argyris et al., 2020).

Influencer marketing is the practice of compensating influencers (either monetarily or with free products, services, trips, or experiences) for posting about services or products on their social media (Campbell & Farrell, 2020). It is a persuasion process aimed at changing follower attitudes and behavior toward products or brands (Farivar, Wang & Yuan, 2021), where influencers leverage the pre-established relationship and trust they have nurtured with their followers (Kim & Kim, 2021). Influencer marketing has become an essential part of almost every digital marketing strategy because it represents an effective approach to connecting brands with potential customers on social media (Kim & Kim, 2021; Tafesse & Wood, 2021). At the moment, Instagram is the most influential platform and the primary choice of influencers for brand collaboration (White, 2022; Seifert, 2020; Ifluenz, 2017; Ki et al., 2020). The importance of this visual and engaging social network is expanding every day in terms of number of users and economic volume (#Hashoff, 2017; Socialbakers, 2018 as cited in Belanche et al., 2021).

Particular brand goals dictate the choice of a social media influencer for brand collaboration. Currently, thousands of different influencers are available, with various characteristics (e.g., different niche area specializations, number of followers, engagement rates); therefore, brands are facing a challenging task when trying to select the best-suited and most effective influencer. Some authors suggest that marketers should always prioritize an influencer's fit with a brand over their follower count, i.e. reach. A mismatch between a brand and an influencer can cause negative consequences for both the influencer and the brand in terms of the influencer's credibility (social media users might perceive the influencer as less credible) and the effectiveness of the brand's marketing efforts (Chahal, 2016; DeVeirman et al., 2017; Koernig and Boyd, 2009 as cited in Breves et al., 2019; McMullan, Laurell & Pitt, 2022).

Before initial contact, a brand needs to identify the right influencers and develop an effective influencer outreach strategy (Backaler, 2018). Influencers can be contacted through their social media accounts via direct messages (DMs), emails, using different outreach tools, through a larger business or a marketing agency (Shaffer, 2022; White, 2022). However, there is no right answer to which of these outreach methods is the best for each SMI, and it usually depends on the influencer's preferences (Backaler, 2018; Shaffer, 2022; Wiley, 2022). A drawback of DMs as an outreach method is that they can be overlooked because of the hundreds or even thousands of DMs influencers get via their social media channels (Seifert, 2020). Interacting and engaging with chosen influencers a few weeks prior to sending a collaboration proposal can show that a brand is genuinely interested in a potential long-term relationship with an influencer and the content they create. This practice can increase the chances that the influencer will become familiar with the brand and consequently respond to the brand's inquiry, leading to a successful outreach effort (Farmiloe, 2022; Ellis, 2017). If an outreach does not generate a response, sending a follow-up email or a direct message to an influencer is a common practice that shows a brand's genuine interest and dedication to collaboration (Shaffer, 2022; Backaler, 2018). For some B2C industries (business-to-customer), paid influencer collaboration is the norm; however, non-monetary incentives or a combination of the two can also be a way a brand or marketers build their initial relationship with influencers (Backaler, 2018).

As the influencer's positive response to a brand's outreach is one of the first and most important steps in influencer marketing and a subsequent successful influencer-brand collaboration, this study aimed to explore Instagram influencer responsiveness to small business outreach. The analysis shows how different Instagram influencer size categories responded to the outreach of the selected brand, as well as which Instagram influencer size category is more inclined to accept an unpaid collaboration proposal (a free product in exchange for an Instagram wall post). As a result, we were able to make several practical recommendations that aim to improve an Instagram influencer outreach marketing strategy in the case of a small business of a similar size.

2. METHODS

To determine the responsiveness of Instagram influencers to a brand's outreach, we chose a small business and the unknown brand Petification (IG:@petification) which operates in the pet industry niche, i.e. they make custom pet-themed digital and printed art. A single feed post campaign was carried out where the goals were to raise awareness of new products and the brand itself, as well as to increase considerations and conversions. However, the effects of the fulfilled collaborations were not within this study's scope. A single feed post campaign is the most cost-efficient way to test out influencers for a brand's marketing campaign (Levin, 2020). Since Petification is a small business with limited advertising resources, the idea was to make an offer to influencers for an unpaid collaboration and propose a free product (a digital pet portrait of their pet) in exchange for an Instagram feed post. One of the first and essential steps for succeeding in an influencer marketing campaign is to write a compelling brief when reaching out to influencers (Levin, 2020). To formulate an outreach message and make influencers clearly understand the terms of the brand's collaboration proposal, a list of questions and guidelines from Levin (2020) was used.

After the brief was completed, the influencer identification and selection process began. A total sample of 116 influencers was manually selected using the brand's existing influencer database and the "Similar Account Suggestions" Instagram feature that gave suggestions to follow other similar accounts based on the followed Instagram profile. The selection process was based on both influencer follower count and their post engagement rates. Selected influencers for outreach had a follower count between 14K and 1.9M, and engagement rates from 0.55% to 69.54%. Usually, smaller accounts get more engagement (Oberlo, 2022). We also followed a common practice to interact and engage (follow and like) with chosen influencers before reaching out to them in order to increase the chances that they would positively respond to the brand's inquiry (Farmiloe, 2022; Ellis, 2017).

The data of Instagram influencer profiles was obtained using Phlanx (phlanx.com) and HypeAuditor (hypeauditor.com) online platforms for social media analytics. This data included follower count, post number, average number of likes, average number of comments, and engagement rate. Follower count is the number of Instagram users subscribed to an influencer's Instagram account. Follower engagement is a key metric to determine the quality of an influencer's content based on the number of interactions the content generates. Finally, the engagement rate defines the quality of influencer deliverables based on total follower responses (likes and comments) divided by total gross reach or follower count (Levin, 2020).

Smaller influencers are generally focused on growing the number of their followers and collaborations, so compared to the big ones, they are less selective when choosing a brand for collaboration (Trend, 2022). Even though a small audience of engaged followers is worth more than a large audience of less active followers, big influencers with a high number of followers are perceived as more popular and likable, with higher chances of converting prospects to customers. Therefore, big influencers can leverage these follower and brand perceptions to negotiate better collaboration deals and to decide which brand they will collaborate with (Anger and Kittl, 2013; Cheong, 2017; as cited in Agam, 2017). Our assumptions that smaller influencers with lower follower counts will be more eager to collaborate and, therefore, more responsive to Petification's outreach match the information provided in the literature. In this respect, we formulated a hypothesis H1 that states:

H1: A significantly higher number of influencers with a lower follower count will positively respond to a small business' outreach and consequently collaborate with it, compared to the influencers with a higher follower count.

3. RESULTS AND DISCUSSION

For assessing influencer response rate to a small business outreach, as explained in the Methods section of the paper, we chose the Petification brand. 116 Instagram influencers of different follower counts and engagement rates were selected and eventually offered a collaboration proposal. The influencers were contacted in the span of approximately eight months, between July 2021 and March 2022.

Influencer response rate to the selected brand's outreach and collaboration proposal was 20.69% (24 influencers), whereas 14.66% (17 influencers) accepted and fulfilled the agreed upon collaboration terms (a free product/pet portrait in exchange for an Instagram feed post). A certain number of contacted influencers, 6.03% (7 profiles), responded to the brand's direct message but either refused the offer, wanted to change the offer significantly, or had accepted it but eventually failed to respond to the brand's follow-up inquiries that were necessary for proceeding with the collaboration process.

Table 1 presents the basic metrics of the Petification brand's Instagram account at this point (September 2022), such as follower count, number of posts, average likes, average comments, and engagement rate. Additionally, Table 1 shows calculated mean values of the same metrics for both contacted influencers and those who afterward collaborated with this brand. Table 2 contains typical engagement rates of Instagram influencers that belong to different follower count categories from Oberlo (2022). As it can be noticed from the results presented in Table 1 and Table 2, the engagement rates of the Petification brand and the selected influencers are both severalfold higher than reported general Instagram influencer engagement rates. This indicates that one of the main parameters when selecting appropriate influencers was focused on their high engagement rates instead of relying solely on follower count. However, the relatively high mean values of the follower count parameter for both contacted influencers and those that collaborated with the brand show that reach, which depends on follower count, was also considered for influencer selection.

Table 1: Basic Instagram account metrics of 1. Petification brand, 2. contacted influencers, and 3. influencers that collaborated with this brand

Instagram account metrics	Follower count	Posts number	The average number of likes	The average number of comments	Engagement rate [%]
1. Petification Instagram account	10,600	279	907	37	8.91
2. Mean contacted	199,655	1,044	10,812	201.6	8.30
3. Mean collaborated	99,100	908	6,727	112.4	11.90

Table 2: Mean engagement rates of different Instagram influencer sizes categories (Oberlo, 2022)

Number of Followers	1K – 5K	5K – 20K	20K – 100K	100K – 1M	>1M
Mean engagement rate [%]	4.84	1.70	1.22	1.06	1.23

Table 3 presents three data sets: 1) the distribution of contacted influencers (relative to their follower count category), 2) the distribution of the influencers who positively responded and collaborated with the brand (relative to their follower count category), and 3) outreach success rates (relative to the contacted influencers for a particular follower count category). Instagram influencer follower count categories were adopted from Campbell & Farrell (2020). The results show that nano-influencers were not considered for the influencer marketing strategy of this brand because there were none selected and therefore contacted. In addition, only three mega-influencers were contacted (2.59% of the total contacted influencers), which did not produce any positive response.

Table 3: Distributions of 1. contacted influencers and 2. those who collaborated regarding their follower count category, and 3. outreach success rate within follower count category

Influencer category (follower count)	Nano	Micro		Macro			Mega
	<10K	10K-50K	50K-100K	100K-250K	250K-500K	500K-1M	>1M
1. Influencers contacted [%]	0	24.14	23.28	31.90	10.34	7.76	2.59
2. Influencers collaborated [%]	0	9.48	0	4.31	0.86	0	0
3. Outreach success rate [%]	0	39.29	0	13.51	8.33	0	0

The distribution of contacted influencers within two subcategories of the micro-influencer category (10K-50K and 50K-100K follower count), and the subcategory of the macro-influencer category (100K - 250K follower count) were relatively uniform (24.14%, 23.28%, and 31.90% respectively). Still, they produced completely different outreach outcomes (of 9.48%, 0%, and 4.31% respectively). It can be noticed that the most effective outreach, with an almost 40% success rate, was achieved in the micro-influencer subcategory that has between 10K and 50K followers (9.48% of the total number of contacted influencers). There is a clear declining trend in outreach success rate and, therefore, the number of collaborations, with the rise of influencer follower count. Additionally, a disruption of this trend occurred and was recorded for the micro-influencer subcategory with 50K-100K followers, which produced a 0% outreach success rate. The number of positive influencer responses to the Petification brand collaboration proposal significantly drops with the increase of influencer size, which supports the H1 hypothesis. However, this data also confirms that a small business' outreach for collaboration with macro-influencers offering unpaid collaboration in the form of free product compensation can have limited and modest success. The reason for this outreach outcome can be explained by the main focus of micro-influencers, which is growing their follower base, so they are incentivized to work with more brands, whereas macro-influencers are usually more selective in this regard. Therefore, compared to collaboration with macro-influencers, a collaboration with micro-influencers is generally easier, more cost-effective, and should enable more intimate and authentic engagement (Trend, 2022). Considering the results of this study, the outreach strategy of a small business and a new and unknown brand does not necessarily need to be exclusively directed towards smaller influencers with a relatively limited reach. This also shows that influencers choose brand collaborations not only based on the physical value that the brand offers for compensation, but also on many other factors and how they perceive the brand itself.

4. CONCLUSIONS

As the selected firm for this study was a small business and still unknown brand with limited advertising resources, nano-influencers and mega-influencers were out of the focus of its influencer marketing strategy. The reason was that, most likely, it would not have been able to meet the common mega-influencer collaboration demands. On the other hand, too many nano-influencers would have had to be collaborated with (and therefore given many more free products) for the intended reach. Therefore, the optimal influencer size and the main focus of this brand's influencer marketing strategy were micro and macro-influencers.

The positive response rate of influencers to Petification's collaboration proposal was 14.66% (17 out of 116 influencers). However, similar outreach efforts toward different influencer size categories produced different outreach response outcomes. The most effective outreach response was achieved in the micro-influencer category, which have between 10K and 50K followers (almost a 40% success rate). With the increase of influencer follower count, the positive response rate of contacted influencers significantly dropped, which supports the set hypothesis H1. Therefore, the main focus of a brand of this size in terms of influencer marketing should be pointed toward micro-influencers with between 10K and 50K followers. However, the results showed that a brand's outreach to macro-influencers offering an unpaid collaboration could have some success regarding the number of agreed collaborations. This shows that influencers choose brand collaborations not only based on the physical value that the brand offers, but instead on other factors and the influencer's perception of a particular brand. Due to the much bigger follower count of macro-influencers compared to micro-influencers, they have a more significant reach which, from the perspective of a brand, can compensate for the small number of positive outreach responses it receives. Thus, the influencer outreach strategy of a small business should not be exclusively pointed toward micro-influencers with relatively limited reach, but also toward the macro-influencer category (100K-500K followers).

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INFOGRAPHICS IN DIGITAL ADS: A/B TESTING FOR CONTENT OPTIMIZATION

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Abstract: *Internet users are bombarded every day with various ads, and they try to block them in all possible ways. If they do not block them, they usually pay little attention to them. Therefore, ads need to be creative and provide as much relevant information as possible about the advertised product or service at a glance in order to lead to conversions. For this purpose, the benefits of infographics can be used very well, in addition to dynamic forms of ads that consist of audio and video elements, especially in a responsive web environment. This type of advertising is also great for posting on social media, where the flow of information and responses is very fast. Infographics actually represent a visual presentation of information through a combination of typography, symbols, pictograms, shapes, and colours and are used to present complex information quickly and clearly. The use of infographics as one of the multimedia elements in digital advertising contributes to the optimization of advertising content, which also contributes to SEO optimization. To investigate the extent to which infographics in digital advertising can contribute to the optimization of advertising content in a responsive web environment, A/B testing of multimedia advertising content presented through infographics and content that contained all relevant information about the advertiser and was not presented in the form of an infographic was conducted on two types of screens. The A/B testing model itself provides the opportunity to maximize conversion rates, but it also provides a significant increase in knowledge about how advertising content is presented. It can also establish a set of optimized practices for multimedia elements of ad content. The proposed testing model provides the perfect opportunity to properly test your ad before launch. The same analogy can be applied to other multimedia elements used to create ads, such as photos, animations, colours, content management system elements, etc.*
The obtained results provide valuable information about infographics possibilities in advertising content optimization in a responsive web environment because they load faster, are suitable for small screens, and do not tire users.

Key words: infographics, digital ads, ads content optimization, responsive web, A/B testing

1. INTRODUCTION

The use of the Internet and social media has changed consumer behavior and the way companies do business. By the early 2020s, more than 4.5 billion people use the Internet, while the number of social media users has surpassed 3.8 billion, and the average Internet user now spends 6 hours and 43 minutes per day online (Dixon, 2022). But 49% of internet users install ad blockers (Dixon, 2022), causing companies to suffer losses and be forced to find more acceptable ways of digital advertising. This opened space for the use of social media, which allows two-way communication. Social and digital marketing offers significant opportunities for businesses through lower costs, improved brand awareness, and increased revenue. However, there are also significant challenges from negative electronic word of mouth and an intrusive and irritating online brand presence.
There is, however, a problem with user attention and retention. Today, the average Internet user is exposed to myriad messages and information throughout the day, and the ability to concentrate is declining. Therefore, effective digital media should be borderless, ubiquitous, creative, personalized, viral, immersive, and data driven.
Considering that 40% of people respond better to visual content than text, it is infographics that enable digital media to convey a message to users in a short period of time. Statistics show that those who publish infographics in their media have 12% more visitors than those who do not. Studies show that 90% of the information that is absorbed on a daily basis is conveyed visually. Infographics are visual content that is easy to adopt. They speak to people with simple images that are easy to read and understand.
Information graphics or infographics are a visual representation of information, data, or knowledge. Such graphics are used when complex information needs to be explained quickly and clearly, such as in signage, maps, journalism, technical writing, and education. They are also used as a tool to facilitate the

process of developing conceptual information. Infographics are visual content that the recipient of the message easily adopts, and on social media, they are shared faster and more frequently than a text post, meaning they go viral more quickly. Infographics also contribute to search engine optimization, but also to brand awareness if the topic of the infographic is related to the company's activity or the company logo is integrated into the infographic.

2. RESEARCH BACKGROUND

Considering the fact that humans are increasingly acquiring information visually, images have recently been used more frequently in visual communication to express views, opinions, feelings, emotions, and moods (Gajarla & Gupta, 2015; Katsurai & Satoh, 2016; Kumar & Garg, 2019). Images are particularly powerful because they are associated with cognition and visual experiences better convey feelings and emotions.

Controlled online experiments are often used to improve website performance by comparing user behavior across different variations of a given website. Although such experiments can have an important impact on the key metrics to be maximized, it is difficult for small websites to use this method because they have few users. Moreover, the variants under consideration increase exponentially with the number of elements that need to be optimized. To solve these problems, an A/B testing method that finds powerful variants with multiple samples is suitable (Iitsuka & Matsuo, 2015).

A/B testing, also known as bucket testing, split testing, or controlled experiments, is a standard method for evaluating user engagement or satisfaction with a new service, feature, or product. It is widely used with online websites, including social networks (Gui et al., 2015; Xu et al., 2015). A/B testing allows a company to evaluate the performance or impact of new features on its website by introducing them to a small subset of visitors (Conti et al., 2018).

In its simplest form, an online A/B test can be treated as a static hypothesis test, where traditional statistical tools such as p-values and power analyze can be applied to help decision makers determine which variant performs better (Ju et al., 2019).

Due to the dynamic environment of today and the increasing number of websites, their assessment and evaluation has also emerged. On the other hand, website users do not like static pages and look for those that can convey more information in less time (Ranjbarfard & Kheiri, 2019). Infographics keep popping up on a variety of websites, so design teams have picked up on the trend of infographics (Albers, 2014) and therefore, in recent years, the use of infographics in digital media has become more popular. Infographics are valued, but only if they are coherently integrated into a story and thus serve an easy-to-understand function, because news consumers actually read infographics regardless of the platform on which the visual is published (de Haan et al., 2018). To this end, the author group (Firmenich et al., 2019) proposed an iterative method supported by a toolkit that allows usability experts to design user tests, run them remotely, analyze the results, and evaluate alternative solutions to usability problems similar to A/B testing. Each solution is created by applying client-side web refactoring, i.e., making changes to the web pages in the client to improve usability. Ranjbarfard & Kheiri (2019) emphasized that infographic is one of the components of website evaluation that has a positive and significant impact on website quality, user satisfaction with the website, and their desire to return to the website.

Fedorchenko & Ponomarenko (2019) tested a number of approaches to website A/B split testing in the context of implementing the company's online digital marketing strategy. They examined the main approaches to implementing A/B split testing as an effective tool for improving conversion of a corporate website using a system structural and comparative analysis. Sinha, Healey & Sengupta (2020) presented an interactive user interface that allows digital marketing professionals to access real-time insights from back-end AI that predicts potential click-through rates for collocated content based on similar past campaigns. Their framework decomposes aspects of previous campaigns into features such as image quality and text readability, which is important for graphic designers and web developers. They have shown that an algorithm with a high predictive value on a historical test set (AUC .80) and using the AI agent's advice can generate content that increases click-through rates by up to 22% on 700 A/B preference tasks given to masters (AMT).

Deng et al. (2017) have sought to accelerate innovation by evaluating ideas quickly and accurately with controlled experiments, also called A/B testing. They introduce A/B testing, share key lessons learned from scaling experiments at Bing to thousands of experiments per year, present real-world examples, and outline promising directions for future work. The tutorial introduces applications of A/B testing in

information retrieval and also discusses the practical and scientific challenges of running experiments on websites and in mobile and desktop apps.
Kumar (2019) emphasized that A/B testing has become the de facto standard for design optimization, helping designers create more effective user experiences by leveraging data. Beyond A/B testing, however, there are other powerful data-driven methods that can link design decisions to desired outcomes. Evaluating data from existing designs can open up a wider space of different solutions to designers than A/B testing. Models such as generative adversarial networks and variational autoencoders can create designs based on high-level constraints or complete them based on partial specifications. This opened a space to develop a model for creating intelligent advertising content, consisting of infographics, in real time. To achieve this, it is necessary to integrate intelligent technologies that work on the principle of ontology and semantic-based information.
Recently, images, infographics, memes, and GIFs have dominated social media feeds. As a result, text posts are pushed into the background. Therefore, an attempt was made to investigate whether there is a difference in social media users' responses when the same message is sent in three different forms. Therefore, multimodal data was used to collect user responses: Text Releases, Image Releases, and Ecology Infographics, which should be analyzed because they have the potential to change, confirm, or evaluate the polarity of sentiment. The model can analyze for each tweet or reaction of a user whether it is positive, negative, or neutral.

3. RESEARCH METHODOLOGY

3.1 Problem formulation

This research is a part of the extensive research within the project "Optimization and personalization of multimedia content using artificial intelligence".
The main goal of this article was to integrate the idea of A/B testing into the context of testing multimedia elements of websites with digital advertising content to provide a method for improving usability in web and ads development. Web developers and ads designers need various tools to enable optimization and personalization of web and ads content to increase conversion rates. Therefore, the well-known statistical approaches in synergy with artificial intelligence served as a platform for the development of this model.
Considering the above requirements, the methodology of this research is described by formulating problems and testing principles and hypotheses.
This requires creating a model capable of copying the logic of each user step to create real-time intelligent advertising content that reaches users through multimedia channels. To achieve this, the first step is to integrate personalization technologies that work on the principle of ontology and semantic-based information. The sequence diagram will connect the user, the multimedia advertising content and the database through modelling, filtering, and content customization (Figure 1).

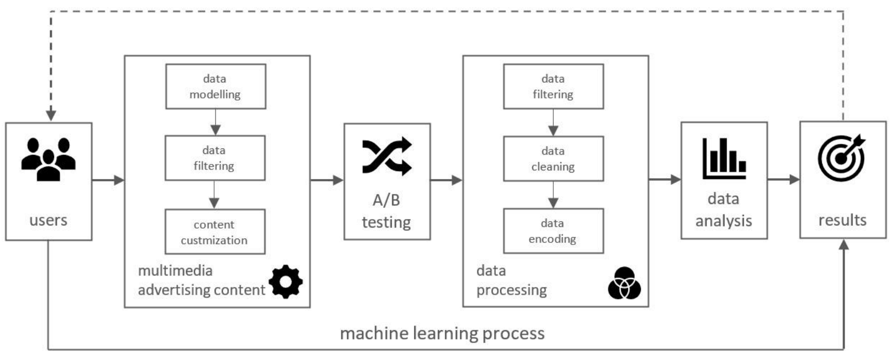

Figure 1: Sequence diagram (Source: own)

Conducting A/B test on ads, regularly can bring in more targeted leads by doing what works and changing what does not.
A/B testing or split testing is a method of comparing two versions of a web page or some parts or elements to see which performs better. This is an experiment in which two or more variants are randomly

shown to different segments of users at the same time and statistical analysis is used to determine which variant better meets the conversion goal. A web page is changed to a second version of the same web page. Half of the visitors are shown the original version of the web page (the so-called control) and the other half are shown the changed version of the web page (the variant).
For this purpose, the infographic was singled out as a key visual structural element. The test was conducted in three iterations, in combinations of text and image, text and infographic, image and infographic (Figure 2).

Figure 2: Tested information carriers

3.2. Testing principle and hypothesis

Statistically, the AB test is an example of a test of a statistical hypothesis, a procedure in which a hypothesis is made about the relationship between two data sets and these data sets are compared to determine whether or not a statistically significant relationship exists. For this purpose, the z-test, t-test, chi-square test, or Fisher's exact test can be used. In this work, the z-test with two proportions was used. A z-test is a statistical test used to determine if the means of two populations differ when the variances are known, and the sample size is large. It is assumed that the test statistic is normally distributed, and interfering parameters such as standard deviation should be known in order to perform an accurate z-test. The observed *z-score* is a number that indicates how many standard deviations above or below the population mean a value derived from a z-test is.

$$z = \frac{(\widehat{p_1} - \widehat{p_2}) - (p_1 - p_2)}{\sqrt{\frac{p_1(1-p_1)}{n_1} - \frac{p_2(1-p_2)}{n_2}}} \tag{1}$$

The hypothesis:

H0: There is no significant difference between two conversion rates from two group of samples ($p_1 = p_2$).
H1: There is significant difference between two conversion rates from two group of samples ($p_1 \neq p_2$).

H0 is rejected if *z-statistic* from this formula is higher than standard *z-score* with degree of freedom ($n_1 + n_2 - 2$) or *p-value* is smaller than significance level ($\alpha = 0.05$).
To test the hypothesis, two experimental plants described above were created and operated for 21 days.

4. RESULTS AND DISCUSSION

In this section, the main results of the study are presented. The results are presented in tables. The first experimental unit consists of text and image as carriers of information. The first website with digital ads is a control website named A that contains text, and the second website is a variant named B that contains an image as an information carrier.
The conversion rates and the standard error rate are calculated and presented in Table 1. Conversion rate is the percentage of users on a website who take act beyond simply viewing content or visiting the website as a result of subtle or direct prompts from marketers, advertisers, and content creators. A good conversion rate is above 10%, with some companies achieving an average of 11.45%. Both of tested web pages have below average conversion rates.

Table 1: Visits and Conversion rates from each variant, variants' conversation rates and standard error text/image

A/B test	Users	Conversions	Conversion rate	Standard error
A Text	4110	264	6.42%	0.0317%
B Image	4216	377	8.97%	0.0054%

Based on the inputs, the estimated confidence interval that the value is statistically significant is determined based on *z-score* confidence intervals for 90% and 95% conversion rate limits. These are then used to test the *p-value* against the confidence intervals (Table 2).

Table 2: Significance levels based on inputs, text/image

A/B test	90% Conversion Rate Limits		95% Conversion Rate Limits	
	From	To	From	To
A Text	3.98%	6.29%	3.22%	5.19%
B Image	7.78%	8.53%	7.05%	8.82%

In the third step, the *z-score* and *p-value* are calculated. The results show that the hypothesis H0 is rejected because the *p-value* is less than 0.05. This means that the test is statistically significant and web page B with the variable font file performs better than web page A. In other words, version B converts 39.75% better than version A (Table 3).

Table 3: Z-score, p-value and significance, text/image

A/B test	z-score	p-value	Significant	Improvement
A Text	3.912	0.0043	yes	-
B Image	5.638	0.0007	yes	39.75%

On the same principle the second experimental unit are created, but the first website i.e., control website named A contains text, and the second website i.e., variant website named B and contains an infographic as an information carrier.
The conversion rates and standard level of error are calculated and for the second experiment unit and presented in Table 4. Tested web page A have below average conversion rate (5.73%), and tested web page B achieved an average rate of 10.67%.

Table 4: Visits and Conversion rates from each variant, variants' conversation rates and standard error text/infographic

A/B test	Users	Conversions	Conversion rate	Standard error
A Text	3261	187	5.73%	0.0007%
B Infographic	3887	415	10.67%	0.0012%

Table 5 shows the estimated confidence interval that the value is statistically significant based on *z-score* confidence intervals for 90% and 95% conversion rate limits, which in turn are used to test the *p-value* against the confidence intervals.

Table 5: Significance levels based on inputs, text/infographic

A/B test	90% Conversion Rate Limits		95% Conversion Rate Limits	
	From	To	From	To
A Text	2.16%	4.09%	3.73%	4.58%
B Infographic	8.38%	9.12%	7.82%	8.59%

Finally, Table 6 shows the *z-score* and *p-value* for the second experimental unit. Hypothesis H0 is again rejected because the *p-value* is less than 0.05. This means that the test is statistically significant and web page B with has better conversion results than web page A. In this case, version B converts 42.70% better than version A.

Table 6: Z-score, p-value, significance and improvement, text/infographic

A/B test	Z-score	p-value	Significant	Improvement
A Text	3.912	0.0078	yes	-
B Infographic	5.223	0.0001	yes	42.70%

On the same principle and the third experimental unit are created, but the first website i.e., control website named A contains image, and the second website i.e., variant website named B and contains an infographic as an information carrier.
The conversion rates and standard level of error are calculated and for the second experiment unit and presented in Table 7. The tested website A and the third time have a below average conversion rate (8.78%), and the tested website B achieved a borderline average rate of 9.95%.

Table 7: Visits and Conversion rates from each variant, variants' conversation rates and standard error image/infographic

A/B test	Users	Conversions	Conversion rate	Standard error
A Image	4008	352	8.78%	0.0061%
B Infographic	4492	447	9.95%	0.0293%

Table 8 shows the estimated confidence interval that the value is statistically significant based on *z-score* confidence intervals for 90% and 95% conversion rate limits, which in turn are used to test the *p-value* against the confidence intervals.

Table 8: Significance levels based on inputs, image/infographic

A/B test	90% Conversion Rate Limits		95% Conversion Rate Limits	
	From	To	From	To
A Image	4.98%	6.12%	5.19%	7.03%
B Infographic	7.43%	8.17%	6.92%	8.76%

And finally, Table 9 shows the *z-score* and *p-value* for the second experimental unit. The hypothesis H0 is again rejected because the *p-value* is less than 0.05. This means that the test is statistically significant and web page B has better conversion results than web page A. In this case, version B converts 27.01% better than version A.

Table 9: Z-score, p-value, significance and improvement, image/infographic

A/B test	Z-score	p-value	Significant	Improvement
A Image	6.217	0.0056	yes	-
B Infographic	2.911	0.0009	yes	27.01%

5. CONCLUSIONS

Interaction between users and websites requires intelligent systems for clusters of similar data that can be used to optimize and customize content for each user. Therefore, it is necessary to know the capabilities of font files to increase the loading time of web pages. The results presented in this paper show that images achieve a better conversion rate than text in digital ads and that infographics achieve better conversions than text and images. This is the expected result, as an infographic combines text and images in an easy-to-read format.

Although the websites from all three experimental units had below-average results for text, this test was not related to the design and appeal of the digital ads, but to the use of a specific information carrier. The model of A/B testing not only provides the opportunity to maximize conversion rates, but also to significantly increase knowledge about how web pages are presented. It can also determine a set of optimized practices for multimedia elements of advertising content.

The proposed testing model provides the perfect opportunity to thoroughly test the web design before launching the website. The same analogy can be used for other elements of the website such as photos, animations, colors, content management system elements, etc. Another test such as the t-test, chi-square test, or Fisher's exact test can be used to verify the results. If a large number of elements are changed on the web, a cluster analysis can also be performed.

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THE INFLUENCE OF DEPTH OF FIELD ON THE APPEARANCE OF CHROMATIC ABERRATION

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Abstract: *Chromatic aberration is an optical defect that causes light rays of different wavelengths to focus at different points along the optical axis of the lens. It is manifested as band of one color at frame transitions around contrasting edges in the photo. There are two types of chromatic aberration: longitudinal and lateral. Lateral chromatic aberration is the color fringing that occurs because the magnification of the image differs with wavelength. It tends to be far more visible than longitudinal. The aim of this research is to examine the influence of depth of field on the appearance of lateral chromatic aberration. For the purposes of the experiment, we used one mirrorless camera (Sony a1), while the lenses were variable. We used Sigma 85mm f/1.4 DG DN and Sigma 40mm f/1.4 to check which type of lens shows the most chromatic aberration and how much the change in f-number affects its appearance.*

Keywords: *chromatic aberration, digital camera, depth of field, f-number*

1. INTRODUCTION

Chromatic aberration was chosen as the subject of investigation. Chromatic aberration is an error that occurs due to inadequate use of the camera, inadequate conditions for photography or a constructive imperfection of the lens. The aim of this paper is to determine the effect of changing the depth of field on the occurrence of chromatic aberration error. The processing of the problem, the causes and consequences of the chromatic aberration error is done in the theoretical part. While in the experimental part the examination of chromatic aberration was carried out. In the continuation of the paper, the performance and results of the lens test in the experiment are presented.

2. THEORETICAL PART

2.1 Chromatic aberration

Chromatic aberration is an optical defect that causes light rays of different wavelengths to focus at different points along the optical axis of the lens (Figure 1). The consequence of this is that all wavelengths (which we see as colors) of the visible part of the spectrum are not refracted in the same focal plane, but in front or behind it. Also, since the magnification of the lens depends on the wavelength of the light, then the components of the visible spectrum are focused on different parts of the focal plane. If the point of refraction moves along the horizontal axis (in front of or behind the focal plane), it is called longitudinal (axial, longitudinal) chromatic aberration, and if it happens on different parts of the focal plane, then these are transverse (lateral, side) aberrations.

Chromatic aberrations are manifested as bands of one color (most often light blue - cyan or red) at the (for example a dark stone, and behind it a bright sky). These imperfections are solved more or less successfully in the lens itself, by installing several different convex and concave lenses. In addition, they can be removed by software (Mehić, 2011).

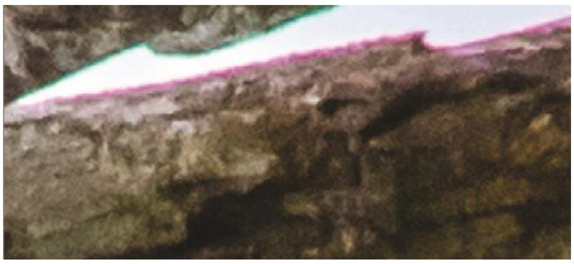

Figure 1: Chromatic aberration

2.2 Types of chromatic aberration

There are two types of chromatic aberration:

1) Longitudinal (axial, longitudinal) chromatic aberration - Longitudinal chromatic aberration results in blurred colors in front of and behind the focal point due to color differences in the focal point. This phenomenon is very noticeable on the periphery of very bright parts of the image, but it can occur anywhere in the image, not just at the edges.
2) Transverse (lateral, side) chromatic aberration - Transverse chromatic aberration primarily leads to color fringing on the edges of the object and on the periphery of the frame, and it is caused by the fact that the lens has a different magnification for different colors. These different levels of magnification lead to a colored glow around the edges of some objects. It is important to keep in mind that transverse chromatic aberration appears only at the edges of the frame (Mehić, 2011).

2.3 Factors influencing the appearance of chromatic aberration

The cause of chromatic aberration usually lies in the fact that the refractive index of light in a certain medium depends on the wavelength. Rays of shorter wavelengths (for example blue) are refracted more (ie at a larger exit angle) than those of longer wavelengths. Rays of shorter wavelengths are focused closer to the lens than rays of longer wavelengths (for example red). These imperfections are solved more or less successfully in the lens itself, by installing several different convex and concave lenses (Husić, 2012).

3. EXPERIMENTAL PART

The experimental measurements were aimed at determining the influence of different lens characteristics and focal length on the appearance of chromatic aberration errors.
The testing was performed in accordance with the requirements of the ISO 12233 standard from 2012, a test card for determining the presence of chromatic aberration in digital cameras.
The experiment was conducted in six steps:

1) Choice of device body and lens
2) Selection of test card
3) Setting the scene, choosing lighting and additional devices,
4) Taking test photos
5) Analysis and evaluation of photographs for chromatic aberration errors
6) Assessment of results

3.1 Test card

The ISO 12233 test card is suitable for testing the transverse chromatic aberration of the lens (Figure 2). Aberrations of this type are best measured at the tangential edges near the sides or corners of the image. The ISO 12233 map contains several border areas that are placed at an angle of 5 degrees from the vertical.

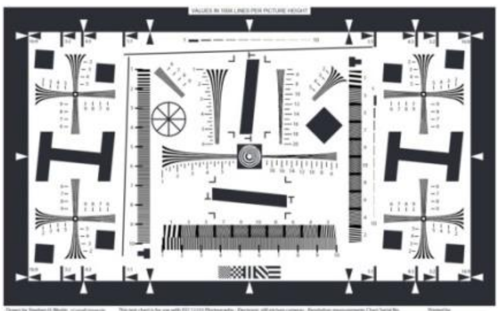

Figure 2: Test card ISO 12233

3.2 Software

Imatest is the most widely used software in the industry. It is currently the most popular digital photo quality testing software package in the world. Using the Imatest software, it is possible to analyze various factors of photo quality. This includes image sharpness, color gamut, noise, dynamic range, tonal reproduction, flare, lens distortion, lens vignetting, sensor non-uniformity, moire, and more.
SFR is a module that measures sharpness, chromatic aberrations and noise level (Figure 3.8). This module was used in the analysis of the photographed test card ISO 12233 (Vukojević, 2013).
Table 1 shows the categorization of the aberration surface by intensity expressed in pixels.

Table 1: Categorization of the surface of chromatic aberration by intensity expressed in pixels

Chromatic aberration surface	Intensity
under 0.5	insignificant
0.5-1	low (hard to see)
1-1.5	moderate (somewise visible in the case of large format printing)
above 1.5	strong (very visible in the case of large format printing)

3.3 Camera body

The Sony Alpha1, better known as the Sony A1, is a flagship model in every sense (Figure 3). This full-frame mirrorless device offers high resolution for photography and 8K for video, exceptional speed and the ability to produce the most demanding professional tasks.
At its core, the Sony a1 features a newly designed 50.1MP Exmor RS BSI full-frame CMOS sensor and BIONZ XR processor. Pairing an efficient sensor with optimized processing makes the a1 capable of full-resolution 30fps continuous shooting, 8K 30p and 4K 120p 10-bit video recording, and high sensitivity up to ISO 102400 for low-light shooting. The sensor design also includes a 759-point fast hybrid AF system, which offers advanced subject tracking and real-time eye AF (Foto Diskont, n.d.).

Figure 3: Camera body Sony Alpha 1

3.4 Lenses

The lens is a set of several plastic or glass elements, with glass usually giving a better quality and sharper result. Each element has a specific function in focusing light onto the sensor, whether it's shaping the light to match the size of the sensor, correcting it, or providing a final focus point (Schiesser, 2014).
In the experiment were used two lenses:

1) The Sigma 85mm f/1.4 DG DN Art for Sony is a premium portrait lens from the ART series (Figure 4). It is an upgraded version of the lens that has an aperture ring which can be switched to continuous mode (without clicks) which is particularly convenient for video recording. It has ultra-fast and quiet autofocus and 11 circular blades apertures that enable a beautiful bokeh effect. It is extremely well made with application of aluminum and thermally stable composite. (Foto Diskont, n.d.).
   Figure 4 shows the parts of the Sigma 85mm f/1.4 DG DN Art.

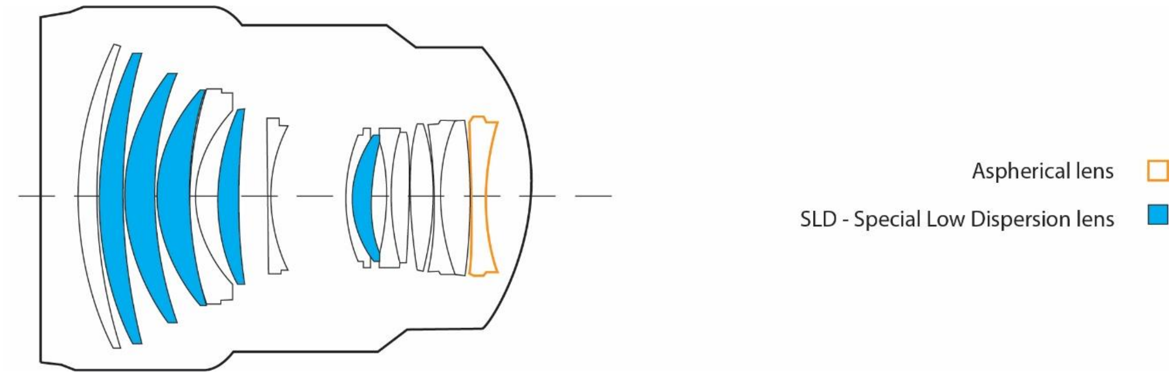

Figure 4: Parts of the Sigma 85mm f/1.4 DG DN Art

2) The Sigma 40 mm f/1.4 is a premium professional lens for Sony mirrorless cameras (Figure 5). On cameras with an APS-C sensor, its focal length is 64 mm. The lens has FLD and SLD optical elements that enable it to have superior optical characteristics. The maximum aperture of f/1.4 makes it ideal for shooting in poor light conditions. It also has an ultra-fast and quiet autofocus motor. It is resistant to weather influences (Foto Diskont, n.d.). The minimum focal length is 40 cm, the diameter of the filter is 82 mm, and the diaphragm is realized in the form of 9 rounded leaves (PCFoto, n.d.). Figure 5 shows the parts of the Sigma 40mm f/1.4

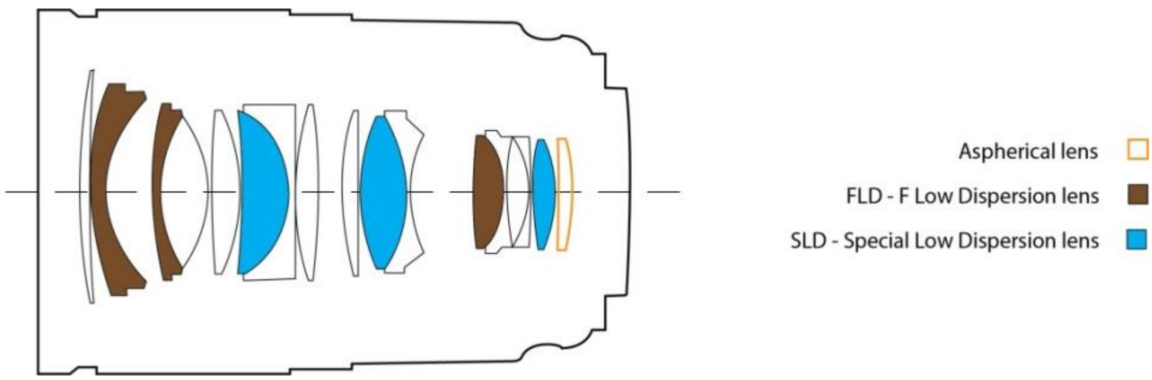

Figure 5: Parts of the Sigma 40mm f/1.4

3.5 Scene setting

The first step in setting the scene is finding a suitable space and providing a darkened room. LED lamps were used in the experimentwhich simulate daylight, with a strength of about 5000 K. They are placed so that the cornerlighting should be as recommended by Imatest, between 30 and 45 degrees, in order toavoided the problem of creating reflections or shadows on the test map.
The test card is placed on a neutral background, a wall, at an angle of 90 degrees.After that, the stand is placed, opposite the test card, on which it is placedthe camera that is used so that there is no blurring of the image due to hand tremors (Figure 6).

Figure 6: Scene setting

After the correct setting of all elements, a test card was photographed and then all other necessary photos, with one body and two different lenses.
Two different lenses were used at different distances from the test tickets. Sigma 85mm f/2.8 DG DN Art lens is placed at a distance of 180 cm from the test map, where is the aperture, and therefore the ISO, a variable factor while the focal length (85mm) and shutter speed (160) fixed value. When taking photos with the lens Sigma 40mm f/2.8 camera body is placed at a distance of 120 cm from the test card, where the apertur, and therefore ISO, were a variable factors while the focal length (40 mm) and shutter speed (1/80) were fixed values.

4. MEASUREMENT RESULTS

4.1 Test results on the Sigma 85mm lens f/1.4 DG DN

The test was performed on the Sigma 85mm f/2.8 DG DN lens at a distance of 180 cm from the test map, where the aperture, and therefore the ISO, is a variable factor while the focal length (85mm) and shutter speed (160) are fixed values.
On Figure 7. a graph is shown with the results for the tested lens at different apertures. The graph shows the X axis, on which the values are aperture, and two Y axes where the chromatic aberration is expressed for the ROI surface on the right and left side of the same image.
Based on the obtained results, according to the values from table 1. we conclude that the lens generally makes either insignificant or weak ones at any given aperture chromatic aberrations that are hard to notice or not noticeable.
The value of the left side is generally higher than the right side, except at the smallest aperture where the value of the left side is significantly higher compared to the previous point, while the opposite is true for the right side.
Correlation between left and right chromatic aberration values in this case is 0.79. Based on this information, as well as on the basis of graphics, we can observe that they behave relatively similarly, with the change being between steps more subtle on the left side.

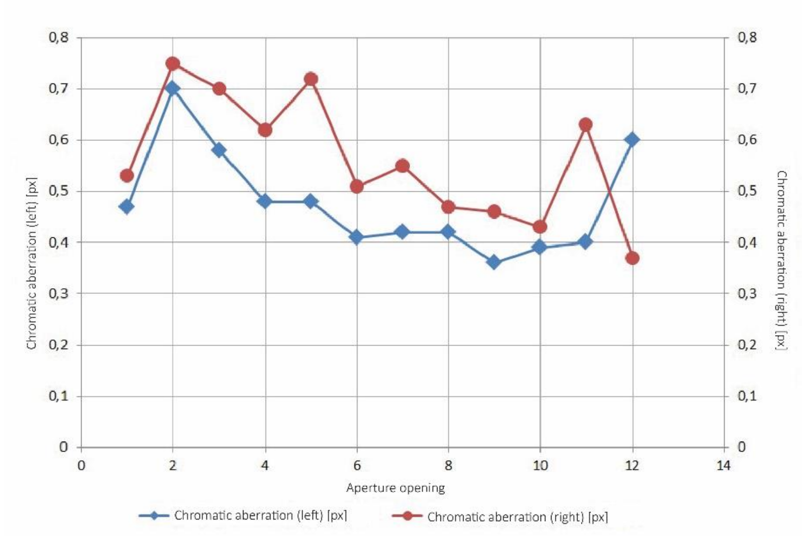

Figure 7: Graphic with the results obtained when photographing with the Sigma 85mm f/1.4 DG DN lens

On Figure 8. the ROI surfaces used in the measurement are shown, where the largest visible chromatic aberration for both sides, at an aperture of f/1.8, while on Figure 9. the smallest chromatic aberration shown for the left side at aperture of f/9.0, and f/11 for the right side.

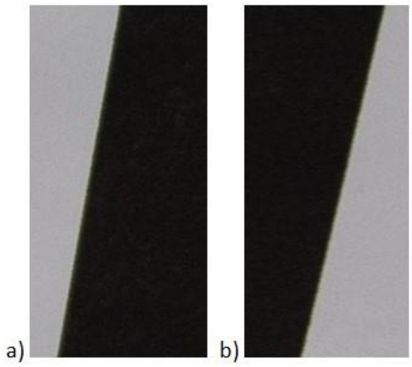

Figure 8: ROI of the surface with the largest chromatic aberration; a) left and b) right side

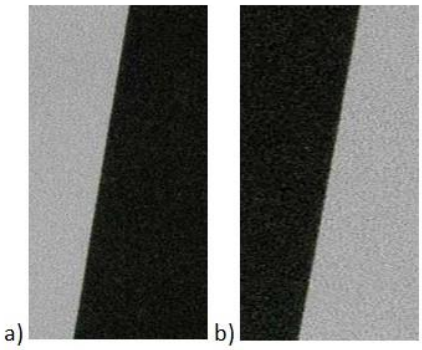

Figure 9: ROI surface with the smallest chromatic aberration; a) left and b) right side

4.2 Test results on the Sigma 40mm lens f/1.4

The test was performed on the Sigma 40mm f/2.8 lens at a distance of 120 cm from the test map, where the aperture, and therefore the ISO, is a variable factor while the focal length (40mm) and shutter speed (1/80) are fixed values.

On Figure 10. a graph is shown with the results for the tested lens at different apertures. The graphic shows the X axis, on which the aperture values are, and two Y axes, on which the chromatic aberration is expressed for the ROI area on the right and left side of the same image.

Based on the obtained results, according to the values from table 1. we conclude that the samples taken from the left side showed chromatic aberration below 0.5 at all apertures, which is insignificant chromatic aberration. They are on the right values in the range from 0.35 px to 0.59 px which, according to the table, are values that fall into insignificant chromatic aberrations and minimum values from the range of weak, that is, hard-to-notice chromatic aberrations.

In this case, the chromatic aberration values on the left and right side when changing the aperture are not correlated, it is very weak and the correlation coefficient is 0.26. Based on this information, we can see the basis of the graph that the left and right sides do not behave similarly in terms of increasing chromatic aberration with decreasing aperture.

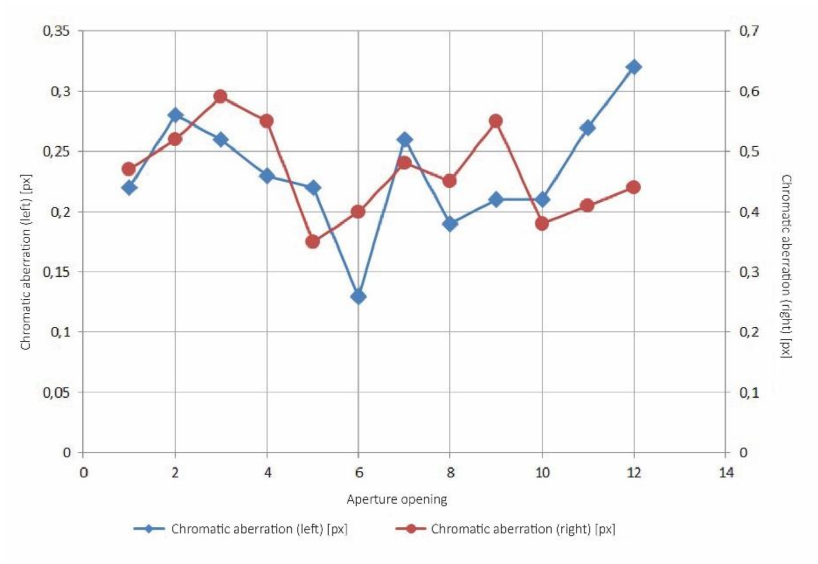

Figure 10: Graphic with the results obtained when photographing with the Sigma 40mm f/1.4

On Figure 11. the ROI surfaces used in the measurement are shown, where the largest chromatic aberration for the left side is at an aperture of f/16, and for the right side is f/2.2. While the values at medium apertures are the most ideal for photography, specifically the smallest chromatic aberration for the left side is at aperture of f/4.5, and for the right side f/3.5 shown on Figure 12.

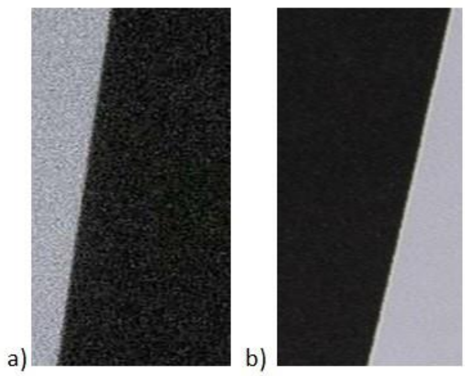

Figure 11: ROI of the surface with the largest chromatic aberration; a) left and b) right side

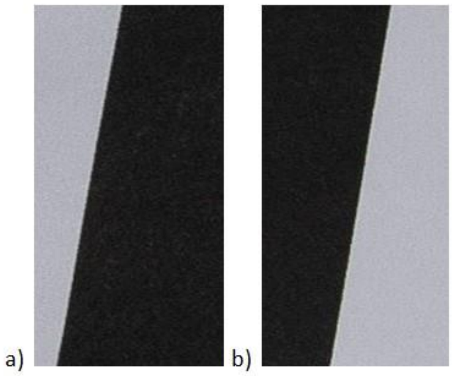

Figure 12: ROI surface with the smallest chromatic aberration; a) left and b) right side

5. CONCLUSION AND FURTHER RESEARCH

When studying the theoretical foundations of photography itself as well as individual parts of the camera system, we come to the conclusion that the theoretically perfect way of creating a photograph does not exist in practice. Deviations from perfect values
the consequence is the imperfection of parts of the photographic system where the construction and quality of the used lenses play a crucial role.
In order for the experimental part to be adequately done, it was necessary to study all the characteristics of the camera body as well as the lenses used, which significantly affect the final quality of the image. All the necessary knowledge for understanding the issues dealt with in this paper are clearly summarized and presented in the theoretical part.
In order to obtain relevant results, the test card was photographed in accordance with the appropriate standards and recommendations. With the help of Imatest software, analyzes were made that gave results about the quality of the tested lenses.
Changing the aperture did not drastically affect the increase in chromatic aberration either in the case of the Sigma 85mm f/1.4 DG DN, or in the case of the Sigma 40 mm f/1.4 lens. In general, at the average value of the examined apertures, the differences in chromatic aberration are the smallest, that is, negligible. Comparing these two lenses, the smallest measured value is for the Sigma 40mm f/1.4 and is 0.13 px at an aperture of f/4.5, and the largest is for the Sigma 85mm f/1.4 DG DN lens at an aperture of f/3.5 and is 0 ,72 px.
The camera body as well as the lens that will be used are of great importance because their selection directly affects the results obtained. Also, it is of great importance to choose the appropriate test procedure, properly light the scene, perform the photography itself, analyze the obtained photos for the aforementioned irregularities with specialized software tools, and then choose the best lens by evaluating the results.
It should also be borne in mind that for the full use of all the performance of the camera and lens, great knowledge and experience are needed, because otherwise the human factor can affect the degradation of the final quality.
By improving the lenses, where recently new materials are used to make the lenses themselves, as well as special coatings that compensate for imperfections, better and better results are obtained. In the future, it can be expected that during the construction and production of the lenses themselves, errors arising due to reduce lens imperfections to a minimum. In addition to the improvement of lens production, software tools for removing lens irregularities are also being improved in parallel.

6. ACKNOWLEDGMENTS

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COMPARATIVE ANALYSIS OF THE INFLUENCE OF COLOUR ON CUSTOMERS' TRUST TOWARDS WEBSITES IN THE FIELDS OF ONLINE BANKING AND CRYPTOCURRENCY TRADING

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Abstract: *This paper focuses on the influence of colour on customers' trust in websites in the fields of online banking and cryptocurrency trading. The literature reviews associated with the use of colour in web design shows that colour has a significant influence on customers' interaction with websites. Considering that, this study aimed to determine the relationship between used colour and trust towards websites in the specific areas of online banking and cryptocurrency trading. The method used to explore these relationships was an online survey, based on Likert scale. The survey inquired data about respondents, such as gender, age, level of education and their use of online banking and cryptocurrency trading. The main part of the survey was the one where the respondents were presented with website stimuli that differed in colour, and evaluated through grades on the Likert scale on given statements related to trust. To define to which extent, the chosen colour palette along with some users' general characteristics impacts the perception toward trust of presented websites, Kruskal–Wallis one-way analysis of variance and Mann–Whitney U test was conducted. The results indicated that there is a difference in respondents' trust towards websites in the fields of online banking and cryptocurrency trading depending on the colour used as the dominant in website design. Statistical significance was partly reached to their age and gender but not to their level of education. Overall, the study showed that when designing websites in the fields of online banking and cryptocurrency trading, choosing colour palettes that are needed to be trustworthy to the targeted audience is the issue that should be addressed with attention.*

Keywords: web design, colour, trust, e-banking, cryptocurrency

1. INTRODUCTION

As an element that affects the perception of the world around us, colour has always been the subject of interest and research. We never really think about colour as a phenomenon, it is present, and we process it unconsciously. From the earliest age, a human is taught to relate colour with some association, so even at the most mature age, it is not easy to describe it without using an example (Fairchild, 2005). Even though we know everything about a certain colour, we see it, we can imagine it if it is not present, we know how to recognize it, yet we would not be able to convey the sensation of colour to someone who does not have such possibilities. For that reason, how we perceive colour predominantly affects our perception of the world around us. Just as the processing of colour happens unconsciously, we also develop interpretations related to it throughout life. Culture, tradition, and religion are all aspects that, in addition to our character, will influence what associations we relate to the colour. Once we create an association, it is challenging, if not impossible, to change it. For example, in Europe, as well as in most other regions, white is considered the colour of purity and innocence; it is associated with weddings, while in the Far East, it is considered the colour of sadness and mourning (Bortoli & Maroto, 2001). Considering cultural differences, it would be absurd to ascribe strict interpretations to colours, although unofficially, but also unconsciously, we do so. In addition to all these factors, however, we cannot expect anyone with common demographic characteristics to share the same perception. This is a consequence of the influence of character on our general existence. Thus, people of the same religion, nationality, place of residence, and even gender and age will perceive colours differently. For example, someone will give the colour red a positive character and associate it with love, happiness, and passion.

In contrast, someone, on the other hand, will associate it with a negative context. They will associate it with danger, fire, and blood, which directly reminds them of disease, and war. Colour as a phenomenon directly affects our subconscious, causing certain emotions and moods. Each individual will interpret colours differently, which originates from psychological aspects. How we interpret particular colour says a lot about us. Research has established a close connection between human character and feelings toward colours. In addition to a persons' character defining how we will perceive a specific colour, the influence

of society, religion, and previous experiences will also impact our interpretation of them (Mikellides, 2012).
A significant amount of research was conducted to define the connection between colours and emotions. Research by Clarke and Costall (2008) confirmed that warm colours evoked more intense emotions than cool colours. The colour red has been found to have the most intense effect on the observer; it was associated with love, passion, warmth, and anger. The colour orange had a similar but less intense connotation. Orange is associated with warmth, happiness, and energy. Yellow, another colour from the group of warm colours, is associated with happiness and warmth. Based on these results, it was determined that with the decrease in the warm tone of the colour (from red to yellow) there is also a decrease in the excitement that the colour causes. Cool colours are, as expected, associated with more subtle concepts, such as peace, nature, and relaxation. Neutral colours were also investigated. Black colour is the most common association with evil, power, and strength, while white is associated with all the opposite emotions. Grey is rated as dull and monotonous but also calming. Brown and purple are colours with which the respondents had almost no association (Clarke & Costall, 2008).
Another study provided very specific results regarding colour preferences in the context of gender. It was concluded that blue is the most preferred colour by both genders, while yellow is the least preferred. Men prefer red more than women, while the reverse is true for green. Interestingly, women show fewer positive emotions towards yellow and orange compared to men. It was also concluded that different time periods are accompanied by different colour preferences. For example, during the 1970s, orange was the second most preferred colour, while nowadays, it is the second least preferred (Mikellides, 2012).
In the research conducted by Coursaris and Swierenga (2013), it was found that respondents show a greater preference towards cool colours or combinations that include cool colours. It has been observed that a website with an immutable design and mutable colour palette causes different reactions according to the used palette. Namely, combinations that contained one of the cold colours as a base (e.g., blue), whether in combination with another cold or warm colour, were rated more positively compared to sites with a warm colour base. Thus, a site whose colour palette was based exclusively on warm colours (e.g., red and orange) was quite unattractive to respondents. Based on the results, it was concluded that cool colours are associated with more positive emotions compared to warm ones. Thus, the blue colour palette is the most common association with security, credibility, and confidentiality (Coursaris & Swierenga, 2013).
In addition to personal preferences, variations in the use of colour palettes were observed in relation to demographic characteristics. Kondratova and Goldfarb (2007) found that there are colour palettes that are widely used globally, but also those that are specific to regions. It was found that the palette of colours with a high application at the international level includes shades of grey, blue and light shades of yellow. In contrast to this palette, the authors extricated the colour palette that dominates the region of Japan. This palette is based on warm colours, shades of red, orange and yellow, where yellow has a distinct dominance when used. This knowledge clearly shows how much influence cultural and demographic characteristics have in this domain as well (Kondratova & Goldfarb, 2007).
Additionally, it was determined that demographic characteristics influence both the choice of colours and the users' desire to purchase through a specific website. Broeder and Scherp (2017) found that colour affects the percentage of purchase realization and confidence in the marketed content through emotions. It has been noticed that this influence is more intense in Asian countries compared to Western countries (Norway, Germany and United Kingdom) (Broeder & Scherp, 2017).
It is inevitable that the colour of the content, it causes different reactions among the users, and for this reason, tests were carried out aimed at more specific user behaviours. In the research of Pellet and Papadopoulou (2012) it was determined that colour is the parameter on web pages that has the most impact on users, compared to the used typography, animations and images. It was also observed that in addition to the basic role of the colour in design, it significantly impacts users through an emotional reaction. Stimuli that used softer colours were more visually appealing to users, providing a more pleasant environment, which is an essential factor in a potential purchase through the website. It has been confirmed that when colours are used following the contrast, they can significantly affect the speed and save time when searching for content. Through this research, Pellet and Papadopoulou (2012) also found that colour significantly impacts remembering content on web pages. A good combination of colours provides more readable content that allows the user to navigate and notice information more efficiently, giving users a more pleasant shopping experience and an easier decision. A lower contrast between the background and foreground colors has been shown to make a marketed web page easier to remember. Remembering the content will positively influence the realization of purchases, where it was

determined that the change of colour brightness also impacts these parameters. The respondents' preferences were directed towards brighter colours as background, which finally led to the conclusion of an inevitable connection between the colours used, remembering the content, and making a purchase (Pelet & Papadopoulou, 2012). In their research, Bagchi & Cheema (2013) investigated the influence of a red background on the desire to buy the presented product. Their research is based on online auctions. The results indicate that red backgrounds (versus blue) cause more significant bid spikes. A red background (compared to blue) has also been found to reduce offers in negotiations, inferring that red colour causes aggression through arousal (Bagchi & Cheema, 2013).

Reliability and trust that the content evokes among users are one of important parameters that are considered when designing and marketing web pages. Bearing this in mind, numerous authors have examined the direct influence of colour on the impression of the reliability of web content. Another research conducted by Pellet and Papadopoulou (2011) made it possible to focus specifically on the effect of colour on user trust in e-commerce. The results showed that colour affects user trust, both positively and negatively. Depending on the colour that was used as the base, the respondents evaluated the amount of trust it evoked through the attributes of competence, integrity, benevolence, and predictability of the site. Bright, low-saturated colours have been shown to instil more confidence in users because they are associated with the aforementioned attributes. These colours are also described as visually pleasing and attractive, leaving an impression of professionalism.

On the other hand, bright, highly saturated colours have a negative impact on the previously mentioned four attributes. The most common reason for this reaction is that these colours are perceived as too aggressive and promotional. In addition to the general use of colours, it was found that users also pay attention to the colours in the images used. They expressed their preference for colours that give an "authentic" impression. The research concluded that the combination of white background and chromatic colours is a crucial factor for initiating e-commerce. It is important to note that although brighter colours were more often associated with trust and the tendency to purchase, they were not always the trigger (Pelet & Papadopoulou, 2011). Pellet and associates (2013) subsequently found that using more saturated and brighter colours in the foreground can motivate users to feel excited about the content on the web page. Colour combinations with bright, saturated foreground colours reminiscent of the natural environment led to more positive user reactions to a website. These colours make the site easier to remember and more pleasant to use (Pelet et al., 2013). Colour contrast is reported to be one of the most important elements for effective visual usability: higher colour contrast is perceived to be more flattering to the users. It is also proven that choosing colour correctly provides a better first impression of a website (Kovačević, Brozović & Banić, 2020). As well as design in digital form, the design of printed products largely relies on colour. Along with the material and shape of the product, colour is one of the most important factors taken into consideration when designing packaging (Vladić et al., 2015) which should be taken into consideration since it is expected that photographs or 3D models of different product packaging are accented on the webpages.

Khrouf and Frikha (2021) found that upon first encountering a web page, the users' attention is primarily attracted by aesthetic elements such as colour. Then the user evaluates the extent to which the used colours match commercial web pages with a similar theme that he has already used. Suppose the dominant colour follows the users' previous experiences. In that case, the content placed will instil additional trust in the user due to coherence with other content of a similar theme. On the specific example (of a hotel) they used in their research, Khrouf and Frikha came up with results indicating that the blue colour suited the content better than the red. This also contributed to a higher level of trust among users, which was previously found to be one of the main factors for making a purchase and leaving personal information on a website (Khrouf & Frikha, 2021). Lee and Rao (2010) conducted similar research. On a straightforward online shopping site with an immutable design except for the colour, the authors found that customers better accepted the blue colour as in most previous research. As the authors analysed the differences between the reactions to the blue and green websites, it was evident that the positive reactions regarding the trust that the site provides to the users prevailed on the side of the blue website. It was also found that users' general colour preferences did not significantly impact the trust users felt when using the site. Thus, it was determined that colour alone does not have such a pronounced effect on the user as when it is viewed as one of the design elements (Lee & Rao, 2010).

Research that included an analysis of the influence of four colours (red, green, blue, and black) on trust was conducted in 2011 by Alberts and Van der Geest. This research primarily confirmed the pre-existing assumption that colour significantly impacts the trustworthiness of websites. It was found that the colour blue was ranked as the most trustworthy, while black caused the least trust among respondents. It also

investigated whether there is a difference when comparing sites, which gave a positive result. This would mean that, depending on the choice of two colours offered, there may be a variation in the amount of trust with the user. In this case, it turned out that the influence of colour on trust is more pronounced in women than men, but also that women were generally more trusting of the sites offered. In addition, it was examined whether there are differences in confidentiality and colour, according to website area of operation. Websites in the fields of law, finance, and medicine were analysed. It was determined that there are no significant variations regarding the relationship between colour and trust but that the generally used colour palette had significantly more influence on trust in the finance field than the other two areas. These results suggest that colour can have different effects in certain areas. However, to see this more clearly, it should be investigated in areas that are much more different from each other, as opposed to the three equally risky areas that the authors selected in this study.
Additionally, it was found that the colour blue was ranked as the most trusted in all three areas, while the reactions to the other colours differed concerning the area. Thus, in finance and medicine, the second most reliable colour was green, while in the field of law, it was black. The third most trusted colour differed between fields: for finance, it was black. For law, it was green. Moreover, for medicine, it was white. The number of respondents who preferred black on legal websites and an aversion to red on websites of a financial nature was interesting (Alberts & Van der Geest, 2011).
Regarding e-banking, Sasidharan and Dhanesh (2007) examined the effect of changing the blue colour brightness on user response, considering that the blue colour was rated in a handful of tests as the most trusted colour. Here, it was found that a light shade of blue evoked the most trust in users. It was also concluded that the use of colour, regardless of shade, gives more trust compared to websites where only black and white were used (Sasidharan & Dhanesh, 2007).
Driven by previous research findings, in this paper, we aimed to investigate the influence of website colours on users' trust in online banking and cryptocurrency trading. The main goal of the conducted research was to determine whether there were statistically significant differences between the answers on trust statements among users based on the dominant website colour and their gender, age, and level of education. Gained knowledge can be used as a particular indicator when it comes to colour choice in terms of providing confidentiality to the content of the websites in these areas.

2. METHOD

The stimuli, online banking, and cryptocurrency trading websites were created using a monochromatic colour palette with five different colours as bases: grey, yellow, blue, red, and green. The elements created within the stimuli were based on the previous research of the existing websites in online banking and cryptocurrency trading. The method used to analyse the connection between colour and trust was a survey based on a Likert scale.
In order to minimize the deviation of the results, the respondents primarily took the Farnsworth Munsell 100 Hue Test. After gaining satisfactory results on this test, they were presented with a survey.
The survey consisted of sets of questions that obtained information about gender, age, level of education, and whether they use online banking and cryptocurrency trading. In the central part of the survey, respondents were presented with the stimuli with the task of evaluating them. The survey consisted of a total of 23 questions. In order to obtain detailed results, statistical analysis was performed using the nonparametric Mann-Whitney U Test and Kruskal Wallis Test.
The results of the nonparametric statistical tests were presented for two websites in five colours: a bank website with online banking service - website 1 and a website for cryptocurrency trading - website 2, based on the answers (given ratings on the Likert scale ranging from 1 – strongly disagree, 2- disagree, 3 – neutral, 4 – agree to 5 – strongly agree) on the following statements:
P1 - the website looks reliable and with truthful information,
P2 - I would have confidence in using one of the services offered on the site,
P3 - the colour palette used instils confidence in the stability and security of the bank/cryptocurrency trading.

2.1 General information about respondents

The total sample consisted of 90 respondents, of which there were significantly more female (63) than male respondents (23) (Figure 1).

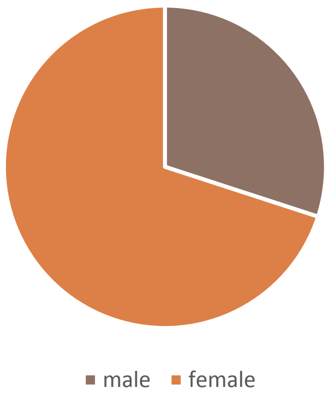

Figure 1: Graphic representation of respondents' gender

According to age, the largest number of respondents is classified in the group of 20 to 30 years old (77%), on the second place by the number of respondents is the group of 51 to 60 years old (13%), and then the group of 31 to 40 years old (6%). The lowest number of respondents was in the age group of 41 to 50 years (4%) (Figure 2).

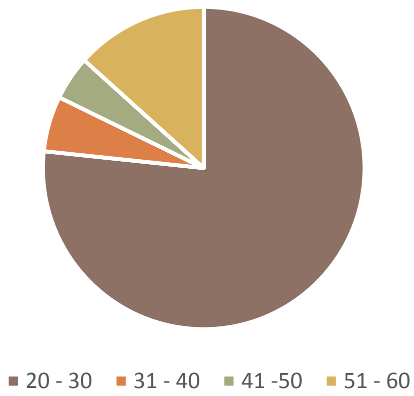

Figure 2: Graphic representation of respondents' age

Regarding education, the highest percentage of respondents has a high school education (56%), 29% of respondents have completed a bachelor's degree, and just 14% have master's degree. It was noticed that there is a very slight difference regarding the level of education in relation to the gender of the respondents, where female respondents have a slightly higher percentage of academic education (Figure 3).

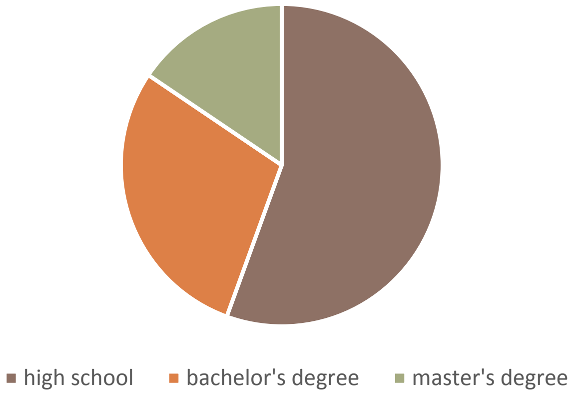

Figure 3: Graphic representation of respondents' education

Online banking services are used by 90% of the respondents (Figure 4). A higher percentage of male respondents (96%) than females (87%) use this banking service.

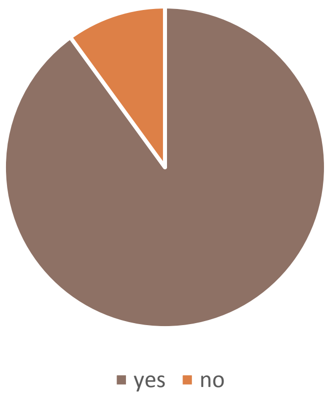

Figure 4: Graphic representation of respondents' e-banking usage

91% of respondents are familiar with cryptocurrency, while only 9% visit sites with this type of content (Figure 5). In addition, only 1 (2%) female respondent visits Internet content related to cryptocurrencies, while 22% of males answered positively.

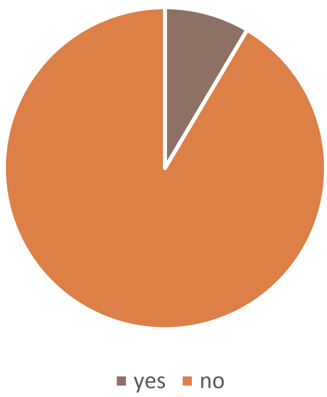

Figure 5: Graphic representation of respondents' usage of cryptocurrency trading websites

3. RESULTS AND DISCUSSION

In order to determine whether gender influences the respondents' answers, the Mann-Whitney U test was conducted. This test showed that a statistically significant difference at the $p<0.05$ level for the tested groups exists only in responses to statement 3 (*the used colour palette instils confidence in the stability and security of the bank/cryptocurrency trading*) for the bank website in red colour: $z=-1.687$, $p=0.017$, $r=0.25$. For all other colours and statements, the test determined that there are no statistically significant differences in the responses of men and women (Table 1).
Applying the Kruskal-Wallis test, it was concluded that there is no statistically significant difference in the reactions to stimuli of three different educational groups (G1, n=50, high school, G2, n=26, bachelor's degree, G3, n=14, master's degree) (Table 2).

Table 1: Results of the Mann-Whitney U test on influence of gender on respondents' answers

		Website 1			Website 2		
		P1	P2	P3	P1	P2	P3
Red	Z	-1.687	-1.746	-2.381	-0.742	-0.136	-0.619
	p	0.092	0.081	0.017	0.458	0.892	0.536
	r	0.18	0.18	0.25	0.08	0.01	0.07
Green	Z	-1.754	-1.887	-1.188	-1.122	-0.160	-0.583
	p	0.079	0.059	0.235	0.262	0.873	0.560
	r	0.18	0.2	0.12	0.12	0.02	0.06
Blue	Z	-1.301	-1.772	-0.786	-0.398	-0.616	-0.759
	p	0.193	0.076	0.432	0.691	0.538	0.448
	r	0.14	0.19	0.08	0.04	0.06	0.08
Yellow	Z	-0.483	-0.507	-0.351	-0.748	-0.041	-0.246
	p	0.629	0.612	0.726	0.454	0.967	0.806
	r	0.05	0.05	0.04	0.08	0.004	0.03
Grey	Z	-0.101	-0.297	-0.472	-0.281	-0.600	-0.750
	p	0.920	0.766	0.637	0.779	0.549	0.453
	r	0.01	0.03	0.05	0.03	0.06	0.08

Table 2: Results of the Kruskal-Wallis test on influence of education on respondents' answers

		Website 1			Website 2		
		P1	P2	P3	P1	P2	P3
Red	c^2	2.850	0.874	1.123	0.536	0.835	0.402
	df	2	2	2	2	2	2
	p	0.240	0.646	0.570	0.765	0.659	0.818
Green	c^2	3.754	3.339	4.393	0.091	0.982	0.307
	df	2	2	2	2	2	2
	p	0.153	0.188	0.111	0.956	0.612	0.858
Blue	c^2	0.966	0.044	1.285	1.215	0.042	1.147
	df	2	2	2	2	2	2
	p	0.617	0.978	0.526	0.545	0.979	0.564
Yellow	c^2	1.218	0.319	3.790	3.478	1.801	2.232
	df	2	2	2	2	2	2
	p	0.544	0.853	0.150	0.176	0.406	0.328
Grey	c^2	1.074	1.067	1.912	0.278	0.054	0.496
	df	2	2	2	2	2	2
	p	0.585	0.587	0.384	0.870	0.973	0.780

Table 3: Results of the Kruskal-Wallis test on influence of age on respondents' answers

		Website 1			Website 2		
		P1	P2	P3	P1	P2	P3
Red	c^2	3.851	3.554	3.513	5.942	5.659	6.825
	df	3	3	3	3	3	3
	p	0.278	0.314	0.319	0.114	0.129	0.078
Green	c^2	4.162	2.803	4.502	3.992	6.909	7.448
	df	3	3	3	3	3	3
	p	0.244	0.423	0.212	0.262	0.075	0.059
Blue	c^2	13.761	14.968	15.846	16.512	19.185	19.887
	df	3	3	3	3	3	3
	p	**0.003**	**0.002**	**0.001**	**0.001**	**0.000**	**0.000**
Yellow	c^2	1.990	3.032	3.126	3.530	6.010	5.260
	df	3	3	3	3	3	3
	p	0.575	0.387	0.373	0.317	0.111	0.154
Grey	c^2	8.559	8.268	8.074	13.533	11.447	11.896
	df	3	3	3	3	3	3
	p	**0.036**	**0.041**	**0.045**	**0.004**	**0.010**	**0.008**

The Kruskal-Wallis test, which was performed to determine whether there is an influence of the age of the subjects on the results, determined that there are statistically significant differences between the four age groups (G1, n=69, 20-30 years old, G2, n=5, 31-40 years old, G3, n=4, 41-50 years old, G4, n=12, 51-60 years old) (Table 3). Since it was determined that statistically significant differences in relation to the age of the respondents exist for the blue and grey websites, a post-hoc test was performed. As a post-hoc test, a series of Mann-Whitney tests were performed to determine between which age categories there was a statistically significant difference in the respondents' answers. These tests showed statistically significant differences between the age groups G1 (20-30 years old) and G4 (51-60 years old) in all four stimuli. The effect sizes r in the group were small or medium. A statistically significant difference was also observed between the age categories G1 and G3 (41-50 years old), but only for site stimuli with a cryptocurrency theme and in the case of both colours. In this case, the influence sizes for each parameter are greater than 0.3. Therefore, they belong to the medium influence group. Also, a statistically significant difference was observed in the responses between groups G2 and G4 for the bank-themed site in blue, with influence sizes exceeding 0.5, and therefore belonging to the high influence group. The calculated effect size shows a high level of influence between the G2 and G3 age groups for cryptocurrency-themed sites in both blue and grey (Table 4).

Table 4: Results of the post-hoc Mann-Whitney test (on influence of age on respondents' answers)

		Blue						Grey					
		Website 1			Website 2			Website 1			Website 2		
		P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
G1/G2	Z	-0.452	-0.011	-0.453	-1.509	-1.974	-2.048	-1.771	-1.245	-1.387	-1.193	-0.895	-1.296
	p	0.676	1.000	0.676	0.153	0.063	0.051	0.094	0.244	0.188	0.263	0.400	0.219
	r	0.05	0.001	0.05	0.17	0.23	0.24	0.2	0.14	0.16	0.14	0.1	0.15
G1/G3	Z	-1.279	-1.587	-1.740	-2.704	-3.003	-2.993	-0.696	-1.150	-1.327	-2.619	-2.552	-2.659
	p	0.231	0.134	0.098	**0.006**	**0.001**	**0.001**	0.519	0.282	0.212	**0.007**	**0.009**	**0.006**
	r	0.15	0.19	0.2	**0.32**	**0.35**	**0.35**	0.08	0.13	0.15	**0.31**	**0.3**	**0.31**
G1/G4	Z	-3.460	-3.642	-3.741	-3.022	-3.029	3.114	-2.492	-2.534	-2.370	-2.623	-2.344	-2.135
	p	**0.001**	**0.000**	**0.000**	**0.003**	**0.002**	**0.002**	**0.013**	**0.011**	**0.018**	**0.009**	**0.019**	**0.033**
	r	**0.38**	**0.4**	**0.42**	**0.34**	**0.34**	**0.35**	0.28	0.28	0.26	0.29	0.26	0.24
G2/G3	Z	-1.273	-1.268	-1.178	-1.549	-1.807	-1.807	-0.130	-0.782	-0.637	-2.095	-2.095	-2.226
	p	0.286	0.286	0.286	0.190	0.111	0.111	0.905	0.556	0.556	**0.063**	**0.63**	**0.032**
	r	**0.4**	**0.4**	**0.39**	0.5	0.6	0.6	0.04	0.26	0.21	0.7	0.7	0.74
G2/G4	Z	-2.567	-2.206	-1.852	-0.843	-0.516	-0.516	-0.548	-0.940	-0.442	-1.209	-1.063	-0.714
	p	0.009	0.037	0.082	0.442	0.646	0.646	0.646	0.383	0.721	0.279	0.328	0.506
	r	0.6	0.5	**0.45**	0.09	0.06	0.06	0.06	0.1	0.05	0.13	0.12	0.08
G3/G4	Z	-0.447	-0.127	-0.441	-1.174	-1.536	-1.536	-0.630	-0.510	-0.128	-0.523	-0.403	-1.141
	p	0.684	0.953	0.684	0.316	0.170	0.170	0.599	0.684	0.953	0.684	0.770	0.316
	r	0.11	0.03	0.11	0.029	**0.38**	**0.38**	0.16	0.13	0.03	0.13	0.1	0.28

In the following analysis, which aimed to give a comprehensive insight into the influence of colour on respondents' answers towards confidentiality statements, respondents were treated as a whole since the level of education does not result in a statistically significant difference in respondents' answers (ratings) to stimuli, and in gender and age-based analysis, statistical significance was partly reached (Table 1-4). Applying the Kruskal-Wallis test, it was revealed that there is a statistically significant difference in the respondents' responses in relation to the site's colour, both with the stimulus of the bank's website and with the stimulus with cryptocurrencies (Table 5).

Table 5: Results of the Kruskal-Wallis test on influence of colour on respondents' answers

	Website 1			Websites 2		
	P1	P2	P3	P1	P2	P3
c^2	38.538	42.512	42.199	18.872	18.932	20.069
df	4	4	4	4	4	4
p	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**	**0.000**

In order to determine in more detail between which colours there is a statistically significant difference, an individual comparison was made between each of the two colours used using the Mann-Whitney test. The comparison was made for the following colour pairs: red-green, red-blue, red - yellow, red-grey, green - blue, green-yellow, green - grey, blue-yellow, blue-grey, and yellow-grey. The tests determined that statistically significant differences do not exist when comparing yellow and grey colours. In contrast, for all other pairs of colours there is a statistically significant difference in the answers to at least one statement for one site. In the first comparison group (red-green), the results indicate that there is a statistically significant difference only with the stimulus of the bank's website, on statement 2 - *I would have confidence in using one of the services offered on the website* (z= -1.341, p=0.033, r=0.22) and statement 3 – *the colour palette used instils confidence in the stability and security of the bank/cryptocurrency trade* (z= -3.126, p=0.002, r=0.33). The second group (red-blue) resulted in statistically significant difference for both sites, namely for the bank site for statements P2 (z= -2.111, p=0.035, r=0.22) and P3 (z= -3.045, p=0.002, r= 0.32), while for the site with cryptocurrencies this difference was observed for all three statements - P1 (z=-2.988, p=0.003, r=0.31), P2 (z= -3.154, p=0.002, r=0.33) and P3 (z= -3.288, p=0.001, r=0.35). When comparing red and yellow colours, there were differences only for bank websites, for statements P1 (z= -2.731, p=0.006, r=0.29) and P2 (z= -2.267, p=0.023, r=0.24). Differences in relation to the same statements also appeared when comparing red and grey colours - P1 (z= -3.326, p=0.001, r=0.35) and P2 (z= -2.766, p=0.006, r=0.29). A statistically significant difference for the cryptocurrency site stimuli occurred when comparing green and blue. This comparison resulted in a statistically significant difference in all three statements - P1 (z= -2.703, p=0.007, r=0.28), P2 (z= -2.190, p=0.029, r=0.23) and P3 (z= -2.166, p=0.030, r=0.23). Unlike the previous comparison group, when comparing the green and yellow colours, the statistically significant differences occur only in bank websites, and in all three statements - P1 (z= -4.122, p=0.000, r=0.43), P2 (z= -4.440, p=0.000, r=0.47) and P3 (z= -4.549, p=0.000, r=0.48). The same is the case with the next two colours (green and grey) – P1 (z= -4.645, p=0.000, r=0.49), P2 (z= -4.868, p=0.000, r=0.51) and P3 (z= -4.679, p=0.000, r=0.49). Statistically significant differences of medium and high impact occur for both sites in all three statements when comparing blue and yellow and blue and grey (Table 6).

Table 6: Results of the Mann-Whitney test (on influence of colour on respondents' answers)

		Website 1			Website 2		
		P1	P2	P3	P1	P2	P3
Red - green	Z	-1.341	-2.134	-3.126	-0.632	-1.253	-1.363
	p	0.180	0.033	0.002	0.527	0.210	0.173
	r	0.14	0.22	0.33	0.07	0.13	0.14
Red - blue	Z	-1.283	-2.111	-3.045	-2.988	-3.154	-3.288
	p	0.199	**0.035**	**0.002**	**0.003**	**0.002**	**0.001**
	r	0.13	0.22	**0.32**	**0.31**	**0.33**	**0.35**
Red - yellow	Z	-2.731	-2.267	-1.122	-0.412	-0.062	-0.075
	p	**0.006**	**0.023**	0.262	0.681	0.951	0.940
	r	0.29	0.24	0.12	0.04	0.006	0.008
Red – grey	Z	-3.326	-2.766	-1.516	-0.698	-0.598	-0.598
	p	**0.001**	**0.006**	0.130	0.485	0.550	0.550
	r	**0.35**	0.29	0.16	0.07	0.06	0.06
Green - blue	Z	-0.030	-0.070	-0.058	-2.703	-2.190	-2.166
	p	0.976	0.944	0.954	**0.007**	**0.029**	**0.030**
	r	0.003	0.007	0.006	0.28	0.23	0.23
Green - yellow	Z	-4.122	-4.440	-4.459	-1.131	-1.282	-1.480
	p	**0.000**	**0.000**	**0.000**	0.258	0.200	0.139
	r	**0.43**	**0.47**	**0.48**	0.12	0.14	0.16
Green - grey	Z	-4.645	-4.868	-4.679	-1.350	-1.902	-1.896
	p	**0.000**	**0.000**	**0.000**	0.177	0.057	0.058
	r	**0.49**	**0.51**	**0.49**	0.14	0.2	0.2
Blue - yellow	Z	-3.905	-4.260	-4.387	-3.661	-3.335	-3.566
	ρ	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**
	r	**0.4**	**0.45**	**0.46**	**0.39**	**0.35**	**0.38**
Blue - grey	Z	-4.449	-4.741	-4.571	-3.650	-3.716	-3.698
	ρ	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	r	**0.47**	0.5	**0.48**	**0.38**	**0.39**	**0.39**
Yellow - grey	Z	-0.758	-0.544	-0.395	-0.307	-0.712	-0.661
	ρ	0.448	0.586	0.693	0.759	0.477	0.509
	r	0.08	0.06	0.04	0.03	0.07	0.07

4. CONCLUSION

Results provided by this research can be observed as a preliminary report considering the users' responses to the use of colour on websites in online banking and cryptocurrency trading. Chosen colour palettes and users' general characteristics impact, to some extent, the perceived trust of presented websites.

In terms of colour, the conducted statistical tests revealed that statistical significance was not reached when comparing yellow and grey stimuli. In contrast, for all other pairs of colours there is a statistical significance in the answers to at least one statement regarding confidentiality and for at least one website.

Among the characteristics of the respondents, statistical significance was observed in the respondent's answers in the context of their age: the greater the age difference, the more the results varied. Gender and level of education were not found to be variables that generate statistical significance in answers to stimuli-related statements. The only exception is in the analysis conducted for the variable respondents' age, where statistically significant difference in respondent's answers was determined in examining the answers given for the statement 3 (*the used colour palette instils confidence in the stability and security of the bank/cryptocurrency trading*) but only for the bank website and only in red colour. Gained knowledge can be used as a particular indicator regarding colour choice in terms of providing confidentiality of the targeted audience to the content of online banking and cryptocurrency trading websites.

5. ACKNOWLEDGMENTS

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INFLUENCE OF TEST CHART CONTRAST ON QUANTIFICATION OF PHOTO SHARPNESS

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Abstract: *Quality control of digital photos is evolving rapidly every day. Procedures and methods of measurement are changing. Cameras on mobile phones are currently in focus because they are largely replacing the cameras used so far. Based on the standards for the control of photos on mobile phones, in this paper one of the essential quality attributes was chosen to be tested, which is the sharpness of the photos. For the purposes of the experiment, five commercially available mobile phones with different rear camera characteristics were selected. Two standard test cards with different contrast ratios were used. The tests were carried out under appropriate laboratory conditions. Sharpness is analaziry via MTF50 value as measured in Imatest software. Based on the results, it is concluded that the contrast of the test chart affects the measured value, therefore it is important to strictly define the conditions of measurement and the used test card when analyzing this attribute.*

Key words: digital photography, mobile phone rear camera, sharpness, test chart contrast

1. INTRODUCTION

One of the important attributes of image quality is certainly sharpness, i.e. the possibility of reproducing fine high-frequency details. Sharpness (resolution) can be defined as the smallest interval measurable by a scientific (especially optical) instrument. Sharpness can be categorized as a local attribute. The appearance of local attributes depends on the viewing conditions with respect to viewing distance and size of the image (Phillips & Eliasson, 2018).
The measurement of sharpness is a measurement of the spatial frequency response (SFR). This function describes how well the system under test can reproduce a range of spatial frequencies (Figure 1) on a scale from 0% (complete loss of information) to 100% (perfect reproduction without data loss) (Image Engineering, 2022).

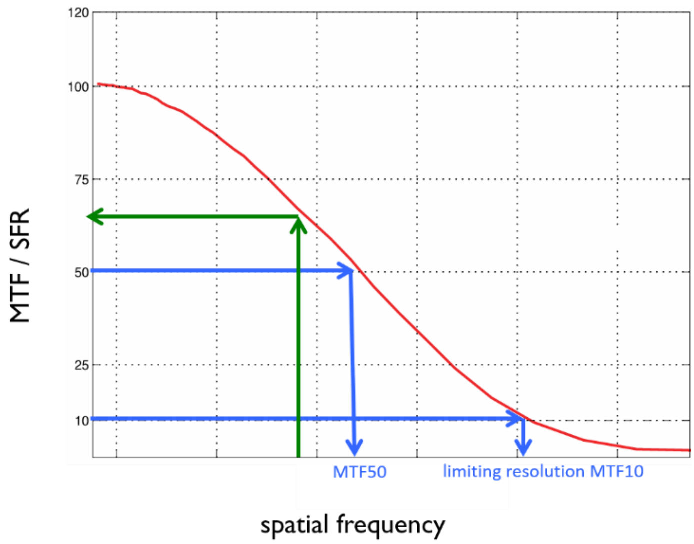

Figure 1: The X-Axis shows the spatial frequencies increasing from left to right, and the Y-Axis depicts the SFR (Image Engineering, 2022)

To measure sharpness in photos, we must first select a test chart. Quality control of photography devices, especially mobile phones, is in daily development, so test charts are also changing and developing constantly. One option is to use the Slanted Edge SFR measurement developed by Burns and Williams (2002) and standardized in ISO 12233 (ISO, 2017). In addition to the slanted edge, a method based on a Sinusoidal Siemens Star is also used which is evaluated on a radius by radius or frequency by frequency basis (Loebicha et al, 2007).

The old high-contrast ISO 12233 chart (Version 2000) is referenced in the ISO 12233:2000 standard but is no longer a part of the standard. It should only be used when results need to be compared with older work (Imatest, 2022).

The obsolete ISO 12233:2000 standard defines a resolution test target with a high contrast ratio. These are typically produced at the maximum dynamic range, which can be anywhere from 40:1 to 80:1. The high contrast can lead to clipping of the signal which leads to overstated invalid MTF values. Some camera manufacturers who want better MTF results may take advantage of this anomaly to overstate the quality of the cameras they produce (Imatest, 2021). The revision of the standard resulted in a new test card where the contrast was reduced to the level of ratio 4:1. New version of test chart should contain minimum 9 slanted squares for slanted edge measurements. The mentioned test charts are shown in the Method section, Figure 2.

The aim of this work is to measure the sharpness of the photo obtained with the rear camera on commercially available mobile phones, and to use two test chart (a high-contrast and a low-contrast), during the measurement. In the continuation of the paper, the experiment and the devices used are described in detail, after which the obtained results are presented and discussed.

2. METHODS

For the purposes of the experiment, 5 different phones were used, the specifications of which can be found in Table 1. In order to check the effect of contrast on the measured sharpness values, two test charts were chosen. The old high-contrast ISO 12233 chart (Figure 2 a) and low-contrast ISO 12233:2017 Edge SFR, eSFR (Figure 2 b). The experiment is carried out under suitable conditions in a darkened room. The only light source used was made for the purposes of the experiment. The stand on which the mobile phone is positioned in the middle, and on both sides at an angle of 45 degrees, there are LED lamps that simulate daylight (5000 K). The camera sensor is placed flush with the center of the test chart, while the distance of the stand is 70 cm from the chart. Photographed test charts were tested in Imatest software, module SFR. The ROI (Region of interest) area was the same for all phones (80 x 160 px). On the high-contrast test chart, 8 possible fields were measured, while on the low-contrast map it was possible to measure 15 different fields.

Table 1: Mobile phone camera specifications

Mobile phone	Aperture	Rear camera resolution
Samsung Galaxy A52s 5G	f/1.8	2400 x 1080 px / 64 MP
LG K10	f/2.2	720 x 1280 px / 13 MP
Huawei Mate 10 Lite	f/2.2	1080 x 2160 px / 16 MP
Apple iPhone 11 Max Pro	f/2.4	2688 x 1242 px / 12 MP
Xiaomi Redmi Note 10	f/1.9	1080 x 2400 px / 48 MP

a) b)

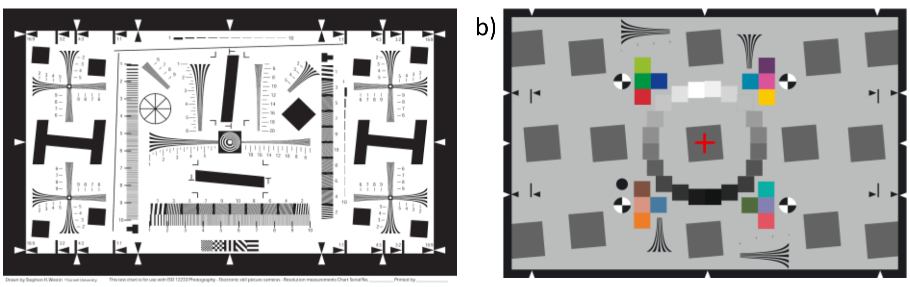

Figure 2: Test charts used in the experiment, a) high-contrast and b) low-contrast

3. RESULTS AND DISCUSSION

The obtained results are shown in Figures 3 and 4. The graph shows the mean values, as well as the minimum and maximum values for each phone. Based on the results, it can be concluded that the number of megapixels, i.e. the resolution of the camera certainly does not affect the quality of the obtained photo, in this case specifically the tested quality attribute - sharpness. Image processing has a much greater influence on the sharpness of the photo. The fourth phone with 12 MP has the highest sharpness when measured on the low-contrast test chart. The MTF50 value for that phone is much higher compared to phone 1 (64 MP) and phone 5 (48 MP). When measuring the old test card (high-contrast), slightly different results were obtained. In that case, the phone with the highest resolution (64 MP) has the highest MTF50 value. Higher values were also obtained during the control of phone 3, while similar results were obtained with the other phones when the test chart was changed.

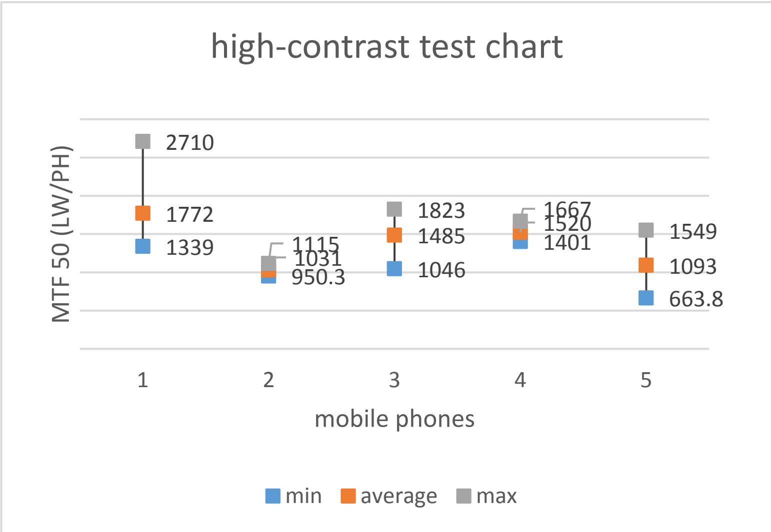

Figure 3: Measured sharpness (MTF50) for high-contrast test chart

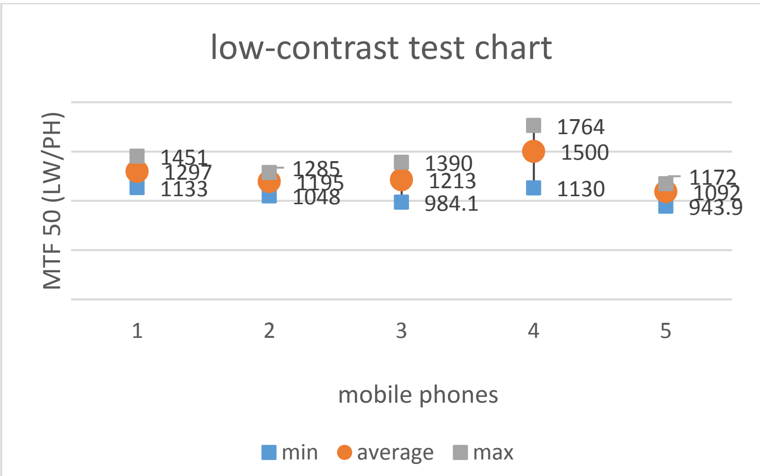

Figure 4: Measured sharpness (MTF50) for low-contrast test chart

Large variations of the measured sharpness at different positions of the test chart were also observed. In the corners of the test chart, the sharpness values decrease significantly. With phone 5, these variations are the most pronounced.

4. CONCLUSIONS

Cameras on mobile phones are already largely replacing semi-professional and even professional cameras in some segments. Therefore, years ago there was a need for a more serious control of the quality of the photos taken with both the rear and front cameras. There are many centers that provide customers with a detailed quality analysis, in addition to the basic specifications provided by the manufacturers. There is also a standard that deals with it, Camera Phone Image Quality (CPIQ). The CPIQ standard seeks to standardize image quality test metrics and methodologies across the industry, correlate objective test results with human perception, and combine this data into a meaningful consumer rating system. One of the important attributes is sharpness, which depends on the viewing distance and therefore belongs to the local group of quality attributes. Inadequate sharpness leads to more than low-quality images; it can also lead to dangerous situations, especially in security and automotive industries that often rely on high-sharpness images and video for safety and effectiveness. It is thus vital to properly test and analyze the image sharpness of the camera under test. In this paper, the influence of the contrast of the test chart on the value of the obtained sharpness was examined. Based on the results, it is concluded that the contrast has an impact. Depending on the selected test chart, different values were obtained. However, for more concrete analyses, a suggestion for future research is to consider a larger number of cameras, as well as a larger number of different contrast ratios on the test charts.

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AN OVERVIEW OF THE USER EXPERIENCE IN ONLINE VIDEO GAME PLAYERS WITH COLOUR VISION DEFICIENCY

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Abstract: *This paper aims to give an overview of the user experience in online video game players with colour vision deficiency by exploring the different methods of daltonization tools given within four popular online multiplayer video games. The paper also considers the different options for improving the user experience of players with colour vision deficiency based on the noticed shortcomings of analysed games. The analysis of the potential colour confusing scenes was done for the four popular online multiplayer games: Rust published by the Facepunch studio, Valorant and League of Legends both published by Riot Games and Overwatch, published by Blizzard. The conducted research has shown that Rust has no accessibility settings, Valorant and League of Legends use partial daltonization, while Overwatch is characterised by full daltonization. Detailed analyses of the pros and cons of each daltonization level for each video game were presented along with suggestions for improvement, including the implementation of the proto-patterns method suggested by Molina-López and Medina-Medina (2019). As the result, it was shown that colour, although an essential part of video game design, can and should be a secondary element in video game graphics over which shapes, outlines and text should lead in the clear presentation of the information and reduction of mistakes due to colour vision impairments.*

Keywords: Colour perception, colour vision deficiency, video games, universal and accessible design, daltonization tools.

1. INTRODUCTION

Nowadays a considerable amount of information and entertainment is being consumed over digital devices where one of the common ways of portraying a message is with a help of colour. Due to the fact that colour is used as an information carrier, individuals with colour vision deficiency have been put in an unfavourable position, forced to navigate the world that their eyes cannot process. Graphics and video games alike use colours as a universal language. However, thanks to advancements in research and technology, a common way of user experience improvement is using some daltonization tools.

This paper looks into different implementation methods of daltonization tools and considers different options for user experience improvement for people dealing with colour vision deficiency. Four popular online multiplayer games are analysed. Each of the games utilizes different methods of image improvement for people with colour vision deficiency. Based on that analysis, some possible improvements to the already applied methods will be identified.

2. BACKGROUND

2.1 The human vision and colour perception

The key organ regarding the sense of sight is the eye. It consists of many parts, but in the context of colour vision deficiency, the most important one is the retina.

The retina is made out of different cells, the ones important in the context of this paper are cones. Three types of cones are in function as photoreceptors. Cones are commonly labelled as L (L – long), M (M – medium), and S (S – short). These labels correspond to the wavelengths that the photoreceptors are responding to. Another set of labels that can be used is R for red, G for green, and B for blue colour, which is convenient, but not necessarily correct since the sensitivity of some cones are including wavelengths of another colour (Fairchild, 2005).

The human reaction to colour is psychological and physiological, making the colour perception individual. Furthermore, colour is the sensation that results from light, which means that if the light changes, so will the colour (Anderson & Reed, 2014).

The lack of ability to differentiate colours can happen due to the lack of pigments in cones, i. e. when one or more photoreceptors in charge of colour vision are not functioning correctly. It is important to note that colour vision deficiency is a genetic disorder, more prominent in men because the gene carrying the disorder is on the X chromosome (Purves et al., 2001).
If there is a lack of sensation of the red or green light, the person will be unable to differentiate between reds and greens. The rarer case is a malfunction of photoreceptors responsible for the blues, causing difficulties in differentiating between blues and yellows (Guyton, 1971). Commonly used terms to differentiate between the types of colour vision deficiency are deuteranopia – green blindness, protanopia – red blindness, and tritanopia – blue blindness. In some cases, people have "faulty" trichromatic vision, also known as anomalous trichromacy (Colour Blind Awareness, 2010). In this case, the terms used to differentiate between the types of anomalous trichromacy are deuteranomaly, protanomaly, and tritanomaly.
Deuteranopia and deuteranomaly are the most common types of colour blindness, and around 6% of the population with XY combinations of chromosomes deals with it (Colblindor, 2015). Ones with these conditions are also consumers of software and applications that use colour as a carrier of information, and therefore it is necessary to have methods and tools that allow the adaptation of images for people with colour vision deficiencies.

2.2 Daltonization tools

Daltonization is a method of image correction that adapts the contents of an image for people with colour vision deficiency. It is a complex task that carries with it the issue of remapping a colour spectre to a smaller one, more suitable for people with colour vision deficiency (Milic et al., 2015).
Generally, there are two kinds of daltonizations, content-independent daltonization which will remap one colour to another, disregarding the content of the image, and content-dependant daltonization which will remap one colour to another, depending on the context of an image, assuring that the object in the image is standing out from the background (Simon-Liedtke et al., 2017). Currently, content-dependant daltonization is taxing for the computer, which makes it potentially inadequate for an image that is changing in real-time, which is the case in video games.
The surface of an image can be changed partly, where only one colour or one part of an image is being daltonized or fully, where the whole image is being remapped. Depending on the customization factor, some daltonizations are made for an individual or a certain group of colour blindness, while some are made universal (Simon-Liedtke et al., 2017). In some instances, the user can control the daltonization level, while in some cases it is automatic.
Other than colour remapping, the option for adding texture, shadow and complementary text to a colour can and will improve the overall clarity and user experience, especially for people with colour vision deficiency.

2.3 Video games

The term video games will be used to describe a type of interactive entertainment that is being consumed via PC (personal computer), mobile phone, consoles, and other devices. The term will most commonly be used to describe online multiplayer games.
In video games, communication with the user is the key element, ensuring that the user can adequately respond to cues and problems presented in a video game. While most games use sound to inform the player of an enemy's location in space, the visual aspect of a video game is essential. Most games successfully convey information about events without sound due to visual cues on the screen that shows where a sound is coming from. For the user to know who in the game is their teammate, who is the enemy, or whether the player has taken damage or regenerated life, many games use colours. The most common colours used were red, often as a marker for an enemy or loss of life, and green or blue, as a marker for a teammate or something positive for the player.
According to *newzoo,* the total number of video game players worldwide is projected to surpass 3 billion by 2023 (Wijman, 2020). Adding to this statement that 1 in 12 men and 1 in 200 women are affected with colour vision deficiency (Colour Blind Awareness, 2010) it becomes clear that accessibility settings in video games should become the norm. However, game developers and publishers vary in how much they take this reality into account.

Due to community pressure, video games are becoming more accessible to users. As a result, video game publishers are becoming more aware of the challenges their users face. As a result, they are increasingly introducing options to help overcome various obstacles.

2.4 Universal design

According to Ronald Mace (1991), "Universal design means simply designing all products, buildings and exterior spaces to be usable by all people to the greatest extent possible... Universal design means simply designing all products, buildings and exterior spaces to be usable by all people to the greatest extent possible.." (Mace et al., 1991)

Referring to the opinion of Ronald Mace, video games should be accessible to users without having to adapt using the currently available means.

The Game Accessibility Special Interest Group (GA-SIG) of the International Game Developers Association (IGDA) defined accessibility in video games as an ability to play under restrictive conditions because of functional disabilities. (Mangiron & Orero, 2012)

Evaluating the state of accessibility design in video games, Brown and Anderson (2020) have stated that to be of value, colour-blind modes should ensure that the critical information that is being portrayed by colour must be visible to people that deal with colour vision deficiency. They suggest that instead of using the traditional red and green combination, the more favourable palette would consist of blues and oranges (Brown & Anderson, 2020).

Accessibility in games refers to the ability to fully play and experience the game, even when players are operating under restrictive conditions (Khaliq & Torre, 2019). Users, i.e., players with colour vision deficiency, are particularly affected by the usual choice of colours (red, green or blue), as these are the colours that people with colour vision deficiencies cannot adequately distinguish. Due to colour vision deficiencies, certain players find games confusing, especially when they start playing games, and in some cases, they become impossible to play. Very often, the available accessibility settings are either not good enough or do not exist at all.

Video games are software, meaning every game contains at least one, and very often more, bugs that can cause the game to malfunction and put one player at a disadvantage compared to another. Losing due to an error in the game itself causes intense frustrations in players, motivated by a sense of injustice.

If the information is not visualized correctly, it can contribute to poor performance and, therefore to something that should be fun, turning into a source of immediate frustration. According to the same principle, frustrations occur in users with colour vision disorders.

3. ANALYSIS OF SELECTED ONLINE VIDEO GAMES

Four popular online multiplayer games were analysed in this paper. Games have been separated into three major groups based on the daltonization methods found that the developers decided to use (Table 1). The first group comprises games that have no accessibility settings. One of the representatives of such games is the game *Rust* by the Facepunch studio. The second group includes the games that have partial daltonization, meaning that only a specific aspect of the game has some daltonization methods, like the games *Valorant* and *League of Legends* both published by Riot Games. Lastly, the third group contains the games that have full daltonization, i. e. every colour of the image is remapped into another colour, which is the case in the video game *Overwatch* by Blizzard. Table 1 showcases each of the 4 mentioned games and the types of daltonization methods they support. The tick marks that the game utilizes a certain type of daltonization, while the x marks that the game is not using a certain type of daltonization.

Table 1: Daltonization methods supported by games

	Accessibility options	Partial daltonization	Full daltonization	Customizable daltonization	Content-independent daltonization	Content-dependent daltonization
Rust	x	x	x	x	x	x
Valorant	✓	✓	x	✓	✓	x
League of Legends	✓	✓	x	x	✓	x
Overwatch	✓	x	✓	✓	✓	x

The game *Rust* utilizes text and symbols to portray some crucial information. For example, to distinguish the difference between allies and enemies, the game uses a circle above the head of the allies. When it comes to understanding the health, hydration and nutrition bar one does not need to differentiate between colours, but look at the icons. Likewise, when placing an object on the ground, the colour of the object's shadow is a secondary information carrier due to the short textual description underneath the shadow. The game fails regarding cards used to access the restricted access rooms because the colour choice aligns with the colours that people with colour vision deficiency cannot distinguish properly (green, blue, and red). Figure 1 shows an example of the cards as seen by a person with regular vision (up) and a simulation of the vision of a person with deuteranopia (down).

Figure 1: An example of the cards as seen by a person with regular vision (up) and a simulation of vision of a person with deuteranopia (down) (Rust Wiki, 2019).

In both games, *Valorant* and *League of Legends,* only certain aspects of the game are changed when the colour-blind mode is turned on. In *Valorant* the key information that uses colour as an information carrier is the difference between the teams. By default, the outline around the enemy team characters is red, which for certain types of colour blindness, can become hard to see and distinguish against the background. The accessibility settings in *Valorant* allow players to choose between three different settings. Selecting the setting for protanopia or deuteranopia will change the outline from the default red to yellow,s and in case the tritanopia setting is selected, the outline's colour will change from red to purple. Looking at the simulation of colour-deficient vision (Figure 2), the settings make a big difference for players, making enemy characters easier to distinguish from the allies. They were, furthermore, improving the clarity of the game due to the outline preventing the character from blending into the game's background.

Figure 2: 1st up and down – Regular vision without filter, 2nd up – Regular vision with tritanopia adjustment, 2nd down – Tritanopia simulation with tritanopia adjustment, 3rd up – Regular vision with deuteranopia adjustment, 3rd down – Deuteranopia simulation with deuteranopia adjustment, 4th up – Regular vision with protanopia adjustment, 4th down – Protanopia simulation with protanopia adjustment (Riot Games, 2022).

Contrary to *Valorant*, *League of Legends* does not have multiple options regarding colour-blind mods. Again, the crucial information that helps the player separate between their own character, teammates, and allies is being communicated via colour. When the colour-blind filter is applied, the player's health bar changes colour from green to yellow, as well as some minor user interface (UI) changes, the most helpful change being the introduction of outlines around certain abilities. The interesting thing to point out is that the colour-blind mode in *League of Legends* is used by both people with colour vision deficiency and without. The biggest issue with this setting is that it was made only for red-green colour blindness deuteranopia. Considering that the *League of Legends* has one of the biggest player bases in the realm of online multiplayer games (150 million active players (activeplayer, 2022)), having non-customizable accessibility settings is underwhelming.

Unlike *Valorant* and *League of Legends*, *Overwatch* is the only game on the list that has implemented the full daltonization. Additionally, Overwatch offers the most detailed list of settings for colour-blind mode, including different filters for different colour vision deficiencies, a slider that adjusts the intensity of the filter and the ability for players to craft a custom colour palette as shown in Figure 3. One major flaw of full daltonization is that in some situations, the characters blend in with the background due to the number of colours being used after remapping being smaller and the daltonization is not dynamic, it is a content-independent daltonization.

Figure 3. Overwatch colour vision deficiency settings (Blizzard Entertainment, 2021).

3.2 Proto-patterns

Molina-Lopez and Medina-Medina (2019) have suggested twelve design proto-patterns (Table 2) for colour blindness. They have addressed the problem when the interaction between the game and the player is dependent on colour (Molina-López & Medina-Medina, 2019). This section aims to check if the selected games fulfil the twelve proto-pattern requirements. The proto-patterns are laid out in Table 2, together with the games, to check if the games include the 12 proto-patterns. The tick marks that the game utilizes a certain proto-pattern, while the x marks that the game is not using a certain proto-pattern.

Table 2: Checking if the games include the 12 proto-patterns

	Rust	Valorant	League of Legends	Overwatch
Set alternative colours	x	✓	x	✓
Associate label/shape with character	✓	x	x	x
Associate icons to the points on a map	✓	✓	✓	✓
Set the cursor	x	✓	✓	✓
Set text font	x	x	x	x
Set interline space	x	x	x	x
On/Off of the text-shadow effect	x	x	x	x
On/Off of the text-gradient effect	x	x	x	x
On/Off of the background animation	x	x	✓	x
On/Off of the cursor animation	x	✓	x	✓
Associate label/shape with the interactive element	✓	✓	✓	✓
Associate auditory description with the interactive element	x	✓	✓	✓

4. DISCUSSION AND SUGGESTIONS FOR IMPROVEMENT

Selected games fall under the category of being playable to an extent for people with colour vision deficiency. The developers' and designers' aim should be an overall improvement of user experience and ensuring that all players can adequately and in time respond to the cues that the games present to their player base.

Rust is the only game on the list with no accessibility options in its settings. This game is also the only game that does not use colour to differentiate between team members and enemies; instead, it uses a shape. Moreover, *Rust* uses text to describe certain states of object placement within the game. On the other hand, when it comes to using certain items in the game, Rust falls short regarding the colour palette for the access cards. Finally, in regards to the suggested proto-patterns observation, the game is lacking in aspects of customisation. It is the only game in which there is no sound effect when hovering over the list of options, making it more difficult for people with colour vision deficiency to identify interactive elements when they are not appropriately highlighted (Molina-López & Medina-Medina, 2019).

Out of the two analysed games with partial daltonization, *Valorant* is more user-oriented compared to the *League of Legends*. By allowing players to select preferred colours for the outline of the enemies, *Valorant* ensures that all players can react adequately and in time. Furthermore, while both Valorant and *League of Legends* give their players the option to change the way their cursor looks, *Valorant* is not limiting its players to in-game settings. Instead, it allows them to create and import fully customized cursors.

Looking at the table *Overwatch* scores the same way as *Valorant*, but upon inspecting the games, *Overwatch* offers a higher level of customisation. Unlike *Valorant*, *Overwatch* allows its players to select key colours from various colours, not just purple and yellow. Furthermore, *Overwatch* has text to speech option and subtitles option that aid people with colour vision deficiency when the game's UI/in-game chat or certain happenings lack clarity.

All of the games in question lack settings regarding text customization. Some games allow their users to change the size and animations of the HUD (heads-up display), but that is where it generally stops. It is clear that all of the games could use improvement regarding the text.

4.1 Suggestions for improvement

One noted problem with the game *Rust* was the colours on the access cards for restricted rooms. A simple solution, other than changing the colour palette itself, is to add text that describes the colour on the card. The disadvantage of this approach is that if the player does not speak English, the text may lose its utility value, in case it is not translated into each of the languages into which the game is translated. This problem can be avoided by using both the shape and the colour labels (Figure 4).

Figure 4: Up – Cards with added text to aid with colour recognition. Down – Cards with added symbols (circle, quadrilateral and hexagon) with the starting letters of each colour name, to avoid the language barrier (Rust Wiki, 2019).

Players of the video game *Valorant* even with character outlines and background details can still find themselves in a situation where character differentiation from the game background can be problematic, especially if they play the video game with lower graphic settings. Therefore, the background details are not displayed. A straightforward solution to this problem could be to add an option to add simple two-dimensional patterns to the background, as shown in Figure 5, to help differentiate a plain wall from a character.

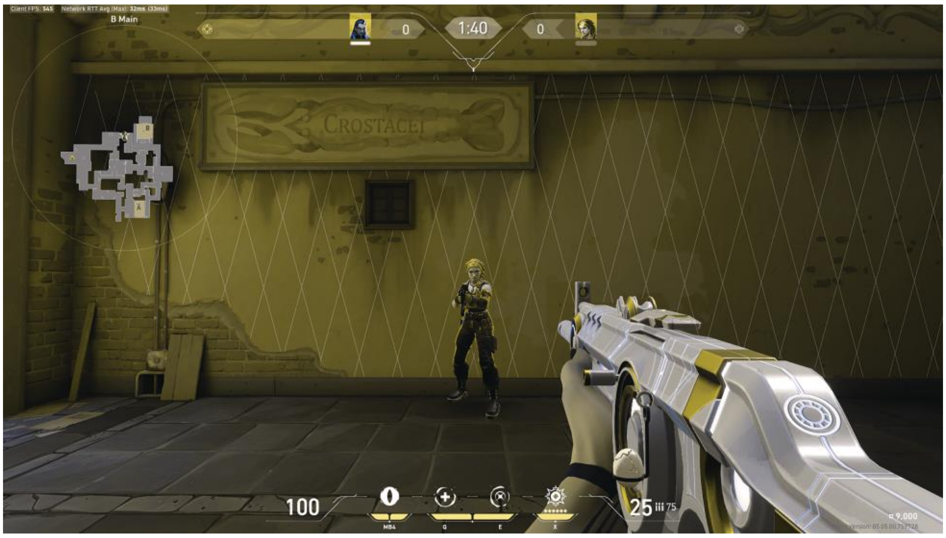

Figure 5: A simple two-dimensional pattern on the walls aids with the differentiation between the character and the wall (Riot Games, 2022).

In *League of Legends*, the first thing that would improve the experience of colour vision impaired players is to add a setting for all colour vision impairments, not just deuteranopia. Another solution could be to add noticeable outlines around all abilities. To simplify the daltonization process, instead of changing the colours of the player's and teammates' health bars, a circle or line could be added above or below the character's health bar. There is also the possibility of difficulty distinguishing characters from the background for people with colour vision deficiency. The solution to this problem can be inspired by the solution for the video game *Valorant*, which is to add clear outlines around the enemy characters, shown in Figure 6.

Figure 6: The simulated vision of a person with protanopia with added outlines to aid with the differentiation between the characters and the background (Riot Games, 2021).

Regarding the video game *Overwatch*, the benefit of full daltonization can be questioned if the game utilises outlines around characters for both teams and allows players to choose the colour of the outlines themselves. In this game, a character blending with the background can be noticed using the colourblind filter, as the colours do not change with the context of the background, an example of this can be seen in Figure 7.

Figure 7: An enemy character is possibly difficult to notice for a person with deuteranopia while having a deuteranopia filter applied (Blizzard Entertainment, 2021).

One possible solution to this problem can be found in content-dependent daltonization. Still, it requires a lot of computing power, so there is a possibility that the computers of players who need this type of daltonization would not even be able to play the video game. Another possible solution is brighter outlines around the enemy characters to make it easier to see if they are further away from the player shown in Figure 8.

Figure 8: Adding a brighter outline for enemy characters may aid players with colour vision deficiency (Blizzard Entertainment, 2021).

It is worth noting that some players with colour vision disorders do not like full daltonization. One Reddit user expressed their feelings regarding a game adding daltonization tools: "*I hope they do it well and not just recolour the whole game. I hate it when games do that for colourblind mode, I really like it when they just change UI and the likes so I can tell the difference between enemies and friendlies. When the whole game gets recoloured it's like it's trying to force a perspective I've never seen and I feel like I'm being punished for being colourblind*" (Cregavitch, 2016). It's crucial that when adding accessibility options to games, the community and experts in the field work together to come up with the most optimal solutions.

5. CONCLUSIONS

In video games and the physical world, paying attention to a few details such as the choice of colours and simple solutions can make the game truly universal for players with colour vision deficiencies. The goal should be that players do not depend on filters, whether they are already included in the video game settings or on third-party software, and especially without the need to invest in physical aids, just to be able to experience this interactive medium.

The conclusion of the presented overview and discussions is that the colour, although an essential part of video game design, should not be the main carrier of information. Instead, research conclusions show that colour can and should be secondary. Using shapes, outlines and sometimes text, the information remains clear and reduces the room for mistakes due to colour vision impairments.

Future research should examine how much the proposed solutions help people and find optimal solutions in consultation with people with colour vision deficiency. Another possible future research direction should be to investigate the possibility of implementing effective content-dependent daltonization in video games so that personal computers can support them.

6. ACKNOWLEDGMENTS

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DEFINING COST-EFFECTIVE WORKFLOW FOR A PHOTOREALISTIC 3D CHARACTER BASED ON A REAL PERSON USING A METAHUMAN FRAMEWORK

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Abstract: *The average estimated time for creating a realistic human-like 3D game character using traditional workflow is approximately one hundred hours. Creating corresponding facial animations for the persuasive narrative of 3D characters is even more time-consuming. The manuscript explores the possibilities of creating a personalized digital character according to an actual person within the newly-developed technology. The goal of the work involves defining guidelines for the workflow of generating a personalized three-dimensional character based on a real person in the MetaHuman framework. The given detailed insight into the state-of-the-art methodology for creating game characters ensures understanding and reproducibility within a timeframe that is ten times shorter compared to the standard 3D character design workflow.*

Key words: character design, game engine, MetaHuman, Unreal, photogrammetry, 3D modeling

1. INTRODUCTION

Iconic characters are much more than just drawings. In visual art, character design is the complete creation of a character's aesthetics, personality, behaviour, and overall visual representation. He is the bearer of the story, and every aspect of the character, like shape, colour, and detail, is chosen for a reason. Personality traits often suggest a character’s appearance, although the reverse is true. Character design aims to create visually attractive, recognizable characters that will easily connect with people. Characters are undoubtedly one of the most important assets of a game, affecting the entire game experience.

The evolutionary course of the appearance of the character can be observed from two aspects - the visual depiction conditioned by the hardware-software display capabilities of the device and the development of trends in character design itself.

In the early days of gaming, what were called game characters were just a few pixels on the screen. With the improvement of the hardware, these characters got more details, whether related to visual representation, animations, or voices. Over time, hardware development has come a long way, allowing display fidelity to unimagined limits. On the other hand, the evolution of character design takes place more slowly, adapting, among other things, to modern social conventions (Iwaniuk, 2017).

The main phases in the traditional workflow of creating a digital 3D character are:

- Profiling - The character must be presented to the player so that he understands the needs and ambitions behind a particular behaviour of the character (Lankoski, 2002). For each character, it is necessary to determine the point of view and attitude since they prompt action and suggest the nature of the character. Similarly, weaknesses or flaws are useful guides for players toward appropriate behaviour. Also, imperfections or customizations make a character more interesting.
- Concept art - The artist explores various sources, finds inspiration and sketches ideas taking into account the profile defined in the previous step. Artists must research references and compare their designs to others to avoid too much resemblance to existing characters. The design must be unique and recognizable. After the moodboard, artists create their brief, where they try out various shapes and figures that they come up with in the form of short drawings and sketches, which help them decide on the best option according to their needs and requirements (Kuntjara & Almanfaluthi, 2017).
- 3D modeling - The evolution of 3D technology has transformed the gaming industry, enabling the creation of unique and realistic content. The 3D modeling phase can generally be divided into

blocking, sculpting, creating an adequate topology - retopology, unwrapping (and baking), and applying textures (Rajpurohit, 2022).

- Rigging and skinning - To make animation more accessible, a system of auxiliary elements is set up, the management of which is reduced to deformations and basic controls of translation, rotation, and scaling. Setting up such a system is called rigging. The elements with which the polygon mesh can be easily and realistically moved are descriptively called the skeleton. Although there are several types of rigging, the one with the skeleton and joints for rigging the whole body is most often used. Apart from it, face rigging is also often used. By rigging, therefore, a skeleton is created for the desired 3D model, which behaves in accordance with predefined principles. Connections between certain parts of the skeleton are defined by the hierarchy and based on it, it can be determined which elements of the skeleton will affect the movement of others in the hierarchy. In order for the skeleton to be able to drive the model, it must eventually be connected to it by defining connections between the skeleton and points on the model, in a process called skinning (Rajpurohit, 2022).
- Animating - Animations of the character's body movements and facial expressions must reflect his personality traits (Rajpurohit, 2022). Movements must look natural and believable to ensure an adequate experience. The created skeleton can greatly facilitate the animation process. The position of each bone (as a part of the skeleton) is defined by animation variable (abbreviated AVARS).

2. A PERSONALIZED 3D CHARACTER CREATION WORKFLOW

The topic of the research is the creation of a digital three-dimensional realistic personalized character modeled on a real person using the Metahuman working framework, as well as the implementation of such a character in Unreal game projects. The MetaHuman uses the information of the 3D network of the cephalic region, mapping the characteristic facial features of a real person, on the basis of which the initial head model is generated as the closest approximation of the input parameters (Unreal Engine, 2022).

The stages of creating a character using a suggested methodology can be divided into five steps:

1. Generating a digital 3D model by photogrammetry,
2. Correcting the topology of the model,
3. Importing the model into Unreal Engine 5 and applying the MetaHuman plugin,
4. Completing the MetaHuman model in the MetaHuman Creator application,
5. Implementing the character in the Unreal Engine 5 project.

2.1 Generating a digital 3D model by photogrammetry

Taking into account objective factors when making a decision, such as simplicity, speed, and practicality of production, reversible engineering will be used for the given task, i.e., creating a model based on an already existing physical object using a method called photogrammetry, with the help of an android mobile device and a free version of the application Polycam.

After photographing the desired subject at least 20 times from different angles, the user is given an overview of the series of shots with the possibility of removing or adding photos to the series. From the additional options, the user can choose the desired level of detail (optimized/medium/full/raw) depending on the needs and later application of the model, as well as object masking to help separate the subject from the background. After settings, the photos can be uploaded and processed, obtaining a finished polygon network ready for export (Figure 1).

Figure 1: Polycam model

2.2 Correcting the topology of the model

The models created in the previous step under the described conditions cannot be directly imported into the Unreal Engine. When reproducing the topology in the previous step, specific errors may occur, such as gaps, i.e., missing polygons; degenerate polygons; overlapping polygons; incorrectly oriented normals; the appearance of a non-manifold topology. Although the MetaHuman plugin can tolerate these errors to a certain extent, specific overlapping errors and non-manifold topology should be removed before importing into Unreal Engine.

In addition, when processing the captured photos, the algorithm takes into account a more extensive area compared to the region of interest. In other words, the initial model contains unnecessary parts that can cause problems in further steps, which is why it is advisable to "purify" the model, leaving primarily the region that will be analysed when creating the MetaHuman model. And finally, using the MetaHuman plugin requires importing files exclusively in FBX or OBJ format. Therefore, before importing the model into Unreal Engine, it should be prepared for further steps in some of the suitable software tools, such as Autodesk Maya, 3ds Max, Meshlab, Blender, etc (Figure 2).

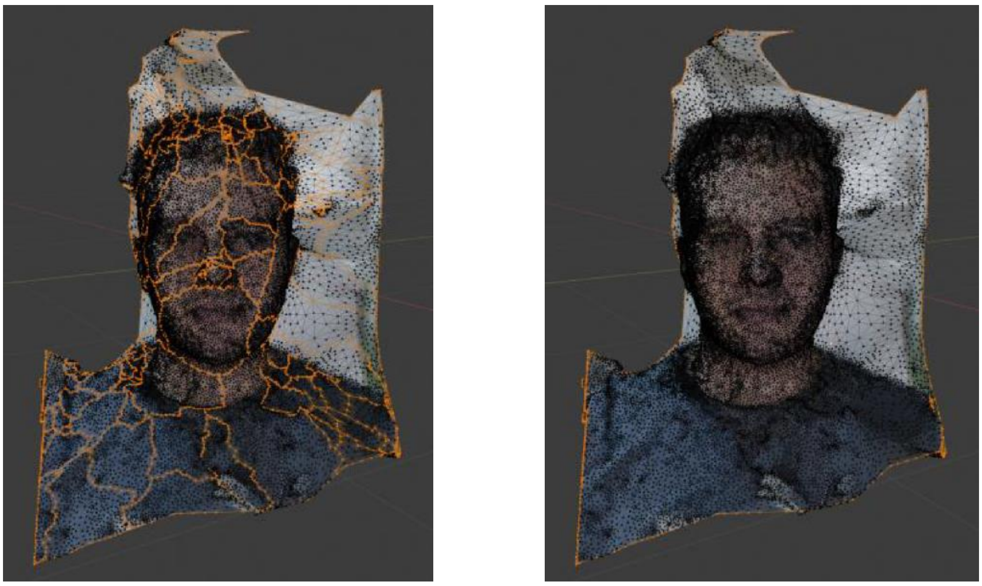

Figure 2: A 3D model in Blender software before and after correcting non-manifold topology

2.3 Importing the model into Unreal Engine 5 and using the MetaHuman plugin

Having a ready, geometrically and topologically appropriate model, the following tools will be used in the next step:

- MetaHuman Creator (MHC) - MHC is a free, cloud-based tool that allows you to easily and quickly create fully rigged, photorealistic digital models of people in a browser window.
- Unreal Engine 5 (UE5) – UE5 installation can be found on the official website provided by Epic Games company. The most critical novelty UE5 compared to the previous UE version is the Mesh to MetaHuman functionality. This plugin allows you to create a fully rigged, ready-to-animate MetaHuman character based on the chosen model (mesh). The starting point is, therefore, a mesh of polygons, i.e., a 3D model of the head with texture data generated in the process of 3D scanning, sculpting, or traditional modeling. The Mesh to MetaHuman function uses automatic landmark tracking on the model to apply a MetaHuman topology template to it, meshing the resulting head with one of the existing predefined models for the rest of the body. This template is then sent to the cloud, where it will be matched with the closest MetaHuman model from the database. After that, the rigged MetaHuman is downloaded or opened by the MHC application and refined and corrected. Certain elements, such as hair and face texture, must be applied subsequently in MHC or another application, which is why it is not necessary to pay too much attention to these regions when forming the input model of the desired person (Unreal Engine, 2022).
- Quixel Bridge - This is an application that will fulfil the task of exporting and downloading MetaHuman models. It acts as a link between UE5 and MHC tools but also offers a library of ready-made models that can be used in projects. After importing the model and enabling the MetaHuman plugin to work, it is necessary to create a MetaHuman Identity asset from the MetaHuman submenu, which can be opened in a new window by double-clicking. The main toolbar suggests the order of the operations. Using the Components from Mesh option, the MetaHuman model will be generated based on the chosen, previously imported polygon mesh. The following step is the selection of representative frames in a neutral pose, which is analysed while processing the final model's topology (Figure 3). It is possible to track and analyse other frames besides the neutral pose by selecting them with a Promote Frame option. After promoting at least one frame and activating markers as representatives of the analysis (Promote Frame and Track Active Frame options), the MetaHuman Identity Solve option becomes available. By selecting it, the points of the template model will be adjusted to the volume of the neutral pose mesh that was analysed in the previous step. The resulting model can be viewed in the viewport window and compared with the initial polygon mesh. Finally, after selecting the Body component and the desired body, the created template mesh can be forwarded to the MetaHuman backend by pressing the Mesh to MetaHuman button (Figure 4). The final MetaHuman model can now be accessed with the help of the Quixel Bridge application for download and the MHC application for additional corrections and finishing of the model

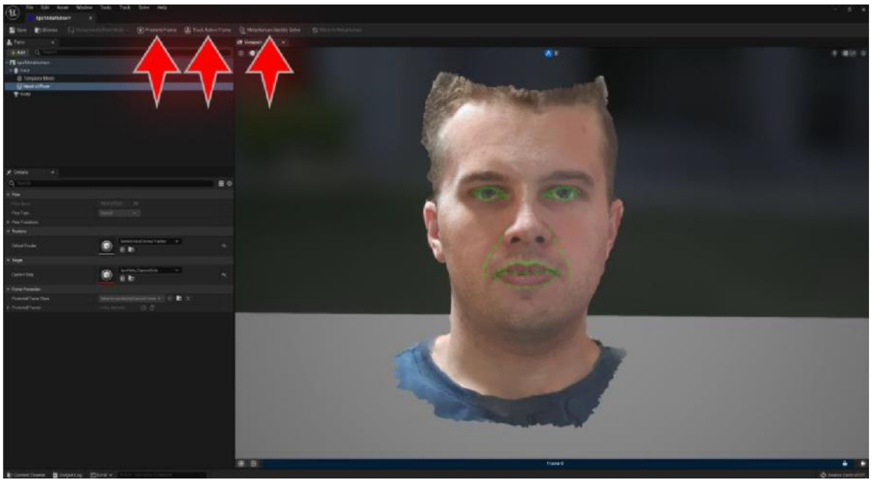

Figure 3: Promote Frame, Track Active Frame and MetaHuman Identity Solve options

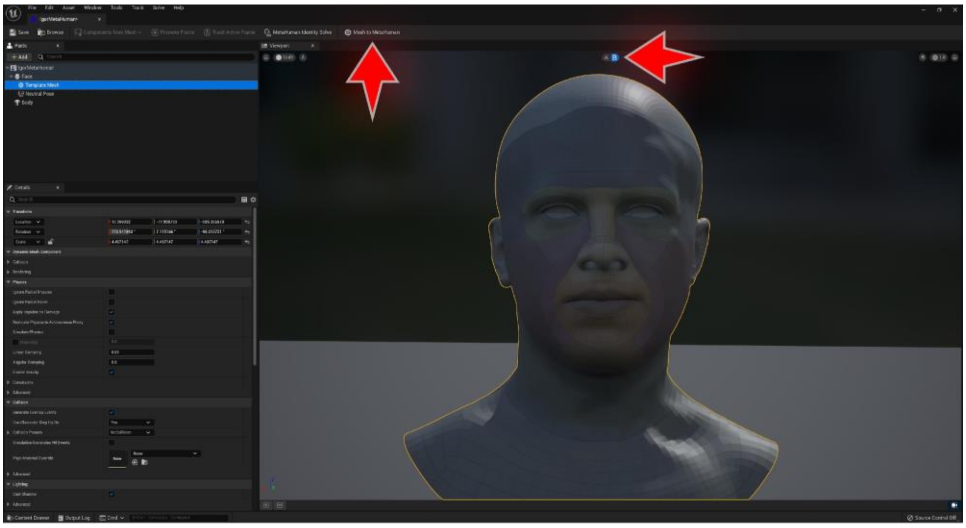

Figure 4: Overview of the final model and exporting to MetaHuman backend (Mesh to Metahuman option)

2.4 Completing the MetaHuman model in the MetaHuman Creator application

The user interface of the MHC application is self-explanatory and intuitive to use so that every user with a short familiarization and getting used to it can effectively use all the current possibilities: correcting the model topology, applying the skin texture, selecting the characteristics of parts of the face (eyes, teeth, applying makeup) and hairy regions of the head (hair, eyebrows, eyelashes, moustache, beard). Personalizing the rest of the body in the app is limited to selecting some predefined body proportions, clothing, and footwear.

For MetaHuman models created using the Mesh to MetaHuman plugin, there is an additional tab with options called Custom Mesh (Figure 5). As stated earlier, Mesh to MetaHuman works by finding a pre-defined MetaHuman model that is the most similar result to the mesh created in the previous step. Additionally, it allows changing the mesh of the matched predefined MetaHuman model by tweaking the amount of volume influence for certain parts of the head (blending the predefined model and generated mesh). These differences from the predefined model are desirable since they make the model unique. However, in some instances, the algorithm could take undesirable parts (such as hair or an accessory) and create a topology that does not match the shape and characteristics of a real person. In this case, increasing the proportion of the predefined model's influence is appreciated if it helps to obtain a more accurate geometry.

Figure 5: Custom Mesh and markers in the MHC tool

The Sculpting Toolbar contains very useful Blend, Sculpt and Move tools. Blend has the purpose of blending, i.e., mixing the proportions of the features of the selected characters' faces. By selecting the Sculpt tool, markers appear on the face that can be used to reshape the region controlled by the particular marker. The influence of each marker is limited to a certain area, while the zones affected by the markers can overlap. Unlike Sculpt, which controls individual characteristics, the Move tool manages a group of markers at once, allowing faster, more drastic model changes. The final result of the correction of the input model is shown in Figure 6, while its comparison to the real person is demonstrated in Figure 7.

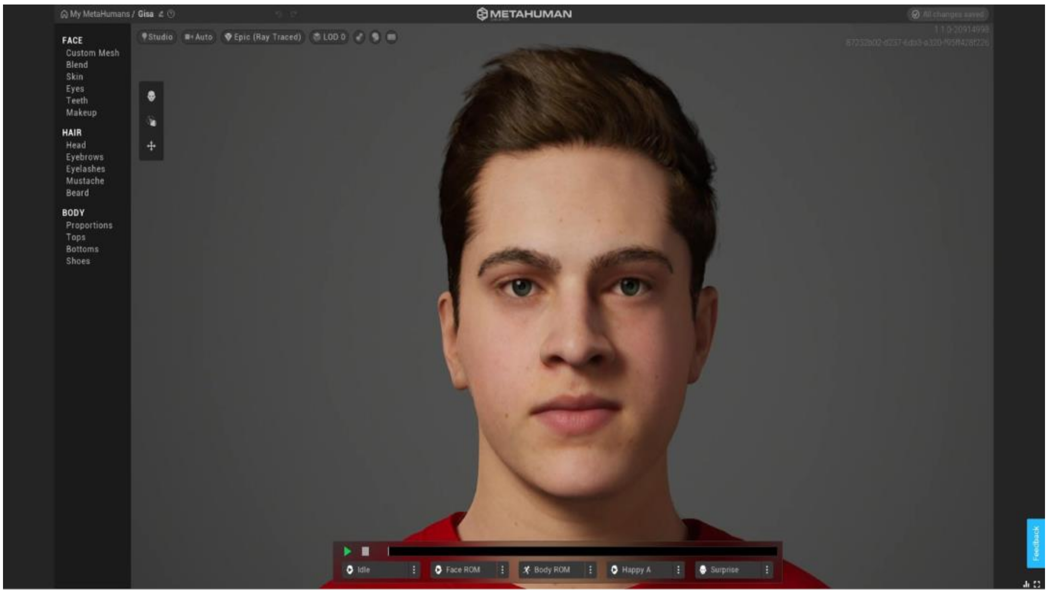

Figure 6: The final result of MetaHuman model correction

Figure 7: Comparison of the real person and the created 3D character

2.5 Implementing the character in the Unreal scene

The implementation of the MetaHuman character into the Unreal project is done through the Bridge tool by selecting it, downloading it, and then adding it to the open project. The character can be used in any imaginable way in games, movies, or presentations... To demonstrate the completed scene, the resulting character is inserted into the project with an iconic environment downloaded from the Unreal Engine resource store, as seen in Figure 8.

Figure 8: The scene with the MetaHuman character of the UE 5 project

3. CONCLUSIONS

The research dealt with creating a photorealistic three-dimensional model based on a real person in the MetaHuman framework. The complete creation of a personalized 3D game character based on a real person is conveyed in an extremely short period, with almost no need for 3D modeling skills. The application and improvement of this technology lie within the limits of the imaginable.

4. ACKNOWLEDGMENTS

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DEVELOPMENT OF AUGMENTED REALITY VIDEO APPLICATION

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Abstract: *The subject of this paper is the development and design solution of an augmented reality application for marketing purposes. The main goal of the study is to examine the functionality of Unity software and Vuforia software development kit, as well as create an application that will allow the user to play video content using augmented reality technology. The application's primary goal is to give the user more information about the Company behind the Augmented Reality target image. The development of the application was preceded by research in the field of immersive technologies and software for Augmented Reality development. The aim of this research is to set up an intuitive system in the form of a mobile application that would identify the image and play and control the video content on the mobile device screen using Augmented Reality technology.*

Key words: Augmented Reality, application design, user experience design

1. INTRODUCTION

New technology is a term generally used to describe new technology, but it can also refer to the ongoing development of existing technology. It can have slightly different meanings when used in various areas of society, such as the media, the business sector, science, environmental protection, or education. New technology allows us more real and concrete experiences with all our senses (Marshall, 2018). Extended reality is a virtual extension of our current reality. Subgroups of extended reality are (Marr, 2021):

- Augmented Reality (AR),
- Virtual Reality (VR),
- Mixed Reality (MR).

Perhaps all of these technologies can be better understood in their proper context within the "virtuality continuum," a term defined in 1994 by Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino. The continuum of virtuality is essentially the span between the real world and physical reality on the one hand and entirely virtual reality on the other (Figure 1) (Gutiérrez, Vexo & Thalmann, 2021).

Figure 1: Virtuality continuum

Augmented reality is an interactive experience of a real-world environment in which objects in the real world are augmented with computer-generated perceptual information, usually via multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory (tom Dieck & Jung, 2019).
Marker-based augmented reality was used for the development of this application. This type of AR works on the principle of tracking and recognition. In this type of AR, a marker must be used to perform the augmentation process. Tracking and recognition are features of computer vision. Recognition is nothing but the identification of any object/media, such as a barcode. Our devices have barcode scanning and recognition software, similar to human facial recognition through security systems. Tracking in AR creates

a specific pattern or image that the AR application can recognize. Once the app finds the pattern, it constantly tracks the position of the pattern in the real world so that the app can precisely place the digital object on the tracked marker. Markers are generally square and may also use a black-bordered image within the white main frame. It helps to separate the marker from the background frame. Internal marker graphics often appear distorted or pixelated. Unwrapping an image is returning a part of an image to its original position. When recognizing images, it is necessary to apply image unwrapping (Linowes, 2021). Similar research on the topic of augmented and virtual reality has been conducted by Đurđević and associates (2019), as well as Đurđević, Novaković and Zeljković (2020) in their papers (Đurđević et al., 2019; Đurđević, Novaković & Zeljković; 2020).

2. MATERIALS AND METHODS

For creating design and interaction through an application, the program Unity was used in combination with SDK (Software Development Kit) Vuforia (Wise, 2018).
The idea was to create an application that will enable the user to control video content augmented in augmented reality. Recognizing the target image will provide video content about the company compared to the basic information that can be found in real-world images. After scanning the target image, the application will load a specific video with a complete description, such as a company marketing video. Also, the user can stop, pause or play this video content using provided user interface.
To understand the application development process, we need to understand the architecture of augmented reality (Figure 2). In this architecture, the camera image is sent to the tracking module and then to the rendering module, where the real and augmented objects are combined. And the output is the enlarged image that appears on the screen. The virtual and real-world components are merged in the Rendering module. Capture Module - captures the image from the camera. Tracking Module is the core of the AR system, and it calculates the relative position of the camera in real-time. The term "position" basically means 6 degrees of freedom, i.e., the 3d location and orientation of the object. The Rendering module helps us to combine the virtual components and the real image into one image using the calculated position, and after all that, it displays the enlarged digital object on the image, projective geometry is a mathematical model for estimating the position (Doerner et al., 2022).

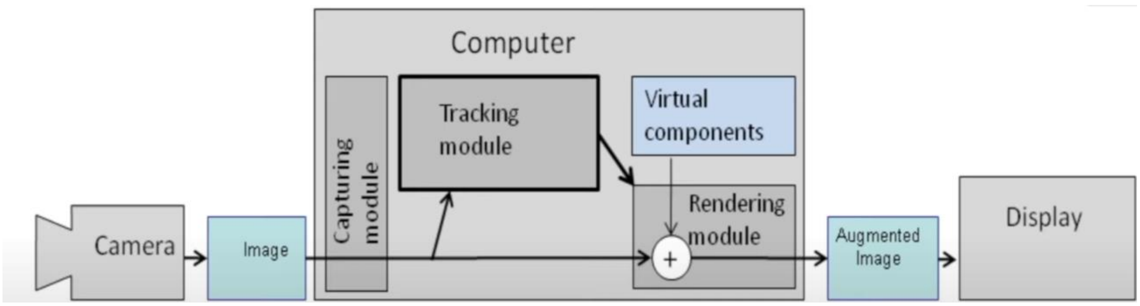

Figure 2: Augmented Reality Architecture

2.1 Vuforia

To create an Augmented Reality application, we have visited the website https://developer.vuforia.com/ and we created an Vuforia account. We Logged in and visited the Downloads section [8]. After downloading, it was necessary first to set everything essential in the web version of Vuforia. We have opened the Develop section, and there was the License Manager, Target Manager, and Credentials Manager. License Manager is for editing licenses, which are specific lines of code that help Vuforia connect to backend services and confirm which type of service we use, Basic or Premium. The basic service is free to use. Here we can get part of the code that we enter in Unity to activate Vuforia. We have started the Basic service by clicking Get Basic. The page opened where we enter the name of the license and accepted the terms of use. We clicked on the created license, where we get the license status and the code that needs to be copied. Then we went to Target Manager. Target Manager – stores markers that we will use in applications. The marker base is created as follows: By clicking on Add Database, defining the name, choosing the Device type and by clicking on Create.

Now it was necessary to click in the list on the appropriate base in which we will upload images of markers. It is essential to have quality markers because it depends on the quality of the image we upload, which will affect the performance of our AR application and the quality of recognition. We clicked on Add Target, and a window opened where we selected the type of marker, where the file is located, the width of the marker, and the name. We clicked on Add button. After the marker has been added, we have check it by clicking on the marker.
We notice the stars that represent the quality of the marker. Anything over three stars is good. Five stars mean it's great for tracking. A Four and five stars rating is recommended. Our marker had five stars. Clicking on button “Show Features” shows the points “+” that follow the marker when it moves. Our marker has great contrast so there was a lot of marker points (Figure 3).

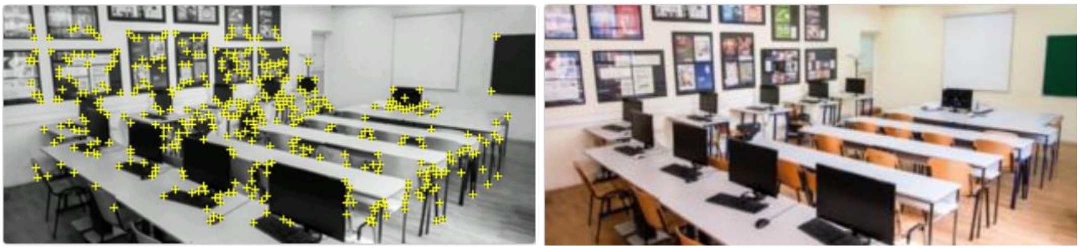

Figure 3: Marker points (left), marker image (right)

We returned to the previous window where the marker base is located, after clicking on Download Database (All), we selected Unity Editor, and clicked on Download button. After that, the file was compiled and saved, and we moved to Unity.

2.2 Unity

Initially, it was necessary to choose the platform type because the process takes much longer if we do it after creating the application. So, we go to File menu - Build Settings, selected the platform and clicked on Switch Platform. All platform options were listed. The Unity thumbnail to the right of the platform name indicates that the Windows platform was active. After switching to the Android platform, we imported the Vuforia SDK.
We opened the folder containing the SDK and dragged it into Unity Assets. The Package window appeared, and we clicked on Import. Then, on the next window, we clicked on Update. A folder has now appeared in the Assets Editor. We also imported markers into Assets. After importing, a window appeared on which we pressed the Import button. Now we have everything ready for AR application Development.
First, we deleted the Main camera (This camera is for virtual rendering, so we don't need it for AR). Then we added the AR Camera from the Vuforia Engine menu. This camera will record the real world and place digital objects into it. Next, we added the License from the site by clicking on the AR camera and, in the Inspector panel opened Vuforia Engine Configuration. Finally, we copied the key from the License Manager website in the App License Key section.
We went to the Hierarchy panel and added Image Target from the Vuforia Engine menu. The Target is white and can be changed and added in Unity, but we want to define it from the Vuforia Marker Base. By clicking on Image Target in the Inspector panel, we found Image Target Behaviour for the type we chose From Database, and we have chosen Database. Finally, we have chosen the marker. Since we only have one marker, it was selected by default. Now we added a 3D Object - Plane. We transformed it so that it covers the surface of the marker and is located in front of it (Figure 4).

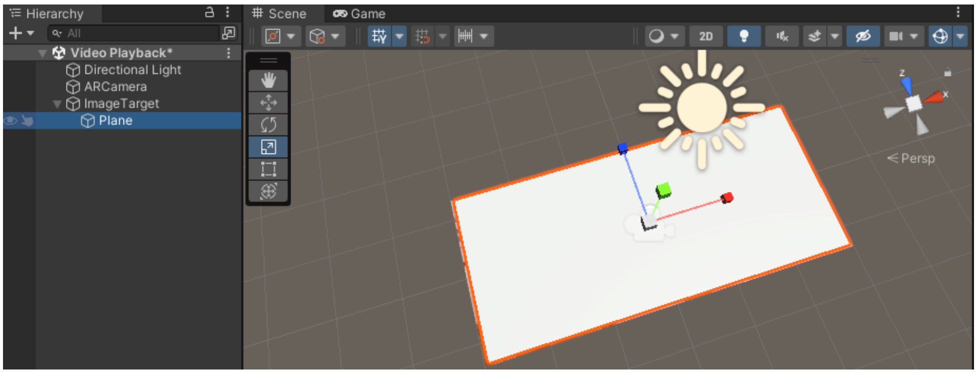

Figure 4: Plane object covering marker image

We selected Plane and added Add Component - Video Player to the inspector panel. We then added the video to Assets. Next, we dragged the video file "GRID Video" into the Video Clip field in the inspector panel while Plane was selected in the Hierarchy panel. When the video is played this way, it is always inverted, so we rotated it using the Rotate Y-axis option to a value of 180.
In the inspector panel, there is an option to Play on Awake. This option means that when the application is started, the Video will also be started. We have turned off this option. Selected the Image Target and noticed the On Target Found and On Target Lost options in the inspector. We have added the On Target Found function with the "+" button. Into the None field, we dragged the Plane representing Video and changed the name of the Plane to Video Player. We selected Video Player - Play() for the function from the drop-down menu. Now we set that when the Target is recognized, the video starts. We repeated the procedure for the On Target Lost() function, connected the Video Player object, and set the Pause() function. We tested the application and noticed that the sound was also played, which signifies that we have set everything right.
We then created similar options using UI Canvas. In the hierarchy panel, by clicking on Image Target - UI - Canvas, we made a window for the 2d interface. We clicked on the Canvas in the hierarchy panel, and then, in the inspector menu, we changed the UI Scale Mode to Scale With Screen Size (this helps the UI to be more responsive). Next, we switched to a 2D view and added UI - Button Text Mash Pro to Canvas. It was necessary to import TMP Essentials for the text to be visible and the font to be assigned. We selected the button in the hierarchy and then, in Rect Transform, clicked on the desired field and, holding Alt (Option) key, selected the position of the interface at the bottom left. We duplicated the button twice and arranged them in the same way, down the centre and downright, naming them PAUSE and STOP (Figure 5).

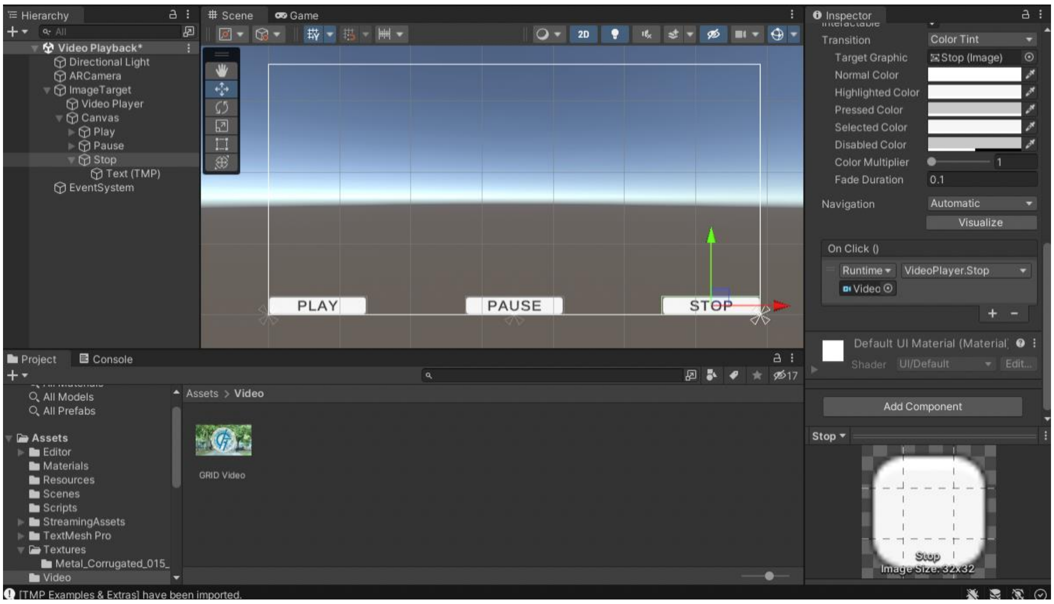

Figure 5: The user interface, play, pause and stop buttons

Then we set the functionality. We selected the Play button, and at the bottom of the inspector panel, we found the On Click() function and added it with the "+" button. Next, we dragged the Video Player object into the None field. Finally, we added the function Video Player - Play(). We repeated the procedure for Pause and Stop.
After testing our application, we were able to augment video content and control it via the created user interface (Figure 6).

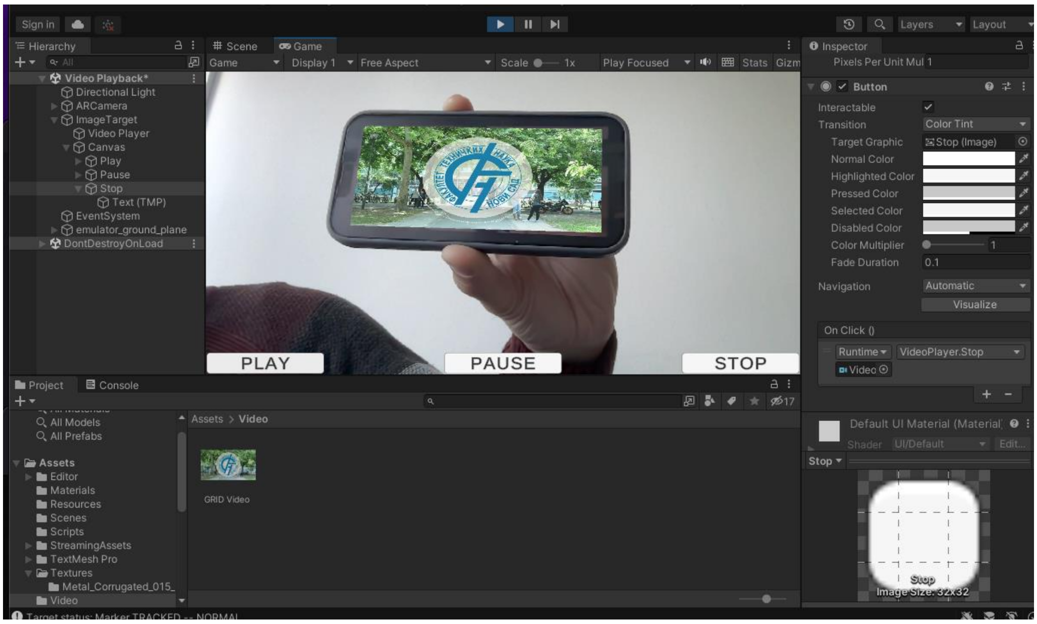

Figure 6: The final application testing

3. CONSLUSION

There is a growing need of the user for technologies that more easily and quickly lead the user to the desired and additional information. In addition to these benefits, the user becomes dissatisfied with the basic information we can find in the real world printed products and thus augmented reality becomes a platform to overcome that. In combination with the newly created application, more detailed and extensive information is offered. Unity with Vuforia SDK are becoming a revolutionary combination to create augmented reality content.

4. ACKNOWLEDGMENTS

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PRINTING QUALITY

https://doi.org/10.24867/GRID-2022-p33 Original scientific paper

EVALUATION OF THE LINE AND EDGE QUALITY OF PRINTED LETTERS ON RECYCLED PAPER WITH STRAW PULP

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Abstract: *Traditional papermaking is based on the use of an aqueous suspension consisting of cellulose fibres obtained by processing wood, non-wood plants or waste paper. With growing environmental concerns regarding deforestation and CO_2 production, the paper industry has been always looking for new sources of non-wood pulp that would produce papers of similar quality to those made from wood pulp. Cereal straw from wheat, barley or triticale crops that remains on fields as a residue after grain harvesting has proven to be a good substitute for virgin wood fibres needed in the production of recycled paper. In this study, the quality of printed text on recycled paper with added straw pulp is evaluated mainly based on the line and edge characteristics of the printed letters. For this purpose, three types of laboratory paper substrates were first prepared using recycled wood pulp with the addition of 30% wheat, barley, or triticale straw pulp. The same letter pattern was printed with black ink on each paper substrate at a standard size of 12 pt with two common typefaces: Arial and Times New Roman. The quality of the printed letters was assessed through the measured print quality parameters such as blurriness, raggedness, fill and contrast. The resulting measurements were compared with the results obtained on the reference and control samples made exclusively from recycled wood pulp as a substrate from laboratory and commercial production. In terms of fill and contrast values, the uniformity of lines printed on the recycled papers with added straw pulp is the same or very similar to the reference and control papers. Letters printed in Arial (sans-serif) typeface show slightly better reproduction quality than letters printed in Times New Roman (serif) typeface. The measured parameters blurriness and raggedness of all laboratory-made paper substrates (with and without straw pulp) had similar values between 0.17 mm and 0.20 mm, resulting in a very similar reproduction quality compared to the reference paper substrate.*

Key words: digital printing, line and edge quality, paper substrate, printed letters, straw pulp

1. INTRODUCTION

The use of papers with alternative sources of cellulose pulp has been widely explored in the recent past, using non-wood, sustainable and renewable materials derived from different types of plants (El-Sayed, El-Sakhawy & El-Sakhawy, 2020). Cereal straw is particularly interesting for paper production because it has a similar cellulose content to wood, and a lower lignin content (Plazonić et al., 2021). It is, also, a cheap and renewable resource compatible with the high demand for paper as packaging and printing medium. Extensive research has been conducted on residual straw of wheat, barley and triticale collected after the crop harvest, and it has shown that cereal straw is a valuable raw material for the paper industry (Plazonić, Barbarić-Mikočević & Antonović, 2016; Plazonić, Barbarić-Mikočević & Džimbeg-Malčić 2014a; Plazonić, Barbarić-Mikočević & Džimbeg-Malčić 2014b).

Papers with an addition of cereal pulp are mostly used for secondary packaging (Kurek et al, 2022) which often contain some kind of printed content: text, barcodes, logos and other types of graphics. This research focuses on evaluating the quality of ink-jet printed text patterns for two different typefaces. Ink-jet printing is one of the most commonly used printing techniques for packaging and labelling in small runs, along with offset and flexography printing. It is a non-contact printing process that does not require ink carrier nor pressure as the ink is applied directly to the printing substrate. However, ink-jet printing can be slower than other conventional printing techniques (Kiphan, 2001). It is particularly advantageous for printing smaller batches, variable data printing and personalized on-demand printing (Li et al., 2018).

For the purposes of secondary packaging, it is very important that the printing medium successfully communicates the printed information because it should, not only serve as protection for the product, but also convey messages in a clear way to ensure good legibility.

The type of substrate has a significant impact on the quality of the printed text (Možina et al., 2020) suggesting that a higher contrast between text and paper and larger text size can contribute to good legibility. Research has also shown that the optimal size for body text is between 8 pt and 12 pt (Možina, 2003). The same parameters used in assessing the quality of line reproduction, such as barcode lines (Bates, Plazonić & Koren, 2014; Korzeniowski, Praiss & Żmich, 2018; Markotić, Puceković & Bates, 2012) can be used to evaluate the quality of printed text (Valdec et al., 2021), namely: blurriness and raggedness as characteristics of line edges, and fill and contrast as parameters of reproduction quality (Tse, 2007). Research on line edge quality conducted by flexographic printing technique showed that those parameters can be applied for different printing substrates such as coated papers, polypropylene (Bates, Petric Maretić & Zjakić, 2014), or even textile prints (Elesini, Pančur & Možina, 2021). Studies on papers to which triticale straw pulp has been added conclude that the printed lines properties are of similar quality to those printed on papers produced only from recycled wood pulp (Bates et al., 2020).

2. MATERIALS AND METHODS

The first step in this research was the formation of the paper samples that served as printing substrates for the assessment of print quality. Phases included here were as follows:

- preparation of recycled newsprint and collected straw for cellulose pulp suspension
- production of laboratory paper substrates from the obtained pulp.

The collected straw from three cereals was manually cut and converted into a semi-chemical pulp according to the soda method in an autoclave at temperature of 120 °C, 10:1 liquid to biomass ratio and an alkali level of 16% for a period of 60 minutes (Plazonić, Bates & Barbarić-Mikočević, 2016). Cereal pulps were added to the recycled newsprint pulp (N) at a weight ratio of 7:3 (newsprint pulp: cereal straw pulp). Recycled newsprint pulp was obtained from the commercial paper (K), which is made from recycled wood pulp used for printing daily newspapers. In the laboratory paper substrate production phase, four different types of samples were produced using the Rapid Köthen sheet former (FRANK-PTI GmbH, Birkenau, Germany) following the standard ISO 5269-2:2004 for production of laboratory sheets. Table 1. lists the marks and abbreviations for the paper substrate samples produced.

Table 1: Composition and abbreviations of commercial and laboratory paper substrates

Abbreviation	Composition	Method of production
K	100% recycled wood pulp paper	commercially produced
N	100% recycled newsprint pulp	laboratory produced
3NW	70% recycled newsprint pulp and 30% wheat pulp	laboratory produced
3NB	70% recycled newsprint pulp and 30% barley pulp	laboratory produced
3NTR	70% recycled newsprint pulp and 30% triticale pulp	laboratory produced

The paper substrate from 100% recycled newsprint pulp (N) was laboratory produced as a reference sample, while commercially produced paper (K) was used as control sample to compare the quality of prints on laboratory and commercially produced papers.

After producing the laboratory paper substrates, the next phase included digital printing of the letter pattern. The pattern consisted of one uppercase and one lowercase letter “A” in the standard size of 12 pt in two common typefaces – Arial and Times New Roman. It was printed over the paper substrates in black ink using the digital printing technique. Printing was carried out by AGFA, Anapurna M1600 (Agfa Graphics NV, Düsseldorf, Germany), piezoelectric drop-on-demand ink-jet printer using UV curable ink.

Print quality analysis was based on measurements of fill, contrast, blurriness, and raggedness of the line edges according to the standard ISO 13660 using a PIAS-II (Personal Image Analysis System) digital microscope and its associated software. These properties are calculated using reflectance measurements of the printed sample (R_{min}) and the reflectance of the paper as a background (R_{max}). Since the printed line edges are never perfectly sharp compared to the ideal lines created in software, the standard uses a dynamic thresholding to determine the locations where the lines end. Dynamic thresholding method calculates line edges from the paper reflectance (R_{max}) and the line reflectance (R_{min}) (ISO 13660, 2001). Briggs (1999), Dhopade (2009) and Pedersen (2012) apply and evaluate the image quality according to the parameters described in ISO 13660 and give guidelines for their interpretation.

Fill is defined as the apparent uniformity of darkness within the boundary of the line. A result of 1 indicates the greatest uniformity of darkness. Contrast is the relationship between the darkness of the printed area and its field (printing substrate, i.e. paper), and it is calculated using equation 1:

$$Contrast = (R_f - R_i)/R_f \tag{1}$$

where R_f represents the reflectance value in the paper (field), and R_i represents the reflectance of the printed area.

Blurriness and raggedness are two characteristics that define the quality of a printed line edge. Blurriness represents the transition between the printed area and the paper. An ideal line has no transition from print to paper, but due to the inhomogeneous surface of the paper and the printing process where the paper absorbs and diffuses the ink there is always some distance from the maximum and minimum reflectance. Blurriness defines the distance between 10% and 90% of the dynamic threshold.

Raggedness is a property that defines the roughness of the printed line edge. While the ideal line edge is perfectly sharp and straight, the edges of the printed line usually show some deviation from the perfect line, due to ink spillage and diffusion, resulting in edge roughness. Hence, to measure raggedness, a fitted line is positioned at the dynamic threshold of 60% and the standard deviation of the residuals from this fitted line is a measure of raggedness.

Table 2 (part 1): 3D surface plot diagrams of printed letters on commercial and laboratory paper substrates

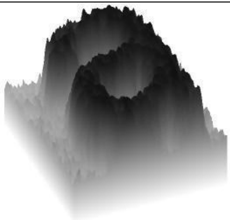
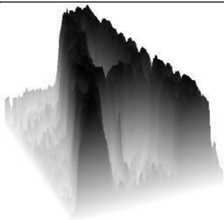
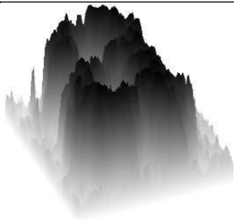
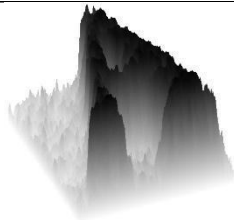
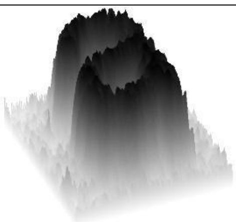
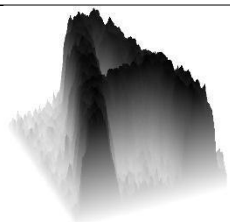
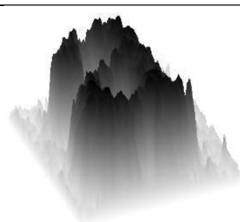
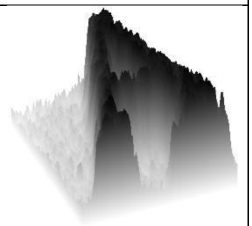
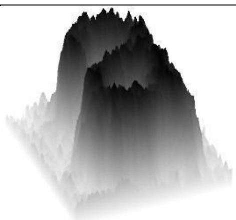
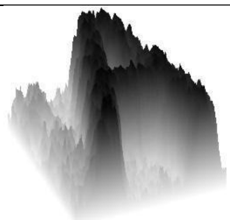
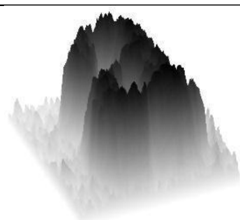
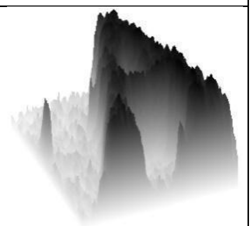
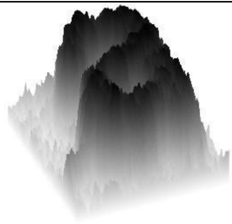
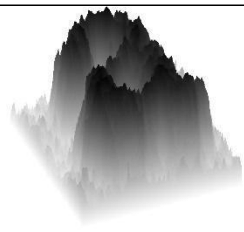
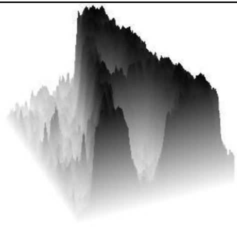
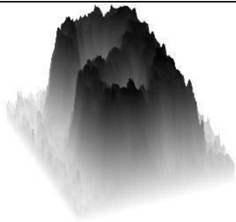
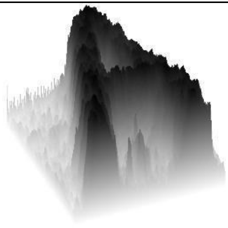
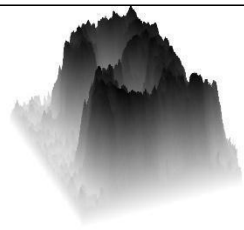
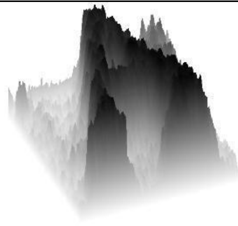
Paper substrate	Arial		Times New Roman	
	lowercase	uppercase	lowercase	uppercase
K				
N				
3NW				

Table 2 (part 2): 3D surface plot diagrams of printed letters on commercial and laboratory paper substrates

3NB				
3NTR				

The quality and homogeneity of the printed letters was first determined by a visual examination of the letter samples. Using ImageJ software, images of the printed letters, obtained by PIAS II microscope, were converted into 3D surface plots where the highest peaks determine the darkest coloration. Table 2 shows that the printed surface of the letters is relatively non-uniform but the significant difference between commercially and laboratory produced papers was not observed. Comparing only the laboratory produced papers with the addition of 30% straw pulp (3NW, 3NB, 3NTR) and without straw pulp of any cereal type (N) also shows no significant difference. A visual examination of the two typefaces, Arial and Times New Roman, shows that letters printed in the Arial sans-serif typeface have a slightly better uniformity of print with less protrusion peaks than the serif typeface Times New Roman.
After a visual examination, the parameters of line edge and print quality: fill, contrast, blurriness, and raggedness, were measured by the PIAS II device on ten sample areas of printed letter samples.

3. RESULTS AND DISCUSSION

Uniformity of the prints was further examined by analysing the fill and contrast parameters. Values in Table 3 show slightly greater or equal results for the fill parameter of Arial typeface for all printing substrates. The largest difference was measured in control (commercially produced) paper substrate K with 0.97 for Arial, and 0.94 for Times New Roman. Laboratory produced paper substrates had smaller or no difference between fill parameter for Arial and Times New Roman typefaces, regardless of the type of straw pulp added to the recycled newsprint pulp. The paper substrate with the addition of 30% barley pulp showed no difference in the fill parameter (0.96) for the two analysed typefaces. The parameter of contrast between the printed letter and the surrounding background field i.e., printing substrate, also showed largest values for the Arial typeface on all printing substrates. Similar to the fill parameter, the largest difference of contrast value was measured on commercial control paper substrate K, while the differences were somewhat smaller on laboratory produced paper substrates.

Table 3 (part 1): Average measured values and standard deviations of fill and contrast parameters on all printing substates for Arial and Times New Roman typefaces

Printing substrate / typeface			Fill	Contrast
K	Arial	avg	0.97	0.95
		stdev	0.08	0.05
	Times New Roman	avg	0.94	0.91
		stdev	0.09	0.06

Table 3 (part 2): Average measured values and standard deviations of fill and contrast parameters on all printing substates for Arial and Times New Roman typefaces

N	Arial	avg	0.96	0.92
		stdev	0.09	0.06
	Times New Roman	avg	0.95	0.89
		stdev	0.09	0.06
3NW	Arial	avg	0.97	0.92
		stdev	0.06	0.04
	Times New Roman	avg	0.96	0.89
		stdev	0.08	0.05
3NB	Arial	avg	0.96	0.91
		stdev	0.07	0.04
	Times New Roman	avg	0.96	0.89
		stdev	0.09	0.06
3NTR	Arial	avg	0.97	0.90
		stdev	0.07	0.04
	Times New Roman	avg	0.95	0.88
		stdev	0.09	0.05

The parameters of blurriness and raggedness help us to determine the degree to which the ink diffused and spread during the printing process due to the paper absorbance, ink viscosity and other printing variables. A higher deviation from the ideal straight, sharp edge of the line means a reduced quality of line reproduction. As visible in the Figure 1, the measurement of the blurriness parameter shows that the letters printed on the commercial paper K had lowest measured blurriness of the line edges, which was expected due to the processing of the commercial paper that improves the smoothness. Smoother paper surface is related to smaller ink deformations. The unprocessed surface of the laboratory produced paper substrates results in a slightly higher blurriness of the letter edges. The paper substrates with added straw pulp (3NW, 3NB, 3NTR) showed no significant difference compared to the laboratory paper substrate without added straw pulp (N). When comparing the two typefaces, Arial and Times New Roman, the prints on laboratory produced papers show slightly lower blurriness on Times New Roman but without significant value, while commercial paper shows a lower blurriness on Arial.

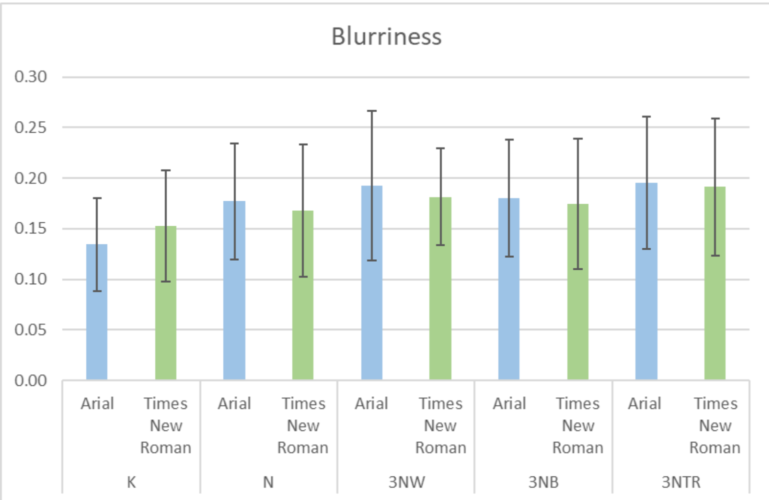


Figure 1: Comparison of blurriness values of letters printed in Arial and Times New Roman typeface on commercial and laboratory produced paper with and without straw pulp

Values measured for the raggedness parameter are presented in Figure 2. The results do not show consistency as with the measurements of blurriness parameter. Regarding the prints on commercial vs. laboratory paper substrate, the letter printed in Arial on sample K had a smaller raggedness value (0.0262) compared to Times New Roman typeface (0.0441). Value of raggedness had no correlation with the printing substrate or the means of production. The printing substrate with added triticale pulp had the lowest measured values of raggedness compared to other printing substrates including both typefaces (0.0239 for Arial and 0.0254 for Times New Roman). The highest raggedness was measured on printing substrates with barley pulp for both typefaces (0.0528 for Arial and 0.0547 for Times New Roman). The prints on the paper substrates with the addition of wheat straw pulp measured similar values as the control and reference paper substrates K and N, which were produced from recycled wood pulp only.

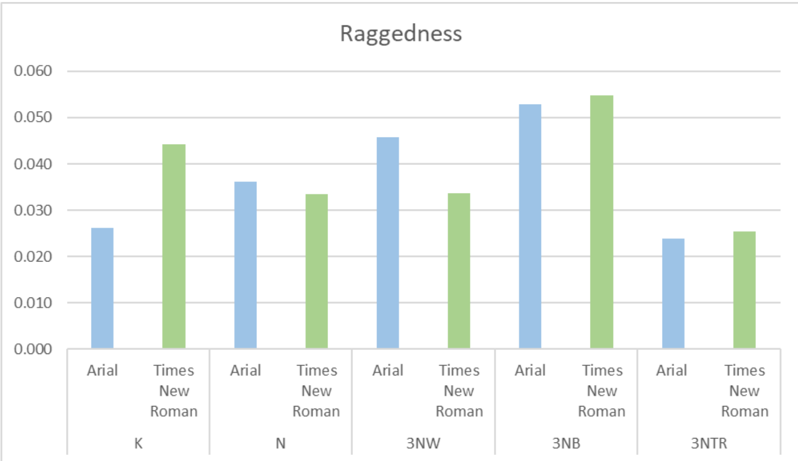


Figure 2: Comparison of raggedness values of letters printed in Arial and Times New Roman typeface on commercial and laboratory produced papers with and without straw pulp

4. CONCLUSIONS

The quality of reproduction is of great importance in conveying information from the printed text to the viewer. The packaging industry and graphic design depend on the clarity of printed text and graphics to enhance the visibility and legibility of the intended message. Therefore, choosing the right paper substrate and printing techniques is as important as choosing the right typography and size of legible text. Paper substrates with the addition of alternative cereal straw material such as wheat, barley or triticale pulp have been shown in previous research to reproduce colour prints with similar reliability as those produced only from recycled wood pulp. Research has also shown that the quality of line reproduction has similar characteristics compared to commercial papers. In this research, based on the evaluation of the printed text quality, it can be concluded that:

- commercially and laboratory produced papers with and without addition of straw pulp show similar results in edge blurriness measurements, with slightly but insignificantly higher values for papers with the addition of straw pulp.
- raggedness measurements show less consistency; the lowest values were determined for papers containing triticale pulp, and the highest values for papers with barley pulp. Papers with the addition of wheat pulp showed similar values as commercially and laboratory produced papers without added straw pulp.
- fill and contrast measurements were similar in laboratory produced papers regardless of the paper substrate composition, with values greater for the Arial sans-serif typeface than for the Times New Roman serif typeface.

Although the surface of the laboratory produced papers was not additionally processed, smoothed, or coated, the results show that the quality of the printed text is acceptable when compared to commercially produced paper without the addition of straw pulp. Suggestions for improving the quality of printed text can be made by smoothing or coating the surface of the papers, reducing the absorbance and roughness of the printing surface.

5. ACKNOWLEDGEMENTS

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OPTICAL PROPERTIES OF DIGITAL INKS ON STRAW-CONTAINING PAPERS WITH TiO_2-BASED COATING UPON AGEING

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Abstract: *Compared to papers derived from virgin fibres, recycled papers possess somewhat limited optical, strength and printing properties. Strength properties are usually increased by blending recycled fibres with virgin fibres in pulp for paper production, while optical and printing properties are often improved by coating after the paper is being manufactured. In this study, the usability of virgin fibres derived from straw as the agricultural residue of wheat, barley and triticale crops for paper production was evaluated based on the stability of prints on laboratory-made paper. For that purpose, in laboratory conditions, the papers with the addition of straw pulp in the pulp of recycled fibres were formed and prior to printing they were coated with TiO_2-based coating. Process inks, in full-tone, were applied on coated straw-containing papers by digital printing process. Optical properties of digital prints upon accelerated ageing were evaluated based on Euclidean colour difference calculated from spectrophotometric values measured on black and magenta prints before and after 48 h and 96 h of ageing. The obtained results were compared with those provided by printing substrates made only from recycled fibres with and without TiO_2-based coating. It was observed that TiO_2-based coating has no influence on the stability of black digital prints, while each layer of TiO_2-based coating reduces deviations in magenta colour upon ageing.*

Key words: straw pulp, paper, TiO_2-based coating, ageing

1. INTRODUCTION

Waste reduction is a fundamental principle of sustainability, and recycling is an integral part of any waste management plan. The recovery of paper for recycling is significantly higher than glass, metal or plastic. Recycled papers are produced from secondary, already used, old paper fibres. However, fibres in the pulp used to make paper cannot be recycled indefinitely because they become damaged during each recycling cycle. Compared to papers derived from virgin fibres, recycled papers have somewhat limited optical, strength and printing properties (Grilj et al., 2011). The increasing use of recycled fibres as a substitute for virgin fibres has resulted with papers with poorer mechanical properties (Gulsoy & Erenturk, 2017; Obradovic & Mishra, 2020) due to reduced interfiber bonding and one way to restore bonding strength of recycled pulp is to blend it with virgin fibres (Czene & Koltai, 2020). To enhance the strength properties of the paper, virgin wood fibres are added to the recycled pulp in most paper mills (Minor et al., 1993; Rowell et al., 1992; Fioritti et al., 2021). Virgin fibres are needed to keep the global fiber cycle going, as recycled fibres degrade after several uses. Although some non-wood fibres are used by the mills, such as cotton, which is the purest form of natural cellulose and sugarcane bagasse, the possibilities of using other sources of non-wood fibres are being intensively studied (Ferdous et al., 2021). On the other hand, different types of coatings can be used to achieve the desired surface properties for high-performance printing on recycled paper. Coated papers restrict the amount of ink that is absorbed into the paper, allowing the ink to sit on top of the paper, in a crisp defined dot, while uncoated papers are more porous. Double coated papers are usually graded as high-quality papers, where the first layer of the coating, a precoat, serves to fill-in the surface pores while the topcoat, which will be printed on, is of higher quality (Mangin et al., 2012). Therefore, it was not surprising that a different number of TiO_2-based white ink layers printed on a paper substrate with the inkjet technology can influence the legibility of prints, where the best print legibility was achieved at two layers of white ink (Možina et al., 2016). However, paper as a printing substrate is subjected to numerous deterioration processes from the moment it is produced, which can lead to the irreversible degradation of text or image printed on it. Paper, bindings, printing inks, dyes and pigments are particularly sensitive to the light because they absorb light energy which can initiate many possible sequences of chemical reactions that damage the paper (weakening the cellulose fibres in the paper and yellowing or darkening the paper) and cause the printed text to fade or change colour (Afsharpour et al., 2011).

In this study, we investigate the role of TiO_2-based coating applied to the surface of the straw-containing paper in the protection of colour fading of the prints against the damaging effect of ultraviolet radiation and visible light degradation.

2. METHODS

This research is divided into the following steps: conversion of straw into pulp; production of straw-containing papers; single and double layer coating of laboratory-made papers; UV inkjet printing; accelerated ageing and evaluation of the stability of prints upon ageing.

Papers for this analysis were produced under laboratory conditions where the pulp of recycled wood fibres (N) was replaced, to a certain extent, by the straw pulp from three agricultural crops (Table 1).

Table 1: Abbreviations used for marking laboratory-made papers

Abbreviation	**Pulp composition**
N	100% recycled wood pulp
1NW, 1NB, 1NTR	10% straw pulp + 90% recycled wood pulp
2NW, 2NB, 2NTR	20% straw pulp + 80% recycled wood pulp
3NW, 3NB, 3NTR	30% straw pulp + 70% recycled wood pulp
* W = wheat pulp; B = barley pulp; TR = triticale pulp	

Straw collected after harvesting wheat, barley and triticale was purified, hand-cut and converted into pulp by the soda method under conditions summarized in Table 2 (Plazonic et al., 2016).

Table 2: Pulping conditions

Crop straw	**Method**	**Pulping conditions**
wheat	Soda pulping	Temperature of 120 °C, alkali level of 16% for 60 min, and a 10:1 liquid to biomass ratio
barley		
triticale		

This obtained unbleached straw pulp was added into the pulp of recycled wood fibres in the laboratory production of paper at the Rapid Köthen sheet former (FRANK-PTI GmbH, Birkenau, Germany) according to EN ISO 526 9-2:2004 standard. The papers produced in the laboratory have a diameter of 20 cm and a weight of about 42.5 g/m^2.

Since the paper substrates (Table 1) were made with the addition of unbleached straw pulp under laboratory conditions and their surface was not pure white, they were coated with one or two layers of TiO_2-based coating before printing to improve the quality of prints. Layers of TiO_2-based white coating were applied to the entire surface of all laboratory-made papers using a digital UV LED inkjet printing machine, Roland VersaUV LEC-300, which works on the piezo inkjet principle. Data on the composition of the TiO_2-based coating used are available in our previous research (Radić Seleš et al., 2020).

Using the same printing machine (Roland VersaUV LEC-300) a test full-tone pattern was printed with black and magenta inks recommended from Roland DG Corporation (Figure 1) on all prepared uncoated and coated substrates (Table 3).

Figure 1: Test pattern of black and magenta ink printed by inkjet printing machine

Table 3: Marks used for substrates prepared for printing

Marks	**Definition**
PS7	commercial paper used as a target reference sample
N_0, $1NW_0$, $2NW_0$, $3NW_0$, $1NB_0$, $2NB_0$, $3NB_0$, $1NTR_0$, $2NTR_0$, $3NTR_0$	laboratory-made papers without coating
N_1, $1NW_1$, $2NW_1$, $3NW_1$, $1NB_1$, $2NB_1$, $3NB_1$, $1NTR_1$, $2NTR_1$, $3NTR_1$	laboratory-made papers coated in one layer
N_2, $1NW_2$, $2NW_2$, $3NW_2$, $1NB_2$, $2NB_2$, $3NB_2$, $1NTR_2$, $2NTR_2$, $3NTR_2$	laboratory-made papers coated in two layers
* W = wheat pulp; B = barley pulp; TR = triticale pulp	

To determine the magenta and black ink layer thickness on the papers with straw pulp without and with coating, the optical ink density (D_i) was determined on all prints by a densitometer eXact, X-Rite (D50/2°). The optical ink density was calculated according to equation 1.

$$D_i = \log\frac{I_0}{I} \tag{1}$$

Where: I – intensity of the light emitted by the ink film in relation to the I_0 intensity of light; I_0 – intensity of the light emitted by unprinted paper substrates.
Thus, a higher optical ink density will mean a higher ink layer or concentration of inkjet ink and higher optical contrast.
All uncoated and coated paper substrates and prints were cut into strips of 60 mm x 90 mm and placed side by side in the Suntest XLS+ test chamber, which is equipped with a daylight filter that emits UV and visible radiation in the wavelength range of 300 nm - 800 nm. The artificial ageing procedure was carried out according to ASTM D 6789-02 standard. The procedure parameters are summarized in Table 4. UV irradiation was performed in two cycles over 48 hours. Approximately one hour of treatment under a xenon lamp corresponds to one day in nature (Debeljak & Gregor-Svetec, 2010; Izdebska et al., 2013).

Table 4: Standard ASTM D 6789-02 procedure in Suntest XLS+ test chamber

Accelerated ageing procedure		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 (%)	49	
Temperature of ambient (°C)	22.3	
Total duration of process (h)	96 (2 cycles of 48 h)	

The impact of a single and double layer TiO_2-based coating on the improvement of print stability upon accelerated ageing of papers containing straw pulp was evaluated based on the Euclidean colour difference calculated according to equation 2. The colorimetric values of papers as printing substrates and prints were determined using an X-Rite SpectroEye spectrophotometer. Colour data were measured under illuminant D50, 2° standard observer. Based on those measurements, the colorimetric difference (ΔE_{00}*), that occurred after ageing, was calculated using the following equation (Luo et al., 2001), using the corresponding unaged print as a reference:

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

Where: $\Delta E_{00}{}^{*}$ – 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.

3. RESULTS AND DISCUSSION

Table 5 summarizes the ink densities of printed substrates before and after two cycles of the ageing process, where the result values represent the average of 10 measurements of the same sample with the corresponding standard deviation. It is important to emphasize that the thickness of the ink layer on the surface of the printing substrate is highly decisive in light resistance. Titanium dioxide (TiO_2) is a white powder, and coating based on TiO_2 increases the reflection of the light from the surface of coated printing substrates. A thicker layer of such a coating provides prints with higher contrast and better quality (Puhalo et al.,2013). As the thickness of the white TiO_2 film increases, the light-fastness will be higher as the number of pigments affected by the light in a particular region will increase. It is therefore important to maintain a continuous ink thickness during printing (Aydemir & Yenidoğan, 2018). From the obtained ink density values (Table 5), it is evident that each layer of TiO_2-based coating applied to the printing substrate slightly increases the ink density of black and magenta prints regardless of the type of printing substrate used. It is also noticed that the ink density of black and magenta prints on uncoated printing substrates (N_0, $1NW_0$, $2NW_0$, $3NW_0$, $1NB_0$, $2NB_0$, $3NB_0$, $1NTR_0$, $2NTR_0$, $3NTR_0$) decreases with each 48-hour ageing cycle.

Table 5: Ink density of black and magenta prints due accelerated ageing

Substrate	Black ink density			Magenta ink density		
	unaged	aged 48 h	aged 96 h	unaged	aged 48 h	aged 96 h
PS7	1.45 ± 0.01	1.41 ± 0.01	1.39 ± 0.01	1.33 ± 0.02	1.28 ± 0.01	1.26 ± 0.01
N_o	1.16 ± 0.03	1.12 ± 0.02	1.13 ± 0.03	1.00 ± 0.03	0.96 ± 0.03	0.94 ± 0.03
N_1	1.17 ± 0.06	1.30 ± 0.02	1.28 ± 0.04	1.01 ± 0.03	1.07 ± 0.03	1.06 ± 0.03
N_2	1.25 ± 0.03	1.26 ± 0.03	1.25 ± 0.02	1.05 ± 0.02	1.13 ± 0.03	1.12 ± 0.02
$1NW_o$	1.15 ± 0.03	1.11 ± 0.04	1.09 ± 0.03	0.99 ± 0.02	0.94 ± 0.03	0.93 ± 0.03
$1NW_1$	1.17 ± 0.07	1.19 ± 0.04	1.19 ± 0.04	1.03 ± 0.05	1.01 ± 0.03	1.00 ± 0.03
$1NW_2$	1.26 ± 0.04	1.20 ± 0.11	1.16 ± 0.10	1.10 ± 0.03	1.08 ± 0.03	1.08 ± 0.02
$2NW_o$	1.28 ± 0.02	1.22 ± 0.04	1.23 ± 0.02	1.10 ± 0.02	1.04 ± 0.02	1.05 ± 0.02
$2NW_1$	1.17 ± 0.05	1.16 ± 0.06	1.15 ± 0.07	1.01 ± 0.03	1.02 ± 0.03	0.99 ± 0.03
$2NW_2$	1.17 ± 0.08	1.24 ± 0.05	1.24 ± 0.04	1.03 ± 0.04	1.06 ± 0.03	1.03 ± 0.02
$3NW_o$	1.11 ± 0.04	1.14 ± 0.03	1.08 ± 0.03	0.97 ± 0.02	0.98 ± 0.03	0.93 ± 0.04
$3NW_1$	1.15 ± 0.07	1.12 ± 0.08	1.12 ± 0.08	1.03 ± 0.04	0.99 ± 0.02	0.97 ± 0.04
$3NW_2$	1.26 ± 0.02	1.21 ± 0.03	1.15 ± 0.03	1.08 ± 0.05	1.07 ± 0.03	0.95 ± 0.03
$1NB_o$	1.10 ± 0.04	1.06 ± 0.05	1.05 ± 0.05	0.97 ± 0.01	0.93 ± 0.02	0.91 ± 0.02
$1NB_1$	1.13 ± 0.04	1.12 ± 0.04	1.11 ± 0.07	0.99 ± 0.06	0.97 ± 0.04	0.96 ± 0.04
$1NB_2$	1.23 ± 0.02	1.05 ± 0.05	1.10 ± 0.07	1.04 ± 0.04	0.82 ± 0.06	0.94 ± 0.05
$2NB_o$	1.07 ± 0.03	1.06 ± 0.04	1.05 ± 0.04	0.97 ± 0.04	0.95 ± 0.02	0.92 ± 0.04
$2NB_1$	1.16 ± 0.02	1.13 ± 0.03	1.10 ± 0.03	0.99 ± 0.04	0.98 ± 0.02	0.96 ± 0.03
$2NB_2$	1.23 ± 0.03	1.20 ± 0.05	1.21 ± 0.03	1.05 ± 0.03	1.04 ± 0.02	1.03 ± 0.02
$3NB_o$	1.09 ± 0.03	1.05 ± 0.03	1.03 ± 0.02	0.94 ± 0.03	0.93 ± 0.04	0.89 ± 0.04
$3NB_1$	1.13 ± 0.02	1.13 ± 0.05	1.16 ± 0.02	0.99 ± 0.04	0.97 ± 0.03	0.97 ± 0.04
$3NB_2$	1.21 ± 0.02	1.16 ± 0.05	1.17 ± 0.07	1.07 ± 0.04	1.07 ± 0.03	1.06 ± 0.04
$1NTR_o$	1.12 ± 0.03	1.09 ± 0.03	1.08 ± 0.03	1.02 ± 0.02	0.98 ± 0.02	0.95 ± 0.02
$1NTR_1$	1.19 ± 0.03	1.14 ± 0.04	1.13 ± 0.05	1.03 ± 0.05	0.98 ± 0.03	0.99 ± 0.02
$1NTR_2$	1.29 ± 0.03	1.27 ± 0.05	1.27 ± 0.04	1.09 ± 0.02	1.05 ± 0.03	1.07 ± 0.03
$2NTR_o$	1.07 ± 0.04	1.05 ± 0.03	0.10 ± 0.03	0.95 ± 0.02	0.92 ± 0.01	0.88 ± 0.01
$2NTR_1$	1.15 ± 0.03	1.09 ± 0.05	1.09 ± 0.06	0.99 ± 0.04	0.93 ± 0.03	0.95 ± 0.03
$2NTR_2$	1.23 ± 0.02	1.21 ± 0.03	1.16 ± 0.02	1.02 ± 0.05	0.93 ± 0.08	0.88 ± 0.10
$3NTR_o$	1.21 ± 0.05	1.15 ± 0.04	1.15 ± 0.05	1.07 ± 0.03	1.03 ± 0.03	1.00 ± 0.03
$3NTR_1$	1.13 ± 0.08	1.11 ± 0.04	1.09 ± 0.07	0.97 ± 0.06	0.95 ± 0.03	0.91 ± 0.05
$3NTR_2$	1.18 ± 0.06	1.19 ± 0.05	1.20 ± 0.05	1.00 ± 0.05	0.98 ± 0.04	0.98 ± 0.03

In our previous research, we noticed that the TiO_2-based coating did not affect the colorimetric values of black prints to such an extent as it affected the colorimetric values of the magenta prints (Plazonić et al., 2022). As can be seen from Figures 2a-f TiO_2-based coating provides significantly greater protection against degrading magenta than the black colour of prints under UV light exposure. Namely, black prints are more stable to UV radiation (ΔE_{00}^* max. = 4) than magenta prints (ΔE_{00}^* max. = 9), regardless of the type of used printing substrate (reference paper PS7, uncoated or coated control paper N and uncoated and coated straw-containing papers). Also, the duration of the exposure to UV light irradiation has stronger effect on colour changes of the magenta prints, while increasing the radiation time from 48 h to 96 h has no significant effect on the degradation of black prints. Printed reference paper (PS7) showed a significant difference in magenta prints after extending the UV light exposure time in the Solarbox from 48h to 96h as evidenced by an 80% increase in ΔE_{00}^* value, while black prints did not degrade further under the same test conditions. The 36% increase in of ΔE_{00}^* value after the second 48h ageing cycle of magenta prints on the unprinted control sample N_0 (laboratory-made paper with 100% recycled fibres) was reduced by 12% with one layer of TiO_2-based coating i.e., by 20% with two layers of TiO_2-based coating. The same trend of reduction in colour deviation was observed for printing substrates containing any type of straw pulp by applying TiO_2-based coating to the paper surface. In addition, a significant effect of the coating applied in two layers on the stability of the magenta prints was observed regardless of the composition of the printing substrate.

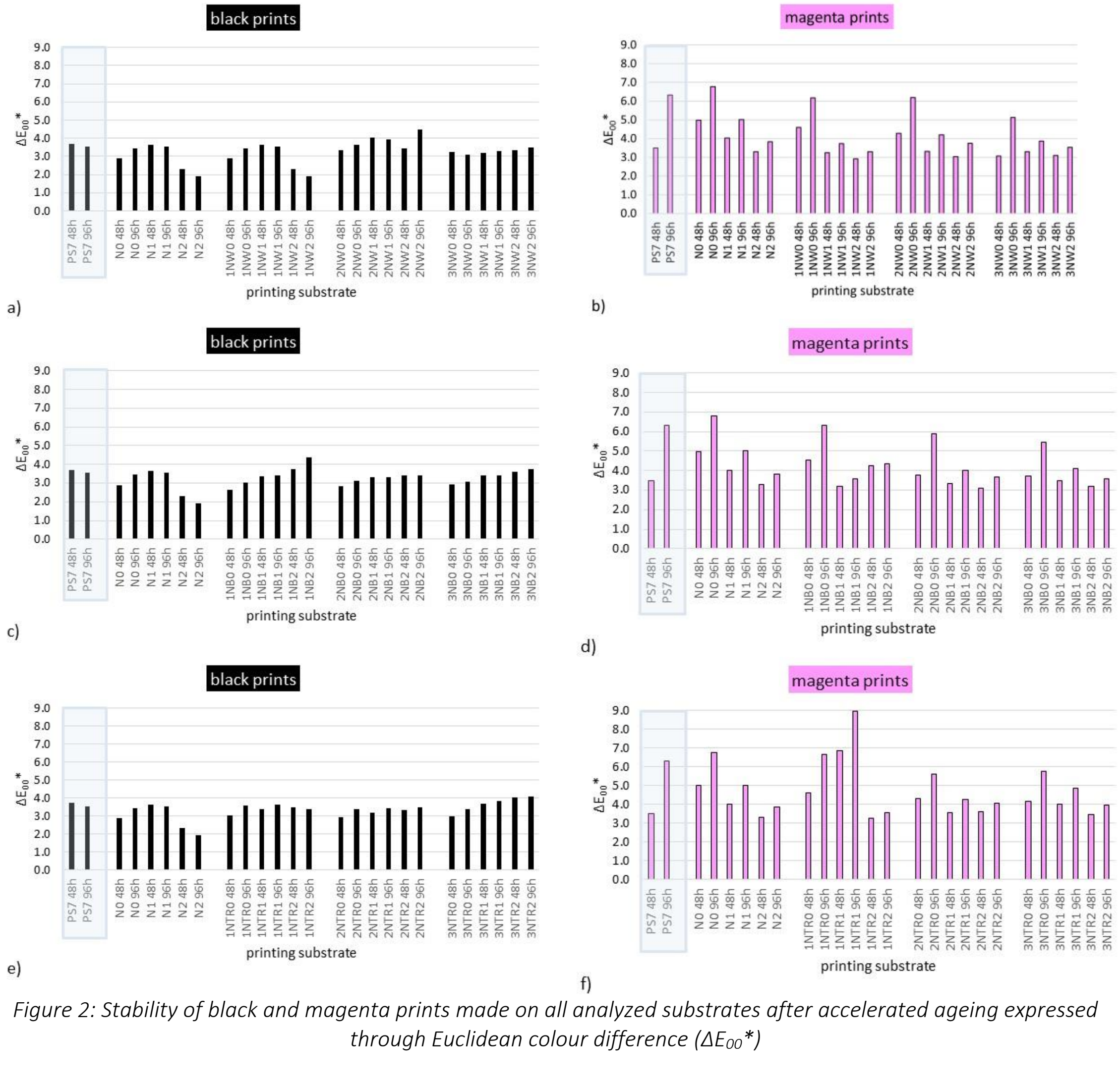

Figure 2: Stability of black and magenta prints made on all analyzed substrates after accelerated ageing expressed through Euclidean colour difference (ΔE_{00})*

4. CONCLUSIONS

Black prints show equal stability to accelerated aging regardless of the type of used printing substrate. Neither the change in the composition of the pulp for the production of the printing substrate nor the coating based on TiO_2 has any significant impact on the stability of the black ink over time. On the other hand, it was noticed that TiO_2-based coating has a dual positive impact on magenta prints exposed to UV radiation. Namely, coating with TiO_2 enables higher stability of magenta prints already with one and especially with two coating layers. After an ageing interval of 96 hours, a reduction in colour degradation was obtained for the coated magenta prints compared to the PS7 reference sample used for commercial purposes. In addition, it was noticed that a TiO_2-based coating has a positive influence on ink stability when exposure time is extended.

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PRINTABILITY AND QUALITY OF PAPERS COATED WITH DIFFERENT BINDERS

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Abstract: *Papers are the most commonly used substrates. A printable paper must have certain properties. These properties include surface smoothness, air permeability, surface energy, colour of the paper, opacity, whiteness, light fastness, gloss, and coefficient of elongation under force. In addition, a good printable paper should not allow ink to pass between its two surfaces. After the papers are produced, they are subjected to surface treatments in order to improve the above-mentioned properties and to provide extra specification. Surface treatments include calendering, surface sizing and coating processes. While filling the recesses and protrusions on the surface with the coating process, the paper's affinity for the ink is increased, and the penetration of the ink to the other surface of the paper is prevented. In the coating process basically, a filler is dispersed in a binder. In this study, it is aimed to obtain the highest quality and most printable paper by changing the type of binder used in the coating. In this study, equal amount (5% w/w) titanium dioxide filler was used in all coating formulations. In coating formulations; cationic starch, hydroxy ethyl cellulose and polyvinyl alcohol polymers were used as binders. Binder amounts are adjusted according to optimum viscosity. The obtained coating formulations were coated on the paper surface with a laboratory type coating device. Colour, gloss, surface smoothness, air permeability, surface energy and surface morphology of the coated papers were determined. It was printed with magenta offset printing ink on three different types of paper coated with different binders, using the IGT C1 offset printability test device, under 400 N/m^2 pressure printing conditions. Colour and gloss measurements of the prints were made. As a result; It was determined that three different binders improved the printability parameters.*

Keywords: printability, paper coating, binder, paper quality

1. INTRODUCTION

Paper and writing symbolize civilization and the future, and no matter how widespread digitalization is in our age, paper consumption will not decrease. Paper use has never decreased from the past to the present. Over time, there have been changes in paper usage preferences and the expected features of paper. Today, with the development of the packaging and label industry and the advertising industry, expectations from paper have also been important developments. Paper manufacturers and the printing industry have also focused on improving printability and many other paper properties to meet expectations. Developments in ink and paper, which are the basic raw materials of the printing industry, will also directly affect printability. Today, especially in the packaging and label industry, paper and cardboard are expected to have additional features. At this point, the simplest process is to improve the surface properties. The processes required to provide the desired properties from the paper are sizing, coating, and calendering.

There are two sizing processes in the paper industry. The first is the addition of internal sizing agents (wet end) to the pulp during production, and the second is surface sizing applied to the paper surface after production (Ginebreda et al., 2011). The sizing process mentioned here is applied to the surface. In the sizing process, the process of filling the pores on the surface is filled by covering the paper with a binder. Starch, polyvinyl alcohol and cellulose derivatives are commonly preferred in sizing processes. Starch is often used in situations in which smoothness and gloss are required for high quality prints. Starch is also used as an adhesive to bond surface fibres, increase paper strength and stiffness and improve offset printability and dimensional stability.

Although starch consumption by the paper industry is high, many synthetic materials can replace starch. The cost and performance characteristics of the substitutes to be used are considered, as well as their sensitivity to environmental factors. However, the use of starch has several advantages (Bamiller, 1997). Starch is a high molecular weight natural polymer that can be depolymerized to a large extent with control. It is a hydrophilic polymer that disperses in water and binds to cellulose fibres and pigments via hydrogen bonding. The key factors in choosing starch are the relatively low cost of the raw material, the fact that it is derived from a renewable resource, and its biodegradability (Bajpai, 2012; Maurer & Kearney, 1998).

PVA is a white granular synthetic polymer that is water soluble and is considered to be one of the strongest binders available in the paper industry. The PVA production process begins with polymerization of the vinyl acetate monomer through a free radical reaction to polyvinyl acetate. Polyvinyl acetate is then hydrolyzed to PVA via a base-catalysed saponification reaction (Gigac et al., 2016; Fatehi et al., 2009).

Cellulose is a widely used bio-based material in the paper industry and in various other industries (Abdel-Rahman et al., 2013; Hashem et al., 2011). Cellulose is the main material used in paper production. In addition to being the main materials, cellulose-based polymers are used as additives in both wet and dry surface applications in the paper industry. Thus, the ink to be printed on the paper was prevented from penetrating the paper. Thus, a higher printing brightness is achieved with less ink (Cao et al., 2009). Chemical modifications have been performed to increase the solubility of cellulose and its derivatives (El-Shafei et al., 2008). In addition to cellulose ether, hydroxyethyl cellulose (HEC) is frequently used in industry because of its biocompatibility, which improves the workability and adhesion of fresh material to the material (Azzaoui et al., 2015).

Hydroxyethyl cellulose (HEC) is a non-ionic water-soluble polymer. This polymer has excellent performance properties, such as the ability to thicken, bind, emulsify, suspend, disperse, stabilize, in addition to the ability to retain water and form film, which provides good protective effect. HEC dissolve easily in hot or cold water to produce solutions with a wide range of viscosities. Hydroxyethyl cellulose has applications in different industrial areas, such as thickening dyes (Dal-Bó et al., 2011), textile finishing (Gorgieva & Kokol, 2011), thickeners in cement mortar (Patural et al., 2011) and sizing agents in paper production (Kugge et al., 2004). HEC samples are often modified by ionic or hydrophobic groups to optimize their properties for various industrial applications. This modification causes an increase in the viscosity and is often thixotropic. Such systems can be further improved by adding small amounts of surfactants (Kästner et al., 1996)

In the coating process, a mixture of pigment, binder, and additives are coated on the paper surface. The main difference of the coating process as a mixture from the sizing process is that it contains pigment and therefore it is also referred to as pigment coating in some sources in the literature. Coating is the main industrial process used by the paper industry to improve the appearance and printability of paper, and accounts for 50% of the total chemical additive used worldwide (Ginebreda et al., 2011). Pigmented paper coating is usually accomplished using a high solids aqueous suspension of inorganic pigments and binders. In this process, basic materials other than the pigment, namely binders, are additives that aim to improve properties such as surface strength, gloss, waterproofing, print compatibility (Duan et al., 1999) and paper speed. As in the sizing process, the most common binders for paper coating are starch, polyvinyl alcohol, and cellulose. Binders can be used either alone or in combination with others such as starch.

Better printability properties are obtained using the paper surface coating process. These features can be counted as smoothness, opacity, surface smoothness, thickness, brightness, whiteness, non-tearing, and non-breaking (Ozcan & Zelzele, 2017). Coating formulations usually consist of inorganic pigments such as kaolin-clay, calcium carbonate, titanium dioxide, binders, dispersants and some other additives (Morsy et al., 2016; Ozcan et al., 2019). In addition to the above-mentioned pigments for coating, many different pigments are added to the formulation, and experiments are being carried out today (Mansour et al., 2000).

One or more pigments could be used in the coating process. The desired properties of pigments used in coatings include chemical resistance, compatibility with other components, appropriate particle size and shape distribution, purity, low density, gloss, opacity, good flow properties and low binder requirements. Binders are necessary for the pigment particles to fill the pores of the paper; that is, they act as a type of glue and determine the rheological properties of the coating. 5-20% binder by weight is used in the coating formulation (Lee et al., 2002). The properties required of binders are good adhesion, compatibility with other compounds, optical and mechanical properties, chemical and mechanical stability, and durability. Natural or synthetic polymers and latex derivatives are used the coating processes. Starch is one of the most commonly used binders owing to its easy supply and cost (Shogren, 1998). Polyvinyl alcohol is also one of the strongest binders that can be dissolved in water and used in the paper industry.

In this study, we aimed to obtain the highest quality and printability of the coated paper by changing the binder type used in the coating. In this study, equal amounts (5% w/w) of titanium dioxide pigment were used in all the coating formulations. Cationic starch, hydroxy ethyl cellulose, and polyvinyl alcohol polymers were used as binders in the coating formulations.

2. METHODS

The technical properties of the base paper used in this study are listed in Table 1. Cationic starch, hydroxyethyl cellulose (HEC) and polyvinyl alcohol (PVA) were purchased from Sigma-Aldrich and their properties are listed Table 2. TiO2 was purchased from Sigma-Aldrich. The Frimpeks UV Offset Process Magenta 22355 commercial offset printing ink was obtained from Frimpeks (İstanbul, Turkey).

Table 1: Technical properties of base paper used in the study

	Standard	Base paper
Grams per square meter (g/m^2)	ISO 536	70
Thickness (µm)	TAPPI T411	165
Whiteness (D65/10) (%)	ASTM E313	96
Gloss (75°)	ISO 8254-1	5.5
Yellowness	ASTM E313	0.06

Table 2: Technical properties of cationic starch, hydroxyethyl cellulose and polyvinyl alcohol used in the study

	Cationic starch	HEC	PVA
Appearance (color)	White	White to faint Beige	White to off-white
Appearance (form)	Powder	Powder	Powder
Viscosity (cps, 20°C)	120	80-125 (2% in H_2O)	120
Fineness %	>98	>98	>98
pH	6.0	6.0-8.5	6.0

2.1 Paper Sizing and Coating

Cationic starch, PVA, and HEC based surface sizing mixtures were applied to base paper. The sizing formulation applied consisted of 0.25% concentration of HEC binder, 7.5% cationic starch, 7.5% PVA in water which were heated up to 95 °C and stirred at 250 rpm with a mechanical stirrer for a while, and the resulting hot mixture surface sizing solution was cooled to 60 °C and then applied on to the paper surface using the Mayer rod with #2 in a laboratory-type paper coating machine. The same preparation process was repeated for the paper coating formulations, when the sizing mixtures cooled at 40 °C 5% TiO2 pigment was also added to the mixtures. The formulations were applied to the paper surface using a Mayer rod in a laboratory-type paper coating machine under laboratory conditions. All samples were conditioned at 50% RH and temperature of 23 °C for at least 48 h before characterization.

2.2 Contact Angle, surface energy, paper roughness and air permeance measurements

The contact angle and total surface energy measurements of the papers were performed using PocketGoniometer PGX+ in accordance with the ASTM D5946 standard. The paper roughness and air permeance of all papers were determined using Lorentzen & Wettre (L&W) in accordance with the ISO 8791-2:2013 - Part 2: Bendtsen method.

2.3 Printing and spectrophotometric properties

Base paper, sized papers and coated papers were printed using Frimpeks UV Offset Process Magenta 22355 commercial offset printing ink using an IGT CG1 offset printability test device under 400 N/m2 pressure printing conditions. All the samples were cured using an IGT UV curing device after printing. Then, the spectrophotometric properties of the papers were determined using CIEL*a*b* colour values by using an X-Rite eXact spectrophotometer according to the ISO 13655:2017 standard. The measurement conditions of the spectrophotometer were determined as polarization filter with 0/45° geometry with 2° observer angle and D50 light source in the range of 400-700 nm. The difference between the colours of the different prints was calculated according to the CIE ΔE 2000 colour-difference formula ISO 11664-6:2014. Calculations were performed by calculating the average of five measurements. ΔL*, Δa*, and Δb*: 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. SL, SC, and SH are the weighting functions for lightness, chroma, and hue components, respectively. The values calculated for these functions vary according to the positions of the sample pair considered in the 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, and separations, for the lightness, chroma, and hue components, respectively (Bates et al., 2012).

2.4 Gloss

The gloss measurements of all papers were carried out with the BYK Gardner GmbH micro gloss 75° geometry in accordance with ISO 8254-1:2009, and the gloss measurements of prints with the BYK Gardner GmbH micro-Tri-gloss 60° geometry in accordance with ISO 2813:2014.

3. RESULTS

The contact angle and total surface energy measurements of the papers were performed using PocketGoniometer PGX+ in accordance with the ASTM D5946 standard. The measurement results are presented in Table 3. When the contact angle results are examined, the contact angle value of the base paper of 70.2°, which is compatible with the literature (Shen et al., 2000), has been reduced by all sizing and coating processes, that is, better wetting of the paper is ensured, and it is possible to print with less water (Crowe et al., 2021). When the sizing agents are evaluated among themselves, it has been determined that the contact angle increases with the order of HEC, cationic starch and PVA. This is due to the number of OH bonds. Polymers with more OH groups make more H bonds and lower the contact angle. The results are consistent with the literature (Ellison et al., 1953). Titanium dioxide in coating formulations has also provided a lower contact angle than you, which is lower than base paper. Because TiO2 has increased absorbency with its water-loving structure.

Table 3 (part 1): Total surface energy and contact angle values of all papers according to ASTM D5946 method

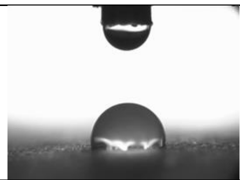
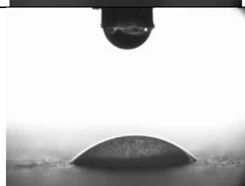
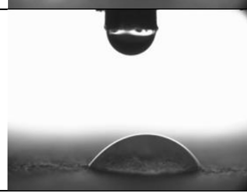
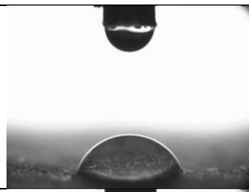
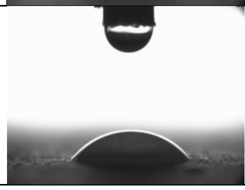
Paper samples	Total surface energy (mJ/m^2)	Contact Angle	**Images**
Base paper	39.6	70.2	
Cationic starch sized paper	47.5	48.5	
Cationic starch+TiO_2 coated paper	51.2	38.3	

Table 3 (part 2): Total surface energy and contact angle values of all papers according to ASTM D5946 method

PVA sized paper	42.3	62.8	
PVA+TiO_2 coated paper	43.9	58.6	
HEC sized paper	50.6	40.1	
HEC+TiO_2 coated paper	50.7	39.6	

The paper roughness and air permeance of all papers were determined using Lorentzen & Wettre (L&W) in accordance with the ISO 8791-2:2013 - Part 2: Bendtsen method. The measurement results are listed in Table 4. The surface roughness of the papers is the parameter that affects the print quality the most. Because ink is lost in rough papers and ink cannot reach thinner spaces. For this reason, it is one of the features that should be checked in papers. When Table 4 is examined, it has been determined that the roughness of the base paper decreases with the processes that have the highest surface roughness. The surface roughness of the coatings is higher than the size papers. This is due to the fact that the pigment creates a small roughness on the surface. The air permeability has been reduced during the processes and is in the same direction as the surface roughness. The results are in agreement with the literature (Karlović et al., 2010).

Table 4: Paper roughness and air permeance measurements for all papers

	Roughness (ml/min)	Air permeance (ml/min)
Base paper	225	821
Cationic starch sized paper	71	94
Cationic starch+TiO_2 coated paper	150	142
PVA sized paper	46	28
PVA+TiO_2 coated paper	58	34
HEC sized paper	55	65
HEC+TiO_2 coated paper	78	174

Paper coatings containing different binders were successfully prepared and coated on the paper surfaces. Then, magenta colour prints were obtained under 400 N/m2 pressure conditions using the IGT CG1 offset printability test device. All the samples were cured using IGT UV curing device after printing. Spectrophotometric colour measurements of all the papers were then performed, and the measurement values are listed in Table 5. When the results are examined, it is seen that all colour changes are below

140, that is, the two colours cannot be distinguished from each other with the eye. This occurs because the ink dries too quickly. Colour shifted to some yellow in all sizing and coating processes. It was concluded that the double bonds in these polymeric binders are due to the chromophore property. The relevant results are consistent with the literature (Ozcan et al., 2020). In addition, higher density was obtained than uncoated papers with equal amounts of ink. Because the polymeric film formed on the surface prevented the ink from entering the paper.

Table 5: Spectrophotometric colour and colour difference values of the papers used in the study

	Density	L*	a*	b*	ΔE00
Base paper	1.10	41.71	69.79	3.08	
Cationic starch sized paper	1.60	41.45	69.19	2.82	0.45
Cationic starch+TiO_2 coated paper	1.38	41.90	68.77	2.12	0.43
PVA sized paper	1.61	41.83	67.34	2.23	1.06
PVA+TiO_2 coated paper	1.48	41.94	67.14	2.17	0.77
HEC sized paper	1.60	42.07	67.48	2.65	1.04
HEC+TiO_2 coated paper	1.60	41.94	67.11	2.27	1.38

The gloss measurements of all papers were carried out with the BYK Gardner GmbH micro gloss 75° geometry in accordance with ISO 8254-1:2009, gloss measurement results of which are shown in Figure 1, and the gloss measurements of prints with the BYK Gardner GmbH micro-Tri-gloss 60° geometry in accordance with ISO 2813:2014. The gloss measurement results for magenta printed papers are shown in Figure 2. When the gloss values of the base and coated papers were examined, it was observed that the gloss values increased in all the sized coated papers. When the coated papers were examined, it was found that the gloss value of sized papers higher than coated papers. Because the pigment creates a slight roughness on the surface. This also reduces the gloss a bit. The increase in gloss in sizing and coating is due to the binders closing the gaps on the surface and reducing the surface indentations. The results are consistent with the literature (Elsayad et al., 2001). When the printing glosses are examined, the gloss decreased in all coated, uncoated and sized papers. Because the pigment in the ink created a slight roughness on the surface, which reduced the gloss.

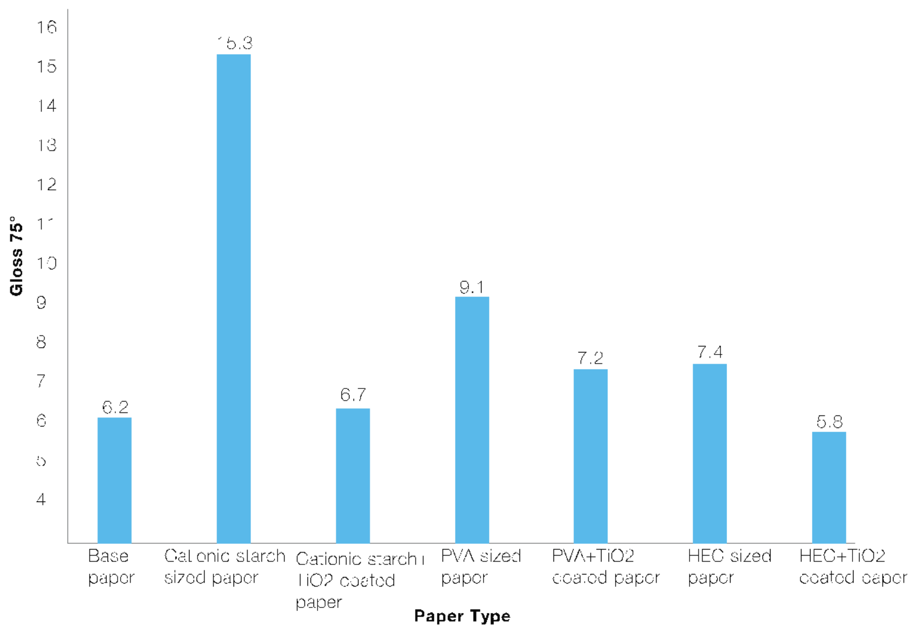


Figure 1: Gloss values of papers according to ISO 8254-1:2009

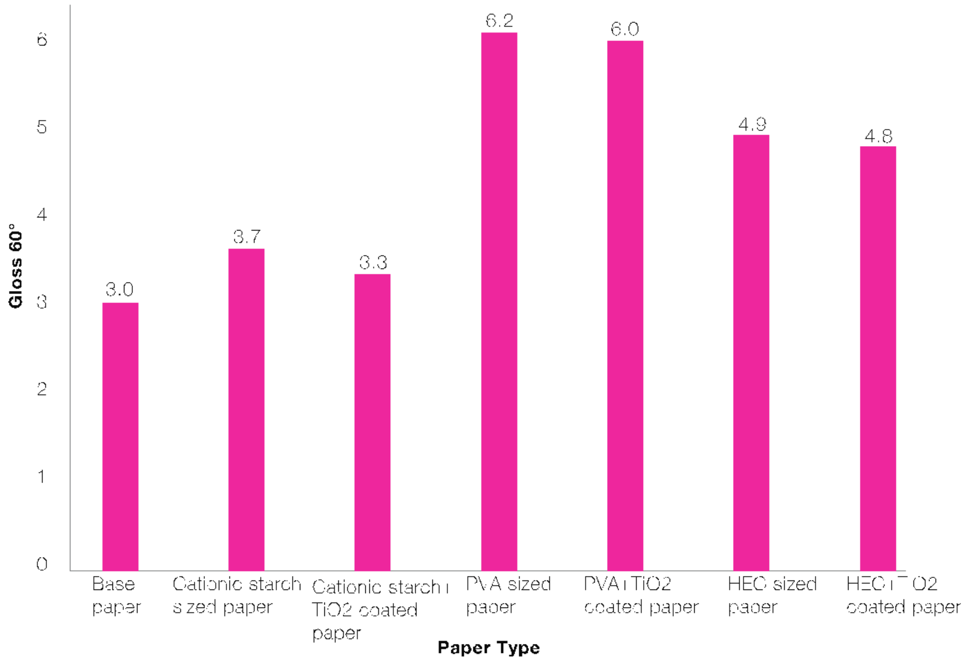


Figure 2: Gloss values of magenta printed papers according to ISO 8254-1:2009

4. CONCLUSIONS

In the paper industry, additives are extensively used for two main purposes. The first is to provide higher productivity by using less water and energy, thus contributing to minimizing the environmental impact of paper. The second is to provide the desired quality features to the final product. Paper is useful in many areas of daily live. Therefore, production and consumption are normal at a global scale. The additives used in the paper and cardboard industry should be made by considering the cost factor as well as the cost factor in the preference of binders and pigments. At this point, the choice of sustainable binders with biocompatibility, low cost, and high performance in addition to them is crucial.

As a result, it has been determined that better wetting is provided for more printing with the coatings made, the colour change is very low in the printing where the gloss is increased, and the surface roughness is reduced. Thus, the print quality parameters were increased and it was found that better quality prints could be obtained with all sizing and coatings. When the binders were compared among themselves, it was determined that the best results were obtained by cationic starch and HEC, but considering the cost, the best performance could be obtained from the cheaper cationic starch.

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EVALUATION OF THE INFLUENCE OF ARTIFICIAL UV AGEING OF PRINTED IMAGES

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Abstract: *The main problems encountered in the long storage of printed or painted images are associated with deterioration of color characteristics and loss of information from them. The changes, that occur are due to the processes of ageing of the inks and papers. Natural ageing is a rather slow process. Therefore a study of the changes occurring with the printed images over the time under artificial UV radiation has been carried out. For the purpose of this experiment, was designed specialized test form, containing thousands of control patches for estimating the spectral, color and optical density shifts during the artificial ageing. The main goals of this research are to investigate the influence of artificial UV ageing on the optical density, spectral and color characteristics of printed images. The experiment have been performed in real printing conditions on state of art offset printing presses. The printing media used in the experiment are matte coated and uncoated offset paper, which are chosen because they are wide used all over the world. The test images and all the thousands of color control patches have been submitted to UV artificial ageing. The spectral and color characteristics of the inks and paper were examined during the different UV ageing period. The obtained results shows changes in all of investigated parameters during artificial ageing. The results are important from scientific and practical point of view. They might be used for modeling of ageing processes and could be very useful for recovering of original color characteristics of aged images.*

Key words: UV ageing, physical - mechanical and optical properties of papers, color characteristics

1. INTRODUCTION

Printing production has a great variety: books, newspapers and magazines, advertising products, packaging and more (Timar, Varodi & Gurău, 2016; Sonderegger et al., 2015).
Over time, sealed materials get older and can be caused by various factors: the natural ageing of paper and inks, the effects of temperature, the environment and human intervention (Valkova, 2016).
The main problems that occur when storing various printed matter for a long time are related to the deterioration of color characteristics and loss of information from them, the change in color range and the color difference that result from the aging of the ink (Fellers et al., 1989; Spiridonov, Shopova & Boeva-Spiridonova, 2012; Yanbing, 2019).
Each paper changes its physical, mechanical and chemical properties over time. The durability of the paper is its ability to retain unchanged over time certain physical-mechanical, optical and chemical properties (Dolezalek, 2004; Timar, Varodi & Gurău, 2016). This ability is determined by the degree of change in the properties of the paper in artificial ageing. The durability of a paper depends on its composition and the conditions of receipt and storage. It complies with the following standards: for document papers ISO 9706: 1994, for archival papers in ISO 11108: 1996, for writing and printing papers - in ISO 11798: 1999. For example, the pH of the aqueous extract on durable paper should be 7.5-10, be stuck in a neutral environment. The paper should not contain high-fiber material and be high in α-cellulose (ISO 2846-1:2006; Modzelewska, Patelski & Okon, 2013; Sonderegger et al., 2015).
Artificial ageing can also be accomplished by light irradiation with UV rays in a special chamber equipped with a UV lamp (300-400nm). The test samples are irradiated on one side. The duration of treatment is from 5min to 320 min at 48°C. Samples are then conditioned.
Purification of water from the pulp and paper and printing industry and the processing of waste paper are important for environmental protection (Beschkov et al., 2020; Kostadinova et al., 2018; Parvanova-Mancheva et al., 2020; Vasileva, Petrov & Beschkov, 2009).
UV irradiation has a significant impact on the elasticity and flexibility of the fibers and makes the paper more brittle and fragile. Improper storage is most often the cause of the mechanical destruction of works of art, it also changes the colors of textile materials (Boeva & Radeva, 2014; Dolezalek, 2004; ISO 2846-1:2006; Kašiković et al., 2015; Li & Lyu, 2020; Stančić et al., 2014; Valkova, 2016).

Improper storage is most often the cause of the mechanical destruction of works of art (Džimbeg-Malčić et al., 2003; ISO 13656:2000, ISO 13655:2003).

2. METHODS

2.1. Materials and conditions of the experiment

Two wide used and popular types of papers have been chosen for the experiment:

- Uncoated offset paper – with weight 80 g/m^2;
- Matte coated paper – 120 g/m^2.

On the paper samples the following analyses were made:

- Estimation of weight, [g/m^2] (EN ISO 536:1998);
- The pH of the water extraction according to (ISO 8947-83). Based on estimation of the pH of the water extract the alkalinity or acidity is determined of the paper.

The results of the analysis of the two types of printed papers are given in Table 1.

Table 1: Characteristics of used the papers

Type of Paper	Weight of papers, (g/m^2)	pH of the water extract before UV ageing	pH of water extract after UV ageing
Uncoated offset paper	80	7.8	7.3
Coated matte paper	120	7.6	7.0

The pH of the water extraction for both types of paper changes slightly, indicating no significant changes in the chemical composition of the fibrous material components.

2.2 Selection of prints that meet all the offset printing technology requirements

Implemented print plates were positive acting and were exposed by Computer to Plate System – Kodak. A special test form, which contains a multiple test charts and patches, have been designed. The printing of the test sheets in this experiment was carried out on a Heidelberg Speedmaster four-color offset printing machine, size 35x50 cm, model SX 52-5-L with ANICOLOR inking unit.
Room conditions: temperature ~ 25ºC and relative humidity ~ 65%. Inks - Huber Group - Maxima Series: Cyan - 43 F 50 MX, Magenta - 42 F 50 MX, Yellow - 41 F 50 MX, Black - 49 F 50 MX; Dampening solution – 6% isopropanol content, pH = 5.3, to 10 ± 1°C. The printing of the test forms is carried out under the following conditions: sequence of the inks – Black, Cyan, Magenta, Yellow.
Optimal inking quantity is predetermined by the ISO (ISO 12647-2:2013) recommendation and maximum print contrast method for each combination of paper-ink-printing machine. Table 2 gives the test values for optimal inking.

Table 2: Optimal inking values for paper

Type of Paper	Cyan	Magenta	Yellow	Black
Uncoated offset paper	1.10	1.10	0.90	1.20
Coated matte paper	1.55	1.60	1.45	1.85

2.3. Experiment conditions

Artificial UV ageing was conducted in a Q-SUN Xenon Tests camera, which uses a full-spectrum xenon lamp to reproduce the material damaging wavelength. The camera for UV ageing irradiation in the UVA and UVB spectrum in the range of 320 - 800nm. In experiment are used fluorescent UV lamps (UVA – 351 and UVB - 313EL). They provide the ability to simulate sunlight with a peak at 340 nm.
The measurements were done on intervals: 0 hours, 6 hours, 12 hours, 24 hours, 36 hours, 48 hours, 72 hours, 144 hours and 200 hours. Colour measurements were performed with spectrophotometer GretagMacbeth Spectrolino and X-Rite i1i0: GM Profile Maker, GM Measure Tool и GM Profile Editor and

i1Profiler. Measurement conditions – standard light source D50, measuring geometry 45°/0° or 0°/45°, 2° standard observer (ISO 13655:2017; European Color Initiative; ICC.1:2004-10; ISO 2470:2002). For the purpose of the experiment, about 36,000 color measurements were performed in the CIE Lab and CIE Lch systems.
Artificial UV ageing is subjected to printed TC 6.02 control scales, which are used to generate ICC color profiles. The scale contains 999 colored boxes measuring approximately 5x5mm. The colors of the fields in the TC 6.02 scale are specially selected because they are important, and some of them are even "critical" in color reproduction. The scale contains "remembering" colors, such as body colors, colors of the surrounding nature (grass, sky), etc.

3. RESULTS AND DISCUSSION

3.1 Influence of artificial UV ageing on the densitometric characteristics

Investigation of the effect of artificial UV ageing on the of printed images. The quality of the printed image is shaped by a number of conditions, including those of the printing process. Optical density measurement refers to solid and raster images obtained with the main colors cyan, magenta, yellow and black. The optical density is determined by the thickness of the ink layer.

3.1.1. Influence of artificial UV ageing on the optical density

Graphic representation of the change in optical density (D) for Cyan, Magenta, Yellow, Black at 100%, 40% and 7% of the raster fields for both papers, depending on the time of artificial UV ageing.
Cyan, magenta, yellow, and black were selected in 100%, 40%, and 7% of the raster fields, respectively, because they represented the dark (100%), medium (40%), and light (7%) tones, respectively. The following several figures (Fig. 1 and Fig. 2) show graphically the dependences of optical density on the duration of artificial UV ageing.

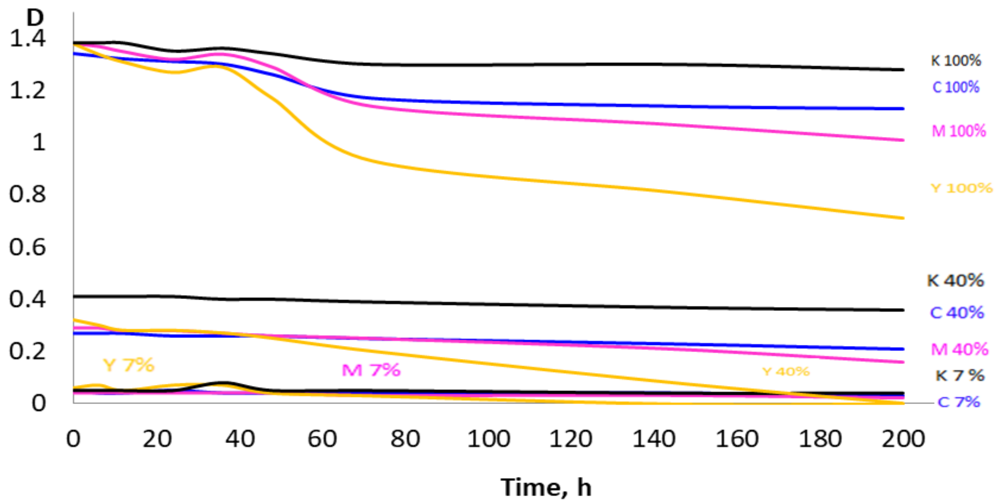

Figure 1: Influence of artificial UV ageing on the optical density of coated matte paper

Figure 1 shows that, as a result of artificial UV ageing of coated matte paper, the reduction of optical density in the dark and medium tones from 0 h to 24 h is relatively small for the 4 colors. After 36 h serious decrease was observed in Yellow and Magenta. In light tones there is a slight decrease in optical density up to the 36th hour, and after the 48th hour there is a serious decrease and even expressed in vanishing of the raster elements for Yellow. In Cyan and Black, the decrease in optical density is almost not observed.
Figure 1 shows that as a result of artificial UV ageing of surface-coated matte paper, a decrease in optical density is observed at 100% Yellow from 6 hours to 200 hours, with a significant difference and a change in the negative direction ($\Delta D_{0/200}$=0.67). For a 40% Yellow decrease in the optical density values is observed from 6 hours to 144 hours, then the values of D = 0 at 200 hours, therefore there is a deletion of the raster elements. At 7% Yellow, a decrease in D was observed from 6 hours to 72 hours, after which

at 144 hours and 200 hours the yellow color "disappears". At 100% Magenta, a significant difference was observed from 48 hours $\Delta D_{0/200}$= 0.37, and for 40% Magenta after 144 hours from UV ageing. For 100% Cyan the losses are relatively small. For the other raster fields 100% Black, 40% Cyan, 40% Black, 7% Cyan, 7% Magenta, 7% Black, the decrease in optical density is almost not observed.

Figure 2 shows that as a result of artificial UV ageing of uncoated offset paper, the decrease in optical density in the dark and medium tones from 0 h to 48 h is relatively small for the 4 colors. After 72 h of ageing - serious decrease was observed in Yellow and Magenta. In the light tones occurs a change between the 72 and 144th hours at Yellow. In Cyan and Black, the decrease in optical density is almost not observed.

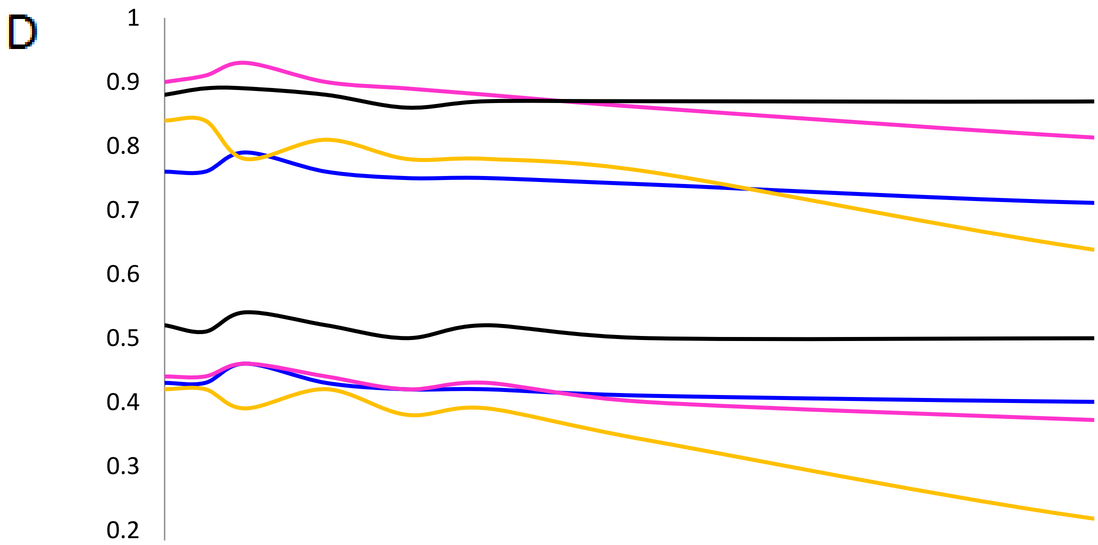

Figure 2: Influence of artificial UV ageing on the optical density of uncoated offset

Figure 2 shows that as a result of artificial UV ageing of uncoated offset paper, a decrease in optical density values is observed at 100% Yellow and 40% Yellow from 6 hours to 200 hours, with a relatively large difference - at 100% $\Delta D_{0/200}$=0.25, and at 40% $\Delta D_{0/200}$=0.24. A decrease of D for 7% Yellow and 100% Magenta has been observed for 72 h.

For 40% Cyan, reductions in optical density values are relatively small and are observed after 24 hours. At 100% Black and 7% Black, no change in optical density was observed. For the other raster fields 100% Cyan, 40% Magenta, 40% Black, 7% Cyan, 7% Magenta, 7% Black, values in the optical density are almost not observed.

3.1.2. Differences in optical density of Cyan, Magenta, Yellow, Black

Table 3 shows the differences in optical density of Cyan, Magenta, Yellow, Black between 0h - 200h of UV ageing for coated matte paper.

Table 3: Difference in optical density for C, M, Y, K on coated matte paper

$\Delta D_{0/200}$	Cyan	Magenta	Yellow	Black
7%	0.02	0.02	0.06	0.01
40%	0.06	0.13	0.32	0.05
100%	0.21	0.37	0.67	0.1

Table 4 shows the differences in optical density of Cyan, Magenta, Yellow, Black between 0h - 200h of UV ageing for uncoated offset paper.

Table 4: Difference in optical density for C, M, Y, K on uncoated offset paper

$\Delta D_{0/200}$	Cyan	Magenta	Yellow	Black
7%	0.01	0.02	0.06	0
40%	0.04	0.09	0.24	0.02
100%	0.04	0.11	0.25	0

The optical color density for both papers is changed in the following order:

Yellow > Magenta > Cyan > Black

3.1.3. Investigation of the change in the color characteristics for both types of papers

Changing the Color Characteristics of Paper in the UV Ageing Process for uncoated Offset Paper (ISO 5631).

- The change in the color characteristics of uncoated offset paper

*Table 5: The change in the color characteristics by CIE*Lch in the UV ageing for uncoated offset paper*

Time, [h]	CIE*L	CIE*C	CIE*H
0	*94.21*	*6.80*	*280.07*
200	*93.97*	*5.14*	*100.14*

From the data in Table 5 shows that lightnes (CIE*L), saturation (CIE*C) and color tone (CIE*H) on offset paper show a decrease in values for 200 hours of irradiation.

Change in light (CIE*L) of the paper color for 200 hours of artificial UV aging is relatively small $\Delta L^*_{0/200}$ = 0.35. With saturation (CIE*C), a difference of $\Delta C^*_{0/200}$ = 1.58 is observed. The biggest change is in the color tone – hue (CIE*H), which reaches $\Delta h^*_{0/200}$ = 11.37. The color difference resulting from 200 hours UV radiation is ΔE = 11.48.

*Table 6: The change in the color characteristics by CIE*Lab in the UV ageing for uncoated offset paper*

Time, [h]	CIE*L	CIE*a	CIE*b
0	93.77	1.40	-6.48
200	94.89	-0.94	4.04

The data in Table 6 shows, that the change in light (CIE*L) and red-green (CIE*a) area is relatively small, whereas for yellow-blue (CIE*b) the area is much larger Δb* = 10.54, that the color of the paper goes to the yellow area when the surface is offset with offset paper. The color difference resulting from 200 hours UV radiation is ΔE = 10.85, which indicates that there is a very noticeable difference.

Changing the Color Characteristics of Paper in the UV Ageing Process for coated Matte Paper (table 7).

- **The change in the color characteristics of coated matte paper**

*Table 7: The change in the color characteristics by CIE*Lch in the UV ageing process for coated matte paper*

Time, [h]	CIE*L	CIE*c	CIE*h
0	97.33	5.42	284.11
200	95.71	7.31	92.92

Table 7 shows that the change in light (CIE*L) of the paper color for 200 hours of artificial UV ageing is relatively small $\Delta L^*_{0/200}$=1.32. For saturation color coordinate (CIE*C), a difference of $\Delta C^*_{0/200}$ = 2.09 is observed. The biggest change is in the color tone (CIE*H), which reaches $\Delta h^*_{0/200}$ = 12.69.

The color difference resulting from 200 hours UV radiation is ΔE = 12.93.

*Table 8: The change in the color characteristics by CIE*Lab in the UV ageing process for coated matte paper*

Time, [h]	CIE*L	CIE*a	CIE*b
0	97.32	1.33	-5.33
200	95.71	-0.29	7.51

The data in Table 8 shows that the change in light (CIE*L) and red-green (CIE*a) area is relatively small, whereas for the yellow-blue (CIE*b) area it is significantly large Δb*= 12.79, which means that that the color of the paper goes to the yellow area with the coated matte paper. The color difference resulting from 200 hours UV radiation is ΔE = 12.95, which indicates that there is a very noticeable difference.

4. CONCLUSIONS

After performing of artificial UV ageing of 200 hours of irradiation, it was found that the greatest changes occurred for the saturation color coordinate, for the coated matt paper reaching values of $\Delta C_{matte\ 0/200}$ = 50.82 and 2 times larger than the uncoated offset paper $\Delta C_{offset\ 0/200}$ = 24.99 units. There is a significant change in the color tone (hue), for the coated matt paper reaching ΔH = 16.53, and for the uncoated offset paper up to ΔH = 11.52. In the process of UV irradiation, for both types of papers there was almost no change in the light (CIE*L) of the selected fields, except for magenta ink, for matt paper $\Delta L_{matte\ 0/200}$=10.72 and twice more for offset paper $\Delta L_{offset\ 0/200}$=4.36 units.
After 200 hours of UV irradiation, it was found, that the optical density become smaller with increasing of time of UV ageing. In some cases, in the light and medium tones of the 7% and 40% Yellow fields, the vanishing of the raster elements is observed.
There is observed the same for both papers optical density changes in light tones (7%). At medium tones (40%), the change in optical density is almost the same, but for matt coated paper the values being slightly higher. For dark tones (100%), it is evident that for matt coated paper occurs three times more changes in density ($\Delta D_{0/200}$= 0.1 ÷ 0.67 units), than for offset uncoated paper ($\Delta D_{0/200}$ = 0 ÷ 0.25 units).

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ANALYSIS OF THE FLEXO PRINTED MATTE VARNISHING STRUCTURE OF POLYESTER SUBSTRATE

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Abstract: *Flexographic printing is one of the fastest-growing sectors in the printing industry. Our related research project examined the potential of matte varnishing as a surface finishing process. Various surface finishing processes, such as various safety varnishes, protective varnishes, barrier varnishes, and the types of matt varnish we have chosen, are playing an increasingly important role in the development of today's packaging material trend. In the course of the research, we tested the changes in the surface structure of the varnishing layer in the case of varying amounts of lacquer application, and we measured the gloss values in the case of the use of clichés with different surface patterns.*

Key words: flexographic printing, varnishing, surface structure

1.INTRODUCTION

A number of factors have contributed to the importance of packaging and it is gaining strength nowadays. The most important of these is globalization and the resulting economic changes. Changes in the role of packaging are also affected by consumer and social changes, which are mainly due to demographic changes. Globally, the growing population is a challenge, which, in addition to the expanding supply of goods, is leading to an increase in the use of packaging. This process leads to a narrowing of packaging raw materials and, in parallel, an increase in their price, which often forces developers to innovate technologically (Dörnyei, 2019).
In the last few years, many product demands have transformed. The main requirement for the production of packaging materials has become a constant supply, constant quality, and simple workmanship, one of the basic pillars of which is varnishing (Kovács, 2021). Varnishes have always played a protective role, from which they developed into individual solutions. Today, most varnishes still play a significant role in mechanical protection, but processes have emerged that open up new opportunities for printers and also increase demand for their products. If the consumer sees a surface that seems interesting during a purchase, they will involuntarily step in to feel it. Just because the consumer grabs the products, he already evaluates them better they are more likely to buy them (Spence, Gallace, 2011).
One of the leading trends today is the solution of highlighting logos or other important elements on products by treating the surface around them with matt lacquer so that the brightly left area becomes dominant. It is no coincidence that this technique has become popular, as the optical experience it provides has a really significant effect, directing the gaze to the right place the result will be clear but dynamic and special. In our opinion, the use of matt lacquer still has many possibilities. We have built our present research to explore these and apply innovative application techniques.

2. MATERIALS AND METHODS

2.1 Stain resistance

The requirements for matte varnish are high heat resistance and fingerprint resistance so that no traces remain on the surface treated with matt lacquer after touch. We launched developments for the latter, during which we developed and tested a special matte varnish. To achieve the desired effects, a mineral filler was used as the matting agent, the proportion of which was increased to 15% and thus the desired opacity and opacity value were achieved. The success of the development is indicated by the positive feedback from our partners, which was followed by a successful introduction in several areas. Our tests were performed in a Hungarian flexo printing house.

2.2 Surface patterning

The visual effect of segmental varnishing is becoming an increasingly desirable feature in the graphic industry. The initial usage of varnishing was to protect products. Today, almost every product, from commercial to personalized items, includes some type of varnishing (Hudika, Majnarić & Cigula, 2020). In terms of design, the varnish is applied to the majority of products to increase their value by enhancing their visibility or personalizing the product for a customer. Varnishing could be, to some extent, conducted with most printing techniques, including screen printing, flexography, standard offset printing, drip-off offset systems, and inkjet digital printing (Kipphan, 2001).

An important aspect is the level of gloss achieved on the matt lacquered surface after the matte varnish. One of the main elements of our research is to examine the range in which we can modify the gloss value of matte varnish even within a given print. This technique can allow different patterns to be displayed by changing the structure of the matte finish. In order to map the possibilities of matte varnishing, we need to examine the factors that can be used to influence the quality and quality of the varnish application.

Surface patterning is a relatively new feature in flexo printing plate production. There are many structures and some possibilities to achieve a structured surface on the print. It is possible to execute lacquering in a post-press, but it´s more effective to do it in one step as part of the printing process. For this reason, we need to find the solution for the best settings of the printing process, what type of printing plate, which structure, and which anilox roller should be used.

A surface structure can be created in two ways: either it is inherently in the plate or it´s software-created and engraved on the plate. The software solutions are continuously improving and can be controlled very precisely in a standardized production process. Most ripping technologies offer their own structures for surface patterning. For the aims of this research, we took the available surface screens from Esko. We used nineteen different surface structures to find out, which one works the best way in our printing process. Between the screens, there have been some micro groovy (MG) screens, microcells (MC) and some others. On the figure 1 there is shown the compiled design of the test plate, which was used in our testing process.

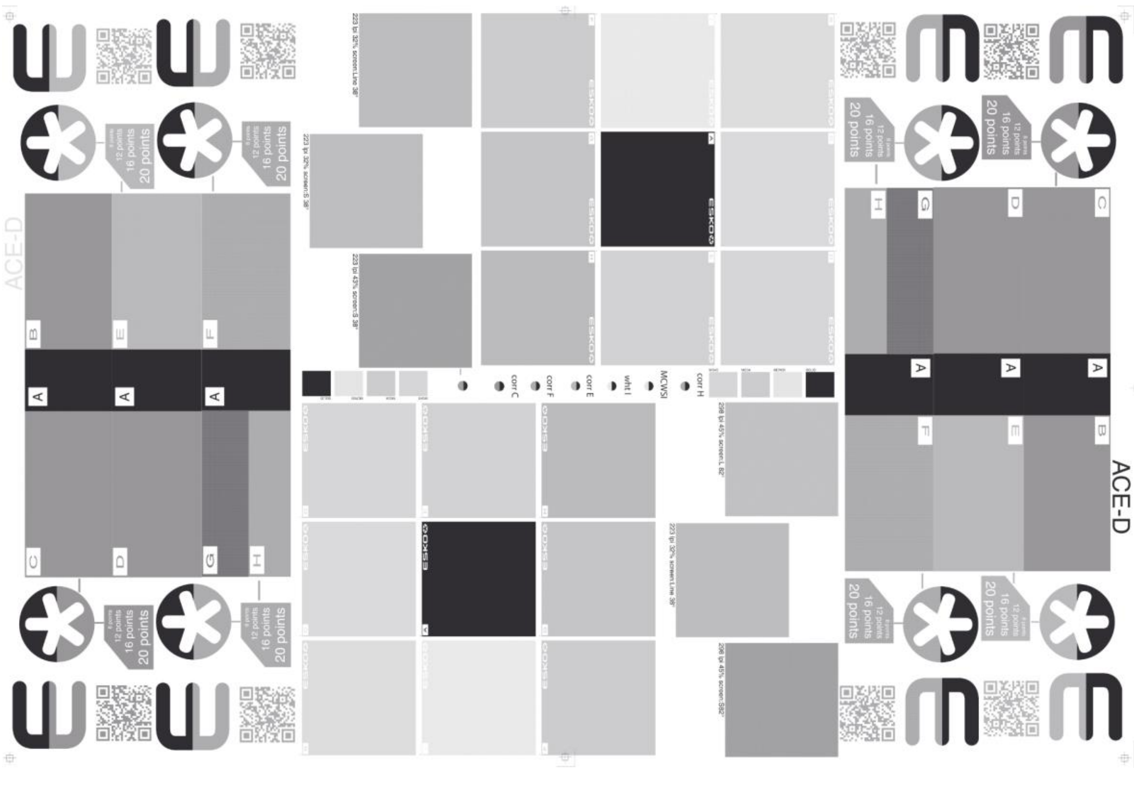

Figure 1: The applied test chart

On Figure 2 we are showing the magnified details of the surface patterning structures we used in the testing process for our research.

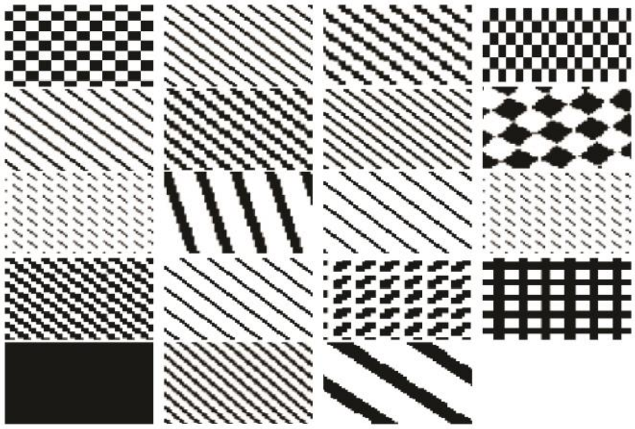

Figure 2: Applied surface patterns

2.3 Anilox rollers

The correct selection of an anilox roller is also a key factor to achieve the optimal ink coverage of a surface. It´s not the purpose to produce a print splashing in varnish (or ink), but to find the optimal balance between the plate and anilox for the specific ink or varnish. For the aims of our research, we used three types of anilox rollers with different ink volumes and screen line densities. Table 1 shows our anilox roller selection for the testing.

Table 1: Anilox rollers used in the testing process

	Screen line density (l/cm)	Ink volume (cm³/m²)
Anilox 1	360	5,5
Anilox 2	260	7
Anilox 3	200	10

2.4 Printing plates

The tests were performed using 3 different plate types. We took 2 plates from the Flint Group, digital variants of the nyloflex® ACE and nyloflex® ACT plates. The nyloflex® ACE Digital is a high durometer plate for the highest quality in printing of flexible packaging, labels, beverage packaging, and corrugated preprint. Its durometer is 78 Sh A. It should have a good ink transfer and provide smooth solids. The nyloflex® ACT Digital is a medium-hard plate, optimized for the printing of designs that combine halftones and solids in one plate. It has a hardness of 74 Sh A. Both plates are "standard" digital plates with no inherent flat-top dot system, but can be processed by hardware technologies to create flat-top dots. For our tests, the plates were processed on the DuPont™ Cyrel® DigiFlow technology, where flat top printing dots were created.
The third plate selected for the test was the MacDermid LUX ITP™ 60. This plate was the first to market with an inherently flat-top dot technology for flexographic photopolymer plates. It´s a hard durometer photopolymer plate with its 78 Sh A, where no additional platemaking steps or equipment are needed to take advantage of the flat-top dots provide.
After selecting the appropriate cliché and anilox rollers, the testing process began. Test printing was performed on a Soma Midi Flex 2 press on a 0.012 mm thick polyester substrate.
Measurements were performed with a Biuged BGD515/3 gloss meter. Furthermore, we visually examined plate surfaces and structural changes of matte varnished surfaces using a high-resolution microscope and Peret Flex Pro instruments.

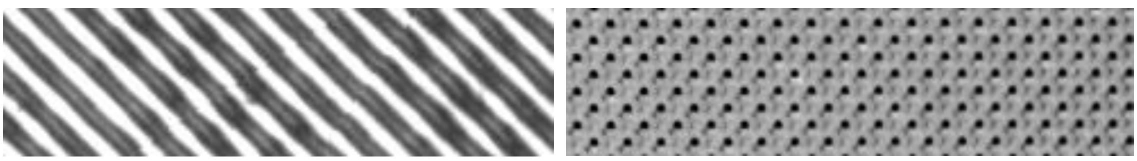

Figure 3: Magnified surface structure on the plate

3. RESULTS

We were the first to perform visual examinations using a high-resolution microscope and Peret Flex Pro. It is clear from the samples to what extent the structure of the location of the matting grains within a given varnished surface can be changed. In the second test cycle, the gloss values were measured in 19 different parts of the test chart.

Table 2: Measurement results for the 360 l/cm / 5.5 cm^3/m^2 anilox roller

Anilox 360L/cm /5.5 cm^3/m^2			
Sample	ITP-60	ACT-D	ACE-D
S1	32,7	40,7	36,5
S2	21,5	24,6	29,7
S3	32,7	27,3	32,8
S4	32,7	34,3	43,3
S5	28,1	33,2	46,3
S6	33,7	32,1	37,3
S7	33,5	35,4	38,2
S8	35,6	30,2	36,3
S9	57,6	54,3	71,8
S10	62,4	66,8	62,5
S11	33,8	35,9	38,6
S12	23,1	23,7	29,4
S13	32,3	29,2	38,3
S14	35,6	33,3	34,7
S15	39,2	35,5	49,3
S16	28,6	27,9	27,6
S17	34,3	41,8	49,8
S18	45,8	41,9	60,7
S19	63,8	46,5	68,1

Table 3: Measurement results for the 260 l/cm / 7 cm^3/m^2 anilox roller

Anilox 260L/cm /7 cm^3/m^2			
Sample	ITP-60	ACT-D	ACE-D
S1	35,3	29,6	33,5
S2	26,7	25,6	22,1
S3	32,9	29,4	33,8
S4	35,7	37,8	42,1
S5	39,8	35,1	42,4
S6	32,0	32,1	35,1
S7	36,2	45,2	32,7
S8	36,1	36,2	39,5
S9	69,3	69,5	71,1
S10	55,4	64,9	54,1
S11	26,1	37,8	33,4
S12	31,1	22,1	25,3
S13	27,7	28,3	30,1
S14	32,2	32,8	33,7
S15	32,5	36,6	56,2
S16	19,8	26,6	29,0
S17	41,2	44,5	59,8
S18	49,8	48,8	59,9
S19	43,8	49,3	66,0

Table 4: Measurement results for the 200 l/cm / 10 cm³/m² anilox roller

Anilox 200L/cm /10 cm³/m²			
Sample	ITP-60	ACT-D	ACE-D
S1	16,3	12,8	15,1
S2	8,6	8,4	8,4
S3	8,9	8,6	9,8
S4	9,6	8,2	10,6
S5	10,5	7,3	9,2
S6	9,7	7,5	8,6
S7	13,7	12,4	18,7
S8	9,0	8,1	8,1
S9	47,4	19,8	63,1
S10	44,8	37,1	48,5
S11	16,1	17,1	19,8
S12	7,8	9,1	9,2
S13	7,7	8,2	9,4
S14	8,3	7,6	9,8
S15	10,6	9,5	10,5
S16	9,3	7,6	9,0
S17	13,1	10,4	14,0
S18	18,1	11,5	15,7
S19	18,2	10,6	17,3

4. DISCUSSION AND CONCLUSIONS

By selecting the appropriate anilox roller, the available gloss range can be defined well as it follows:

Table 6: Gloss range

Gloss range	Screen ruling (L/cm)	Ink volume (cm³/m²)
8-50	200	10
20-70	260	7
25-70	360	5.5

In all cases, the lowest gloss values were obtained with the Flint nyloflex® ACT plates, from which it can be concluded that the opacity of the lacquered surface can be increased by using softer printing plates.
By evaluating the results, we determined the range over which the gloss of the varnished surface can be changed using different cliché surface structures. Within a printed test sheet, the maximum brightness difference from a minimum of 8.4 to a maximum of 63.1 can be achieved using Anilox 3 (200 L / cm screen line density, 10 cm³ / m² ink volume) and Flint ACE-D cliché.
Most matte surfaces were obtained by the surface patterns with the geometry shown in Figure 4.

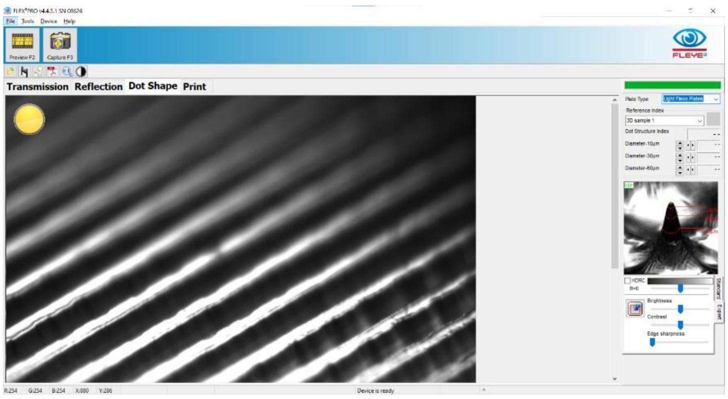

Figure 4: A surface pattern that formed the most matte surface

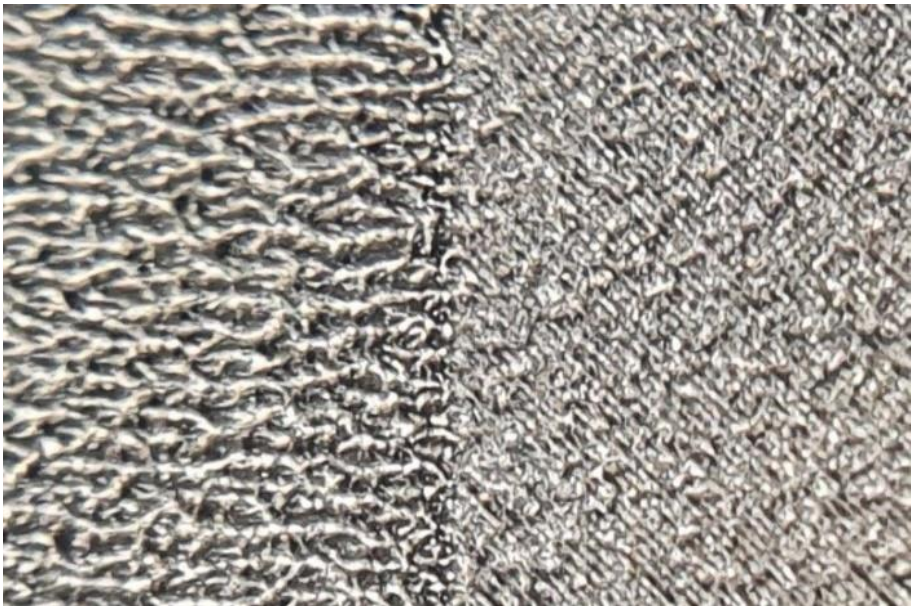

Figure 5: printed without a pattern (left) and with pattern (right)

It can be seen in Figure 3 that we were able to change the structural surface of the lacquered parts with the microcellular patterns, without printing on the left side, with a line pattern on the right side.
The above test results, as a segment of the potential of flexo printing technology, can have a significant economic impact in terms of efficiency and economy, thus contributing to the protection of our environment. In addition to minimizing the amount of varnish used, production can be optimized with the most suitable surface pattern and the most efficient varnish type to use. With the help of the test results, we got a more accurate picture of the brightness values of the type of varnish developed by us when using clichés with different surface patterns, thus allowing covering the widest possible range of applications.
Despite the crisis of the past two years the packaging industry and the the flexographic printing haven´t lost their dynamics ensuring the realization of many research and development projects. Between our future research plans is included further research, where we want to detect the appropriate screen ruling to achieve the minimal gloss values for our matte lacquering research project.

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INFLUENCE OF THE DIFFERENCE ELECTRIC CHARGE ENERGY TRANFER INK TO PAPER IN DIGITAL PRINTING

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Abstract: *By integrating light and static electricity to form a passive electrostatic image on an image unit covered with a light conducting substance, the electrophotography principle is applied to digital printing. and employ powder ink with a charge or toner on both the recording unit's image and non-image areas. Static electricity also causes the image to transfer to the printed material. The quality of the image that is conveyed and received depends on the electric charge energy. This study's objectives were to examine how the electric charge energy difference in a digital press image impacts the color value. By changing the electric charge's five levels to -10, -5, 0, +5, and +10, evaluate the color difference value, and selected each of electric charge energy value to improve color quality of digital printing.*

Key words: electrophotography, electric charge energy (ECE), color gamut

1. INTRODUCTION

Electrophotography is the most widespread of nonimpact-printing technology that exists. The principle of electrophotography printing is a direct printing process where image information in the form of electronic signals is converted to a latent electrostatic field stored on a photoconductive dielectric material (Johnson, 1992). The latent charged image, stored on the photoreceptor, is inked with dry toner particles and then transfers directly or via intermediate belt to the paper. Inking takes place by inking units that transfer the fine toner particles in a noncontact manner to the photoconductive drum through electric potential differences (electric fields) and thus image becomes visible (Sardjeva & Mollov, 2013). That latent image is made visible by depositing charged colorant particles on the field pattern and then made permanent by fixing (Johnson, 1992).
The principle of electrophotography printing is achieved by using light and static electricity to create images. There are the following principles;
1. Use a recording unit coated with an optical material or photoconductor material. (photoconductor) that is a semiconductor It is a semiconductor and has dielectric properties, i.e., it is both a conductor and an insulator depending on the light exposure conditions. Will conduct electric chart and allow to flow through it but when there is no light or when in the dark is an insulator or conducts less electric. Before the image is formed on the recording unit electrical charge must be applied to the surface of the recording unit first.
2. Light projection on the recording unit to form the initial image electrostatically. When the recording unit is exposed to light with high sufficient energy. Particles in a semiconductor at the imaging surface at the uncovered locale are transformed by the light excitation of the peripheral electrons with higher energy until they take off the particle. This permits the exposed area to conduct power and the discharge from the area, such as permitting it to stream along the ground. As a result, the light-exposed region is not one or the other charged nor electrically unbiased (neutralized), and the un-covered region can either be a picture region or a non-image region, depending on the printer innovation. The regions that were not uncovered to light retained the same electrical charge. After light will occur within the image region on the recording unit It may be idle image which is undetectable to the bare eye and has electrostatic properties, that's may or may not have an electric charge depend
3. Electrostatic printing of pictures on substrates utilizing electrically charged inks. It may like a fine powder or liquid ink called toner transfer on the recording unit. The printing ink will selectively adhere to as it were the covered-up image zone by electrostatic constrain. Then a picture with toner that shows up to be obvious. This image is at that point transferred to print on a substrate, for the most on paper. Toner to be able to stay to the paper. It is caused by an electric charge that's inverse to

the electric charge on the toner on the back of the paper. But it causes attractive force to ink on the paper that's more grounded than suction drive to print ink on idle pictures. The toner can be transfer from the recording unit to adhere on the paper (Tungwichacharn, 1982).

In digital printing mostly used electrophotography method, toner is transferred to the paper base and then fused in place. The paper is usually uncoated, and the images are reasonably stable, because they are composed of pigment particles that are fused to the paper with a durable polymer binder material (Fogra, 2018).

The manufacturers of digital printing, on the other hand, use their own brands with different properties and features, generally of electrophotography printing uses a direct-current electric field (DC) to transfer toner from an image transfer belt onto paper. New technology to use an alternating-current electric field (AC), which produces a condition that enables toner to transfer easily to the concave portion of the paper (Ricoh, 2022).

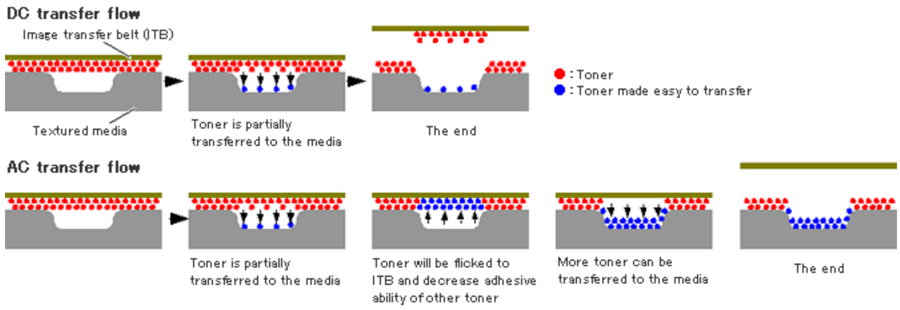


Figure 1: Flow image of DC transfer and AC Transfer

The objectives were to study the influence of different electric charge energy transfer of ink (toner) to paper in digital printing, and selective for improve color quality to be able to create a color gamut close to HDMCoated color data. For this study have been used test files as a characterization target for device profiling and for quality analysis. Used test chart for ISO 12642-2 / ANSI IT8.7/4 random were printed by the Heidelberg versafire EV, compared color reference from data for HDMCoated color data.

2. METHODS

2.1 Printing Substrates

The printing substrate in this study was used same nominal coated paper with 250 g/m^2 paper properties show as Table 1.

Table 1: Properties of substrate

Substrate	Properties			
	Type	Basic weight (g/m2)	Whiteness (%)	Color Value (L* a* b*)
Type1	Coated	250	81.63	92.70/-1.01/-0.06

2.2 Digital Printing

The digital printing as Heidelberg Versafire EV, delivers high quality and offers the possibility of reliable production of CMYK standard jobs, as well as the embellishment with the white special toners. The image quality is achieved to the resolution of 4,800 × 2,400 dpi. Enhanced toner transfer system for structured media (AC/DC) and controller by Prinect Digital Frontend (DFE).

2.3 The condition for examination (electric charge energy; ECE)

The objectives of this study were as follows:

- To study of the electrical charges energy that affect the quality of image transfer on digital printing, order the following conditions: ECE1 (-10), ECE2 (-5), ECE3 (0), ECE4 (+5) and ECE5 (+10)
- To study the color difference under conditions of electric charge energy for each color.
- To improve image quality consequence after analyze result to adjust electric charge energy.

2.4 Image transfer (electric charge energy: ECE)

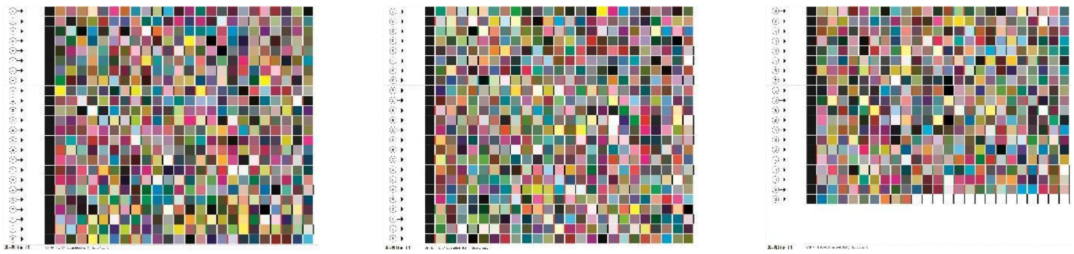
This model for examination were adjust quality output of the electric charge energy for each color that shown in Table 2.

Table 2: The electric charge energy for each color.

Electric charge energy (ECE)	Black	Cyan	Magenta	Yellow
ECE 1 (-10)	-10	-10	-10	-10
ECE 2 (-5)	-5	-5	-5	-5
ECE 3 (0)	0	0	0	0
ECE 4 (+5)	+5	+5	+5	+5
ECE 5 (+10)	+10	+10	+10	+10

2.5 Test Chart

Reference test chart for ISO 12642-2 / ANSI IT8.7/4 random_S25 target, CMYK" for i1Pro amount 1,617 patches; this standard defines a data set of ink value combinations that may be used to characterize four-color process. While it is primarily aimed at process color printing with CMYK inks, it may also be used with any combination of three chromatic inks and a dark ink.



(a) IT874_Random_S25_P1_i1 (b) IT874_Random_S25_P2_i1 (c) IT874_Random_S25_P3_i1

Figure 2: Testchart IT8.7/4_Random_S25 for i1Pro

2.5 Colorimetric Testing

The evaluate of these colorimetric values of test chart after print on coated paper of prints for difference electric charge energy was measured by spectrophotometer EFI ES-2000. The colorimetric difference (ΔE) measured ΔE^*_{00} in L*a*b* the color data were measured under illuminant D65, 2° standard observers. shown equation below;

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

Table 3: Evaluation according the total color difference (ΔE)

ΔE value	Assessment
0 - 1	Unnoticeable difference
1 – 2	Very little difference
2 - 3.5	Middle difference
3.5 – 5	Noticeable difference
>6	Unacceptable (strong difference)

3. RESULTS

After the experiment, all samples were subjected to colorimetric testing by spectrophotometer EFI ES-2000 Model i1Pro of each sample were performed by Prinect Color Toolbox 12.0 to obtained color value for comparison and created La/Lb diagram graphs of the color difference. And improve quality printed of color reproduction by adjust electric charge color for quality transfer.

3.1 The Color value comparison

The color data from test chart; ISO 12642-2 / ANSI IT8.7/4 random_S25 was measured by spectro-photometer EFI ES-2000 model i1Pro with Prinect Color Toolbox 12.0. In test chart combination of color patch of single, double and triple color combination are there. This paper was assessed total color data and total color difference (ΔE^*_{00}).
The result of these test chart it is determine the color difference of digital printing, and then compared data between HDMCoated color data with samples; was compared different electric charge energy in the color values data. The color difference of each sample these show in Table 4 and Figure 3.

Table 4: Color difference between HDMCoated color data and Samples on coated paper.

ECE	Black	Cyan	Magenta	Yellow	Red	Green	Blue
ECE 1 (-10)	3.4	2.74	2.07	29.44	2.22	2.7	2.56
ECE 2 (-5)	3	1.37	1.79	1.43	1.36	1.92	3
ECE 3 (0)	4.48	1.21	1.25	1.4	2.18	1.93	2.68
ECE 4 (+5)	3.34	1.96	3.21	1.79	2.71	3.73	5.29
ECE 5 (+10)	4.5	3.04	4.43	2.76	5.12	7.57	9.05

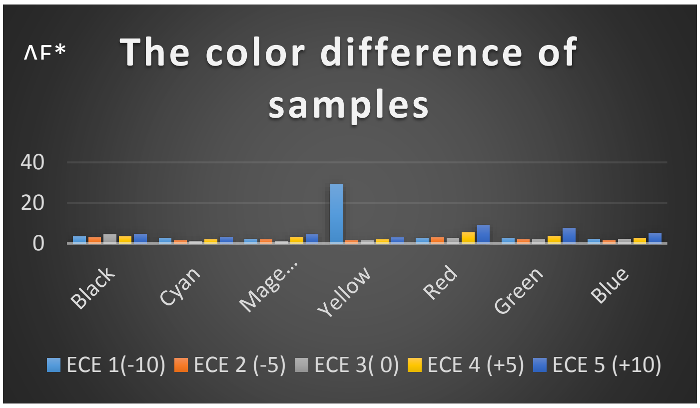
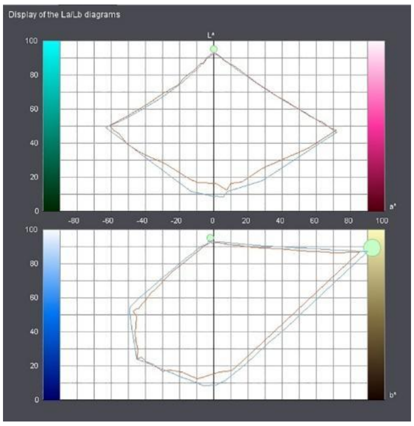


Figure 3: Compare for color difference (ΔE^*_{00}) between HDMCoated and Samples

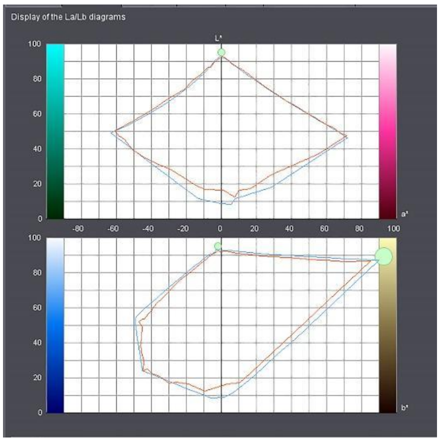
In Table 4 and Figure 3 show color difference (ΔE^*_{00}) between HDMCoated color data (reference) compare with five samples that founded as ΔE of each sample under condition as; Black for ECE2 has the color difference (ΔE) lowest is 3.0. cyan and magenta have the lowest color difference for ECE3 are 1.21 and 1.25 respectively and yellow has the lowest color difference for ECE3 is 1.40. At color combination represent to red green and blue; red and green lowest color difference for ECE2 and lowest of blue for ECE1.

3.2 The La/Lb diagrams Comparison

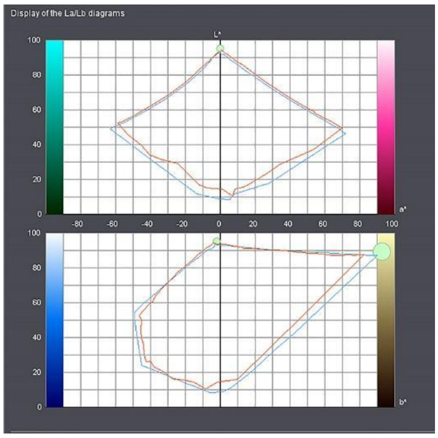
In order were compared the difference color gamut La/Lb diagrams comparison on coated paper by Prinect Color Toolbox 12.0 of Heidelberg manufacturer are shown in Figure 4. These La/Lb diagrams represent HDMCoated data (blue line) and samples (red line) of difference electric charge energy.



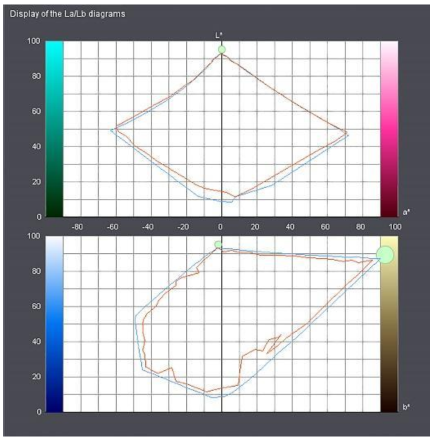
(a) Display of the La/Lb diagrams; ECE3 (0)



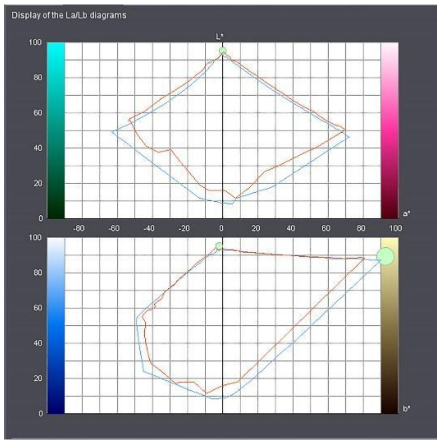
(b) Display of the La/Lb diagrams; ECE2 (-5)



(c) Display of the La/Lb diagrams; ECE4 (+5)



(d) Display of the La/Lb diagrams; ECE1 (-10)



(e) Display of the La/Lb diagrams; ECE5 (+10)

Figure 4: Compared the La/Lb diagrams and ΔE of each color from Heidelberg Versafire EV

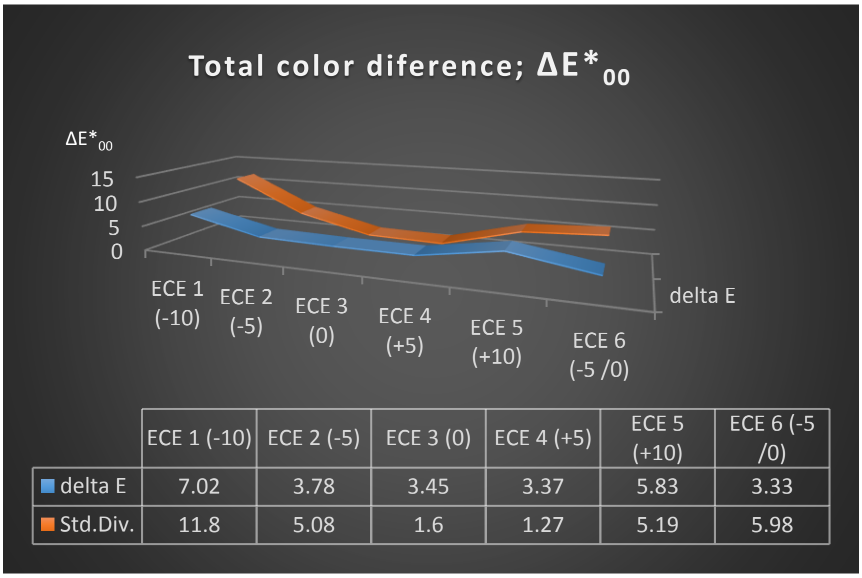
The results of comparison between HDMCoated color data with samples. The color gamut of HDMCoated is larger when compared other samples the Δa*/ Δb* for ECE 3 (0) can produced color tone similar the reference data. But the samples for ECE3 (a) cannot produced green/red color gamut almost equal to the reference data.

In the Figure 4 for the ECE2 (b) can be show color gamut about of yellow and blue nearby than ECE3 (a) and ECE1 (d) cannot to produced red and green that not as good enough. For ECE4 (c) and ECE5 (e) cannot to produced red/green yellow and blue similar color gamut of HDMCoated.

3.3 Improve quality printed of color reproduction by adjust electric charge color for quality transfer

After analyzed we founded the cyan and yellow for ECE2 (-5) have lowest color difference. By adjust electric charge energy of quality transfer for improve quality output of color reproduction as black is 0, cyan is -5, magenta is 0 and yellow is -5 the result show in Table 5 and Figure 5.

The results of these test chart it is determined the color gamut of digital printing, and then compared data from samples under conditions; different electric charge energy was compared the color values data between HDMCoated color data with samples. The total color difference of each sample these show in Figure 5,6.



	ECE 1 (-10)	ECE 2 (-5)	ECE 3 (0)	ECE 4 (+5)	ECE 5 (+10)	ECE 6 (-5 /0)
delta E	7.02	3.78	3.45	3.37	5.83	3.33
Std.Div.	11.8	5.08	1.6	1.27	5.19	5.98

Figure 5: Compared for total color difference (ΔE^*_{00}) between HDMCoated and Samples

In Figure 5 show total color difference between HDMCoated color data with five electric charge energy on coated paper. At ECE 3 we adjusted electric charge energy at zero has the total color difference (ΔE*) lowest is 3.45 and when analyzed data we adjusted electric charge energy (ECE6) as black and magenta is zero and cyan and yellow are -5. After compared between HDMCoated and new ECE 6 by Prinect Color Toolbox 12.0 the total color difference of ECE6 is 3.33 that lower ECE 3 the result show in Figure 6.

Hide CIELAB color values

	Reference L	Reference a	Reference b	Comparison L	Comparison a	Comparison b	ΔE*(2000)
Paper white	93.00	-0.00	-2.97	92.61	0.74	-1.60	1.71
Black	16.00	-0.11	0.03	18.97	1.59	-3.54	4.48
Cyan	54.00	-36.00	-48.98	53.29	-34.01	-45.89	1.21
Magenta	46.00	72.01	-4.99	47.11	73.02	-3.55	1.25
Yellow	87.00	-6.01	90.01	86.56	-7.36	84.92	1.40
Red	46.00	66.98	46.97	48.11	63.79	42.00	2.68
Green	48.99	-62.99	26.02	49.94	-61.74	21.77	1.93
Blue	24.00	20.99	-44.98	22.19	22.10	-42.85	2.18
Overprint	22.02	-0.07	0.04	31.07	4.64	-3.10	9.43

0.0 5.0 10.0

Hide analysis

Mean	3.45
Deviation	1.60
Maximum	9.65
Maximum at patch	682

(a) CIE report and analysis color difference (e) of ECE 3 (0)

Hide CIELAB color values

	Reference L	Reference a	Reference b	Comparison L	Comparison a	Comparison b	ΔE*(2000)
Paper white	93.00	-0.00	-2.97	93.52	1.02	-3.24	1.53
Black	16.00	-0.11	0.03	18.14	1.78	-0.23	3.06
Cyan	54.00	-36.00	-48.98	54.63	-34.64	-43.40	1.81
Magenta	46.00	72.01	-4.99	47.07	72.14	-1.84	1.64
Yellow	87.00	-6.01	90.01	86.12	-6.04	84.34	1.30
Red	46.00	66.98	46.97	47.47	65.99	41.54	2.65
Green	48.99	-62.99	26.02	51.50	-59.57	23.46	2.75
Blue	24.00	20.99	-44.98	24.33	24.10	-42.11	3.32
Overprint	22.02	-0.07	0.04	24.74	2.03	-0.68	3.60

Hide analysis

Mean	3.33
Deviation	5.98
Maximum	65.43
Maximum at patch	424

(b) CIE report and analysis color difference (e) of ECE 6 (0/-5)

Figure 6: Display the total color difference (ΔE$_{00}$) from Prinect Color Toolbox 12.0*

In Figure 6 that show about of CIELAB color values report between HDMCoated with samples: ECE 3, ECE 6 (change electric charge of cyan and yellow to -5 and still black and magenta is 0 (ECE6)). Consequently, the total color difference (ΔE*) of sample to decrease to 3.33.

4. DISCUSSION

Dry toners consist of pigments embedded inside polymer beads. The fusing phase of the electro-photographic process melts the polymer beads to the surface of the paper (Ordant, 2019).

Toner is transmitted from an image transfer belt onto sample (coated paper) that was employed with a direct-current electric field when electrophotography printing is functionalized (DC). In order toner from the belt onto the paper, new digital printing technology uses an alternating-current electric field (AC). The samples (ECE6) showed a slight reduction in ΔE*$_{00}$ (0.12 for cyan and yellow was adjusted). In comparison, the overprint (CMY) samples, which show similar the HDMCoated data in ΔE*$_{00}$ (5.83). While ECE 6's deviation value deviates from the distribution's average (5.98).

5. CONCLUSIONS

For all ink combinations, the electric charge energy had an impact on how accurately the colors in the test chart and its overprints were reproduced. The Heidelberg Versafire EV prints from digital printing at ECE6 are better at reproducing color. Future analyses should functionalize each substrate's unique characteristics, and it is anticipated that doing so will bring color value closer the output target and apply so boost the reaction of the other substrate

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CORONA TREATMENT AND ITS IMPORTANCE IN FLEXO PRINTING

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Abstract: *With the increasing importance of flexible packaging in recent years, the trend of packaging printing in the printing industry has increased. The most widely used printing systems in flexible packaging printing are flexo and rotogravure printing. Although rotogravure printing is as high quality and fast as flexo printing, it has made flexo printing more preferable because the printing preparation processes take longer and are more costly. Flexo printing is a high printing system, and it is a printing system that is widely used especially in corrugated cardboard and flexible packaging printing.*
In flexo printing, the main factors affecting quality are the material to be printed and its physical properties. In flexo printing, the main factors affecting quality are the material to be printed and its physical properties. In particular, the surface structure of plastic film and metallized packaging substrates with low surface energy is expected to be ink-retaining. Because the surfaces of synthetic plastic films and metallized foils have a smooth and slippery structure, preventing printing inks from sticking. Because the binder in the structure of the ink does not have a rough surface to penetrate. In order for plastic films to be printed, their surfaces must have certain properties. For this, surface improvement process called corona is applied to these material surfaces. With this process, the film material surfaces are made micro-rough and the ink adheres to the surface better and is more resistant to external factors. It should be borne in mind that the surface of a film material that has undergone a corona treatment may deteriorate over time unless it is printed on. Because the effectiveness of the corona treatment is time-limited and the surface energy inevitably decreases after a while. They are also affected by environmental conditions such as temperature and humidity.
In this study, to show the importance of corona surface coating, test prints were made with flexo printing on corona treated film materials whose corona became insufficient due to time. In the examination of the microscopic images of the test prints, it was observed that the ink adhered very well and was resistant to external factors on the surfaces where the corona treatment was adequately applied. On the other hand, it was determined that the ink color intensity decreased and the print quality deteriorated in the material with insufficient corona after the corona period.
As a result, in printing systems, the surface energies of the plastic films must be approximately 10 mN/m higher than the surface tension of the ink during the printing process, in order to maintain good printing quality and unchanged throughout the printing, and for this, the surface energies of the plastic films must be increased by corona surface treatment. demonstrated on test prints and microscopic images of prints.

Key words: Flexo printing, Corona treatment, Flexible packaging printing, Plastic films

1. INTRODUCTION

Flexo printing is a high printing system. The high image on the printing plate (the printed product) is transferred directly to the material surface in contact with the plate. The most important distinguishing features from other printing systems; the use of low-viscosity inks, the anilox roller that adjusts the ink volume, and the rubber-based elastic of the printing plates. The elastic plate allows high quality and very high volume printing (Figure 1) (Büyükpehlivan & Oktav, 2020). Flexo printing is one of the basic printing systems used in commercial printing production, and it is a very preferred printing type in packaging printing on high-volume plastic and metallized films with its print quality being improved day by day (Żołek et al., 2020; Abdel-Bary, 2003). Especially frozen foods, nuts, pulses etc. It is preferred for printing dry foods, liquid foods and plastic bags (Żołek-Tryznowska et al., 2020; Büyükpehlivan & Oktav, 2020).
In determining the flexo printing quality; In addition to the paper, cardboard, plastic and metallized films and ink properties used, environmental, mechanical, physical and procedural factors are effective. In addition, the compatibility of the materials used with the printing technique, the plate material and preparation, the improvements in the anilox roller, machine and control systems also affect the quality.

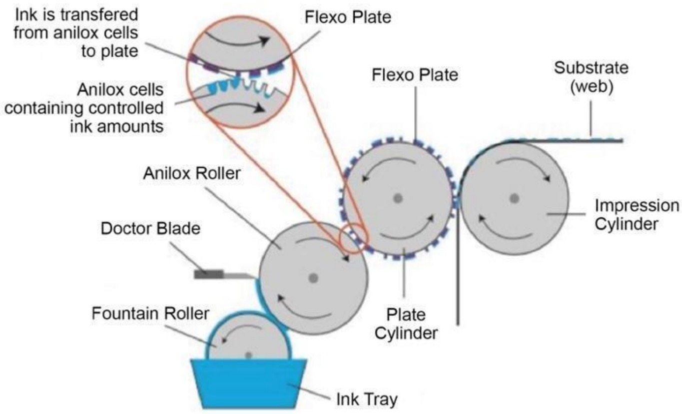


Figure 1: Flexo printing scheme (Wikimedia commons, 2022)

In flexo printing, with rubber-based flexible photopolymer plate, dots with 80% screen frequency and 3% screen ton value can withstand millions of pressures (Bould et al., 2004). The printing plate is prepared by completely computer-controlled exposure and solvent-free developing. The stages of the preparation process of the printing plate from design to printing and the physical properties of the plate made ready for printing have parameters that directly affect the quality. By transferring water-based, solvent-based and UV-curing low-viscosity inks onto the plate by means of an anilox roller, 3-5 micron-diameter dots are printed on the flexible printing material that can flow at a speed of 500 meters/minute in roll-to-roll printing machines. For a good print, there are very important quality elements that must be kept under control (Tomašegović et al., 2020; Ülgen, Oktav & Gençoğlu, 2012; Büyükpehlivan & Oktav, 2020).

One of them is that the surface energy of the substrate is desired and suitable. This shows the ink adhesion in printing, that is, the adhesion feature. Surface energy of the substrate; It determines the interfacial relationship and adhesion strength of the substrate material with ink and other plastic films (print job). In order to increase the surface energy of plastic-based substrates, corona treatment should be applied and controlled.

The surface tension of the plastic films and low viscosity inks used in flexo printing is the most important parameter in the material-ink interface relationship. Having these parameters at optimum values is essential for quality printing results. The corona treatment applied on plastic materials determines these optimum values. For this reason, a comprehensive examination of the corona process will contribute to the applications (Ülgen, Oktav & Çakır, 2019; Lindner et al., 2018).

Corona treatment is a process step defined in the industrial sector in 1951, developed after an engineer in Denmark was asked to find a safe way to print on plastic surfaces. This process is a method used to ensure that printing inks and lacquers adhere well to synthetic materials and metal foils. In the corona process, high-frequency electronic beam is applied to the synthetic material surface. Electron particles leaving the electron source quickly crash onto the flowing material. But before the electrons reach the material, they collide with the light-carrying air molecules; They partially react with ozone and nitrogen oxides. When electrons come into contact with the material, they dissolve carbon hydrogen and carbon bonds due to their high energy. Thus, ink and lacquers are easily adhered to the material (Figure 2) (Louzi & de Carvalho Campos, 2019; Pego et al., 2019; Jones, Strobel & Prokosch, 2005; Rocca-Smith et al., 2016).

The duration and severity of the corona surface treatment are determined by the chemical structure of the printing material and the surface tension difference between the material and the printing ink (Carradò et al., 2011). Corona treatment systems do this by applying a certain level of power to the surface for a certain period of time. This power/time parameter is measured in watt density, defined as watts/ft^2 (or m^2)/minute. Although the applied watt density is directly related to increases in dyne level (surface tension), the relationship is non-linear and depends on system and material parameters.

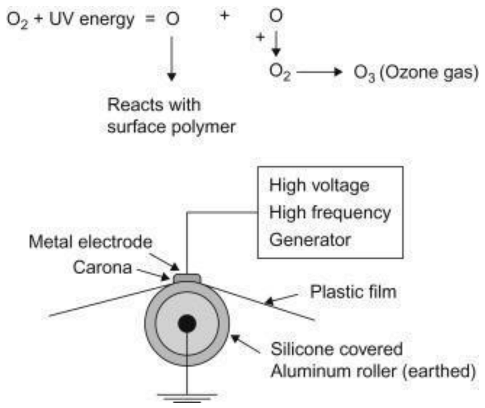


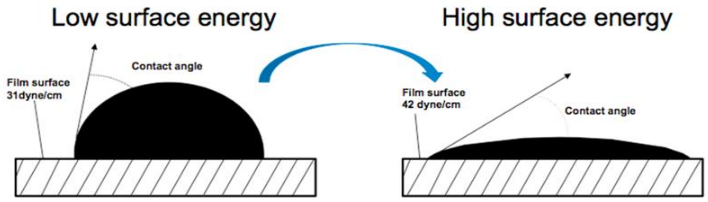
Figure 2: Corona Treatment System (Gilbertson, 2022)

Corona density is the changing factor and can be calculated mathematically using the following formula (1):

$$Power = M * W * S * T \tag{1}$$

T – the number of sides that will be treated
S – the line speed, measured in m/min
W – the width of the film, measured in m
M – material factor, measured in watt/m squared per min (ZOi Films, 2022).

Corona surface improvement processes are not applied to all film materials in the same way. Different processing is applied depending on the type of material you plan to use. In order to ensure good adhesion, the surface energy of the printing material must be higher than that of the printing ink to be used.
As a general rule, when the surface energy of a printed substrate is greater than the surface tension of the ink by about 10 mN/m, a correct bond and adhesion can be established between the liquid and the substrate surface (Gilbertson, 2022; O'Hare, Leadley & Parbhoo, 2002). Since solvent-based printing inks have a surface tension of approximately 25 dyne/cm, it is clear that films such as PE (31 dyne/cm) and PP (29 dyne/cm) must be subjected to corona surface coating before printing (Figure 3) (Permabond, 2022; ZOi Films, 2022; Sun, Zhang & Wadsworth, 1999; Wegman & Van Twisk, 2012).



Material – Basic	Dyne/cm
PP	29
PE-LD	31
PE-HD	32
BOPP	32

Process - Application	Dyne/cm
Print – solvent based ink	40-42
Print – water based ink	46-48
Coating	44-54
Lamination	46-56

Figure 3: Plastik film baskı altı malzemeleri yüzey gerilimleri ve baskıda olması gereken yüzey gerilimleri (Permabond, 2022)

Corona surface treatment only affects the surface layer of the plastic film to such an extent that it creates micro-pits approximately 0.01 microns deep (Vetaphone, 2022).
The common point of these processes is that these films increase the surface energy. This leads to a better wettability as well as a higher bond strength (Brock et al., 2016). Plastic films most commonly used in packaging applications; polyethylene (PE, LDPE, HDPE, MDPE), polypropylene (CPP, OPP, MOPP, BOPP,

metallized films), polyamide (PA), polyvinyl chloride (PVC), polyvinyldene chloride (PVDC), polyethylene terephthalate (PET) (Büyükpehlivan & Oktav, 2020; Wu et al., 2011). These materials, whose surface properties differ from each other, can be used alone or in a mixture depending on the characteristics of the product (Abdel-Bary, 2003; Plastik ve Ambalaj Dergisi, 2022).

a)  b) 

Figure 4: Untreatment (a) and Corona Treatment Surface (b) (AFM Images taken with AFM (Atomic force microscopy) (Popelka et al., 2018).

The higher the surface energy of a plastic film, the higher the bond strength of anything adapted to its surface. One reason for the low surface energy may be the property of the material. For example: many plastics have very low surface energy, so chemical or physical treatment is necessary to achieve good adhesion (Figure 4) (Wu et al., 2011; Villermet et al., 2003).

In general, the lower limit on these materials to be printed with flexo printing is 38mN/m. If the surface energy is lower than this value, the adhesion of the printing ink will be weak (Figure 5a), if it is above this value, the adhesion will be sufficient (Figure 5b). Therefore, for a good printing result, it is necessary to measure the surface energy of the plastic film before it is printed. Dyne corona pens are used to control surface energies. Using these pens is the cheapest, fastest and easiest way to check if a plastic substrate has sufficient surface tension for printing operations. This control method is always recommended to avoid having to scrap large quantities of substrate due to insufficient bad press (Vetaphone, 2022).

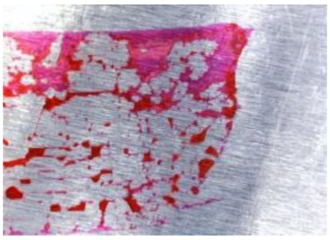
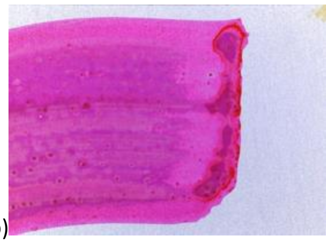
a)  b) 

Figure 5: The image on the corona weakened surface (a) and well corona treated surface (b) using a 38 mN/m corona pen

2. METHODS

In particular, the surface energies of the materials used in flexible packaging should be approximately 10 mN/m higher than the surface tension of the ink. Otherwise, ink adhesion will not occur at the desired level and the expected print quality will not be achieved. In this case, the surface energies of flexible packaging need to be increased. Ink adhesion is related to the wetting properties of the substrate and ink materials. Corona surface improvement process is the most widely used roughening process, which gives good results on plastic-based printing films to improve ink adhesion and adhesion properties by increasing the surface energies of plastic films.

In the study, prints were made on polypropylene material, one of the most widely used plastic film materials in flexible packaging printing, to test the importance of ink retention, which affects quality. In the study, printing was carried out with 50 g/m2, 40 micron OPP material, Zahn 3 viscosity measuring cup and ink, the viscosity of which was determined as 20 seconds in ASTM D4212 standard. Test prints were made on the 10-color Omet X10 flexo label printing machine with the ability to make physical corona. A Corona test pen with a medium value of 38 mN/m was used to control the printing surfaces. Test prints were made on corona weakened and corona treated OPP film material. Microscopic images of test prints were taken with a Leica S8APO DFC295 stereoscopic microscope. In the study, the effect of corona surface improvement on the print quality is explained by examining the test print surfaces rather than theoretically.

3. RESULTS

In the study, firstly, prints were made on OPP film material with insufficient corona. When the friction pressure was applied physically on the printing surfaces, it was observed that the frictional strength of the inks was insufficient by means of a finger test. In addition, it was seen in stereoscopic microscopic shots that distortions in both solid tone and process printing and white holes in ground prints were printed on the OPP plastic film, the surface of which became unstable due to the corona weakened due to long storage time and adverse conditions (Figure 6). This caused deviations in the printing colors.

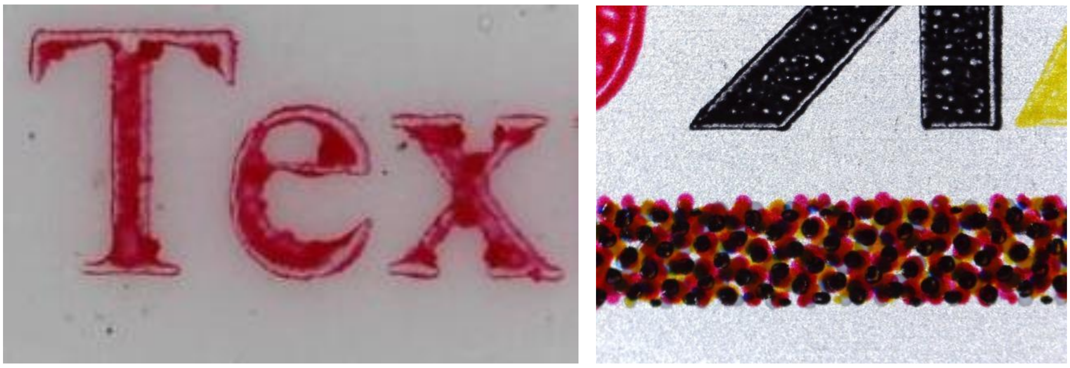


Figure 6: Examples of solid tone and process printing on OPP film material with weakened corona

It was determined that the printing results of both solid tone and process printing works were of the desired quality in the printing made on OPP with sufficient corona surface improvement (Figure 7). It was observed in microscopic shots that the ink adhesion to the surface was sufficient, and it was determined that the colors were in the desired and expected color tones.

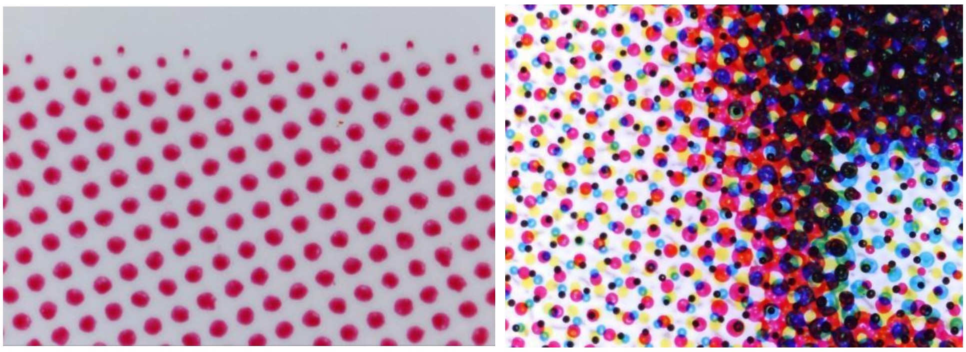


Figure 7: Solid tone and process printing examples on OPP film material with sufficient corona

4. CONCLUSIONS

In all printing systems, consistency at the beginning of the press and throughout the press is very important for quality. The physical and structural properties of printing materials, printing plates and inks, environmental, mechanical, physical and procedural factors are the main factors in ensuring consistency. The improvement of the printing quality specific to the flexo printing system; The knowledge and skills of the printing master depend on the anilox roller, scraper blade, machine and control systems.

Corona process usually is used for the treatment of polypropylene, vinyl foils, polyethylene, metallized surfaces, PVC, Paper and cardboard stock, PET and other similar material surfaces. These materials must have some features for printing and post-print lamination processes. For this, the surfaces of these materials must be treated with corona surface improvement. With the corona treatment, the material surfaces are made micro-rough and the ink adheres to the surface better. Printing is sometimes done on both sides of the material. In such cases, having corona on both sides may cause blocking of the prints. In this case, the prints must be dried very well.

The surface of a film material that has undergone corona treatment may deteriorate over time as long as there is no pressure on it. Because the effectiveness of the corona treatment is time-limited and the surface energy inevitably decreases after a while. They are also affected by environmental conditions such as temperature and humidity. Ink adhesion will weaken as the plastic surface will return to its original state. For this reason, if the corona treated plastic film has been kept for months for a long time before printing, the corona process must be repeated. Corona surface treatment can change the surface structure of plastic films and affect their adhesive properties. Increased surface roughness can result in increased or decreased adhesion depending on surface energies, potential bonding, and the presence of voids. Excessive application can cause bumps to form on the surface of the material and have a deteriorating effect on adhesion and wettability properties.

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ANALYSIS OF BLACK ELECTROINK SCREENING ELEMENTS AFTER PRETREATMENT THE FINE ART PAPER SUBSTRATE

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Abstract: *Coating the substrate as a method of surface finishing is very common in the printing industry. It is used to improve the properties of the final printed paper substrate and also as a pre-treatment method before applying the printing ink. Such pre-treatment is primarily used to modify the surface tension of a substrate, which primarily aims to achieve higher print quality and better ink adhesion. In this paper, the effect of the HP Indigo WS 6800 print press on the paper substrate was tested with a variation of corona power (0 W, 450 W, and 950 W) and the application of the different thicknesses of primer intended for working with ElectroInk inks (0 g/m^2, 0,5 g/m^2 and 1 g/m^2). To determine their influence on achromatic reproduction, an image analysis is carried out to determine the diameter of the black halftone elements (Personal PIAS), which could also diagnose the halftone shapes (deformation of the circle of black print dots). Black separation without corona treatment produces the smallest, but also the most deformed halftone elements, while the optimum (highest print dot) is achieved by a corona voltage of 450 W. The most effective black print is achieved by applying a primer of 0,5 g/m^2.*

Key words: paper pretreatment, HP Indigo, print quality, screen element analysis

1. THEORETICAL PART

In order to realize the basic process colors during the printing process, it is necessary to apply 2/3 of the transparent inks to the white reference printing substrates. In other words, CMY prints reflect 2/3 of the visible spectrum while absorbing 1/3 of it. These colours are cyan, magenta, and yellow, and are also known as process colors with addition to achromatic black. Their halftones can be achieved by screening mixing, which is performed in the prepress process, where multi-tone images are converted into 4 halftones color separations (CMYK). Such an image will be composed of a series of small halftones that, depending on the position and size, will cause different tonal perception (due to the sluggishness of the human eye, which cannot register halftones). (Heidelberg, n.d.)

Screening methods have been modified over time. i.e., the application of mathematical methods (RIPs for image processing). Depending on the applied mathematical algorithm, it is possible to form the following screening methods: amplitude modulated screening (AM), frequency modulated screening (FM) and hybrid screening. In Figure 1, examples of commonly used screenings applied in the printing industry are shown. Amplitude screening is the oldest halftone image generation principle used in the printing industry. It is characterized by the exact positions of the smallest halftones (dots) whose size varies depending on the tonal value. Thus, light tonal values on picture will have small dimensions of halftones (area coverage), while darker tonal values will have larger dimensions that will be gradually closed. Amplitude screening is recommended for reproduction of mid-tones (with light and dark tones, halftones are lost, and with it many details). The screen elements of each colour separation are placed at different angles in CMYK colour prints. A colour rosette made of halftones can be seen when the angles of halftones are well defined. (Rousu, Gane & Eklund, 2003)

Frequency-modulated screening is a modern process of generating a color image that cannot be performed without a computer. At the beginning of its application, a random distribution of screen elements whose dimensions are always the same is characteristic. Sizes in the range of 40 µm to 10 µm are typically generated. Thus, light tonal areas will be realized with a lower concentration of halftones, while dark tonal areas will be realized with a higher concentration. Some of the advantages of stochastic screening are good reproduction of details, lines, and small typography elements, many colors can be achieved on the print, less consumption of ink (it dries faster), and no problems with halftones corners and the appearance of moiré. Higher quality reproduction is achieved by using the smallest possible raster elements that create a very sharp image with a lot of details. Disadvantages are high technical requirements (when making and imaging printing plates), higher quality printing material is required, and there is a problem with the increase of screening values (mostly in the area of mid-tones), which causes worse reproduction of tonal values in mid-tones. For the needs of electrophotographic digital printing, a special principle of frequency-modulated screening is applied. That means that each halftone is generated within an 8-bit matrix. Thus, all halftones (dots) will have the same dimension, but their tonal value will vary by the tonal value (coverage of image). With these screening methods, the Moiré effect is eliminated. However, color images are characterized by a specific graininess that is visually noticeable in the mid-tone areas. (Kipphan, 2001)

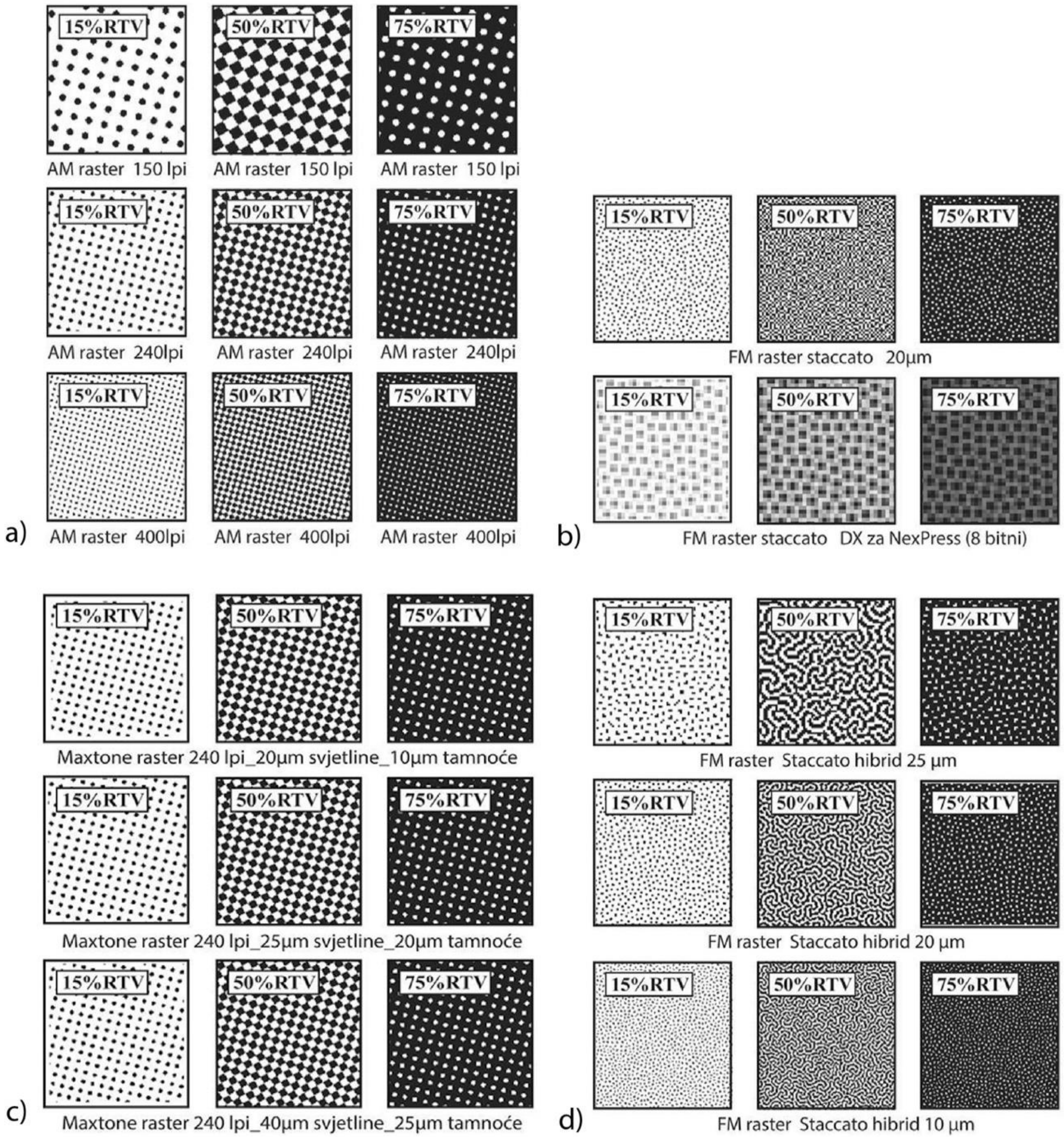

Figure 1: Enlarged image of printed typical screens: a) AM screen of 150 lpi, 240 lpi, and 400 lpi; b) FM rasters with an element of 20 µm and 8-bit staccato raster; c) hybrid Maxtone screening of 240 lpi 40 µm, 25 µm; d) FM raster Stacato hybrid 10 µm, 20 µm, and 25 µm

Since amplitude and frequency modulated screening has certain disadvantages, to achieve optimal color results, there is a need for their corrections (combining their positive properties). This is the reason for the generation hybrid screening process. In prepress, a common screening method is Maxtone. It is an amplitude-modulated screening in which the light and dark tonal values are additionally corrected (the smallest halftones are only in the low tonal values and are slightly increased, while the smallest halftones in the high tonal values are slightly reduced). This allows the reproduction of a wider range of grayscale, which is problematic with poorer printing substrates (flexographic printing). (Bartolić et al., 2013)

With the development of faster and stronger computers, the possibility of combining different frequency-modulated screenings has been realized. A representative of such screening methods is Staccato, wherein a color image, in addition to the stochastic distribution of halftones, different dimensions (from 25 to 10 µm) are found.

This reduces the traditional image graininess (better sharpness) while reproducing a larger range of gray colors. To apply this screening, the printing units of the offset machines must be ideally adjusted. This refers to the printing unit system (exactly defined diameter of cylinder and hardness of the offset rubber cover), the wetting units (applying a minimum amount of damping solution with the use of IPA alcohol), and the inking units (temperature-controlled cooling). One such printing unit is Heidelberg's Anicolor printing unit. (Zjakić, 2007; Majnarić, 2015)

Screening in flexo printing

The screening method is especially important in flexo printing. In flexo printing, the halftones are small, and they are made on a relatively soft polymer printing form. Under the influence of pressure, the deformed halftones bend and create deformations that result in a bad quality of imprints. This problem is especially visible when printing large format width OPP films that require more pressure or when printing uneven printing substrates such as cardboard. For this reason, the minimum size of the halftones is defined in the prepress. The white point is defined in percentages and serves as orientation when creating printing forms so that the halftones are not too small. Of course, the definition of this minimum point depends on the type of printing machine, the printing conditions, and the printing substrates. Precisely by defining the minimum size of the raster element, the performance quality of more demanding designs is directly affected. This problem is particularly emphasized when printing soft transitions or shadows that should start at zero. In this case, the transitions end with sharp edges in the values of the minimum halftones. (Bolanča, 1997)

Hybrid raster has also found application in flexo printing. It solved the problem in flexo printing known for bad blending from one color to another, colloquially called the "flexo break effect". By using XM screening technology, the mentioned problem is reduced to a minimum. Manufacturers of CtP equipment currently offer different solutions for these transitions, known under the factory names Artwork System Quantum Hybrid and Heidelberg Prinect Hybrid. However, each of the mentioned screening technologies still has its advantages and disadvantages. FM technology, for example, is recommended for printing sharp images, whereas grainines may occur when printing medium tonal values. AM raster is suitable for printing mid-tones, but it has issues when printing lighter transitions; lighter tones typically look cut off. As for XM technology, it will reduce the visibility of moiré, and provides the possibility of reproducing high dot line frequency without losing details and transitional tones.

HD screening is also a more advanced raster technology known as HD technology (HighDefinitionScreen). It is based on the application of CtP devices with high-resolution optics, which enables a finer recording on the printing plate and the reproduction of more advanced types of halftones. HD technology works on the principle of reducing the size of the white point and making the size of the halftone as small as possible. By using this technology to achieve lighter tones, the classic reduction of raster elements is not used as with AM technology, but a combination of larger and smaller dot elements is created. Thus, larger dot elements serve as a support and carry the pressure load, thus preventing the deformation and damage of smaller dot elements. This way, a smaller amount of ink is transferred and creates the impression of a lighter imprint. With this technique, a finer record of higher resolution is possible (in the size of 4000ppi) and a regular (round) shape of the printed halftone is obtained.

Kodak's Flexcel NX system eliminates all possible disadvantages characteristic of flexo printing. It is a system with many innovations and advantages compared to existing solutions for making photopolymer printing plates. The technical advantages of the Kodak Flexcel NX CtP device are manifested in: a speed of 9,5 m^2/h, a printing resolution of 10,000 dpi, and the possibility of making a printing plate for all printing techniques (except gravure printing). In this way, the prerequisite to produce printing plates was realized, the characteristics of which are: the halftones are completely flat and of the same height over the entire surface of the printing plate, regardless of the tone values, the durability of the printing plates is seven times greater, and the lowest tone value that can be produced and printed is 0,4%. (miraclon, 2021)

2. EXPERIMENTAL PART

In experiment, we use an HP Indigo WS 6800 7-colour printing machine with an integrated in-line priming device and corona unit to generate prints. For colour separation, an ESCO HPE ProLiant ML350 RIP model was used, with standard LUT 0,5 calibration curves and 180lpi. The standard print form "FOGRA Image Quality" of SRA3 was used as a test form and only black separation was studied (Kraushaar, 2018).

The printing substrate used is 90 g/m^2 Condat digital gloss RL (gloss-coated fine art paper). The paper is made out 50% virgin cellulose, 40% calcium carbonate, 4,5% water, and 5,5% latex and adhesive (Lecta, 2018). During the printing, process paper was treated through two different primer depositions (Michem® In-Line Primer 030 manufactured by Michelman) in an amount of 0,5 g/m^2 and 1 g/m^2. The corona treatment impact test on the reproductions was also performed. The Vetaphone model VE1A-A (C4) 410 corona unit was used with 450 W and 950 W charging power settings. (Vetafone Corona & Plasma, 2020)

Experimental prints were obtained with a variety of predefined corona voltages (0 W, 450 W, and 950 W) and a different amount of primer applied: a) untreated surface (without primer); b) surface treated with primer deposit of 0,5 g/m^2 (46 rpm) and c) surface treated with primer deposit of 1 g/m^2 (96 rpm). As a result of combining all the setups, nine distinct monochromatic samples were obtained. (Fig. 2). To determine the quality of monochromatic reproduction, the QEA PIAS II digital microscope (QEA, 2006). The obtained CIE L*a*b* and CIE LAB ΔE results were compared to the existing graphics industry standard ISO 12647-8 (Morić, Majnarić & Modrić, 2020; International Organization for Standardization, 2012).

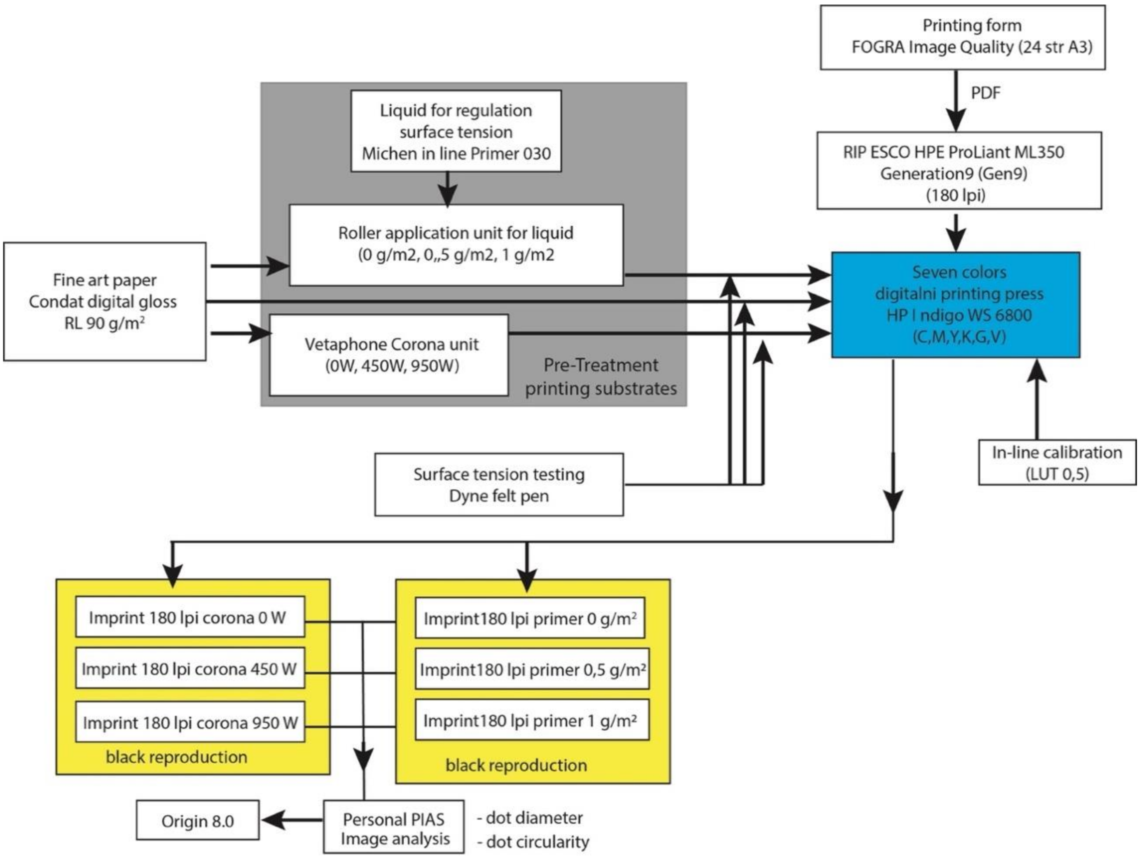

Figure 2: Schematic representation of a chronologically executed experiment

3. RESULTS AND DISCUSSION

As a result of printing, a double transfer of inks is achieved from the virtual printing form to the offset rubber and from the offset rubber to the printing substrate. As a result of these transfers, tone value increments (TVI) are realized, and thus deformations of the smallest print elements. Figures 3 and figures 4 show deviation curves in diameters and circularity of black ElectroInk halftones printed on a measured surface of 2,54 x 2,54 mm.

Figure 3a shows that the size distribution of the diameters of the black halftone is non-linear. Deviations in the sizes of halftones are visible on all tone values, but the most significant is the deviation of halftones on imprints without treatment. In the area of 30% TV, it amounts to $\Delta d_{30\%\ (0W-450W)}$ = 19µm. The largest

raster elements were formed on a printing substrate treated with a 450 W corona (d_{avr_450W} = 61,77 µm), while the smallest were on prints without corona treatment (d_{avr_0W} =50,43 µm).
The curves in Figure 3b show the diameters of black halftones with minimal primer application. They have a regular, linear shape. All resulting deviations in all measured fields of TV are minimal, regardless of the application of corona power. This is also evident from the sizes of the diameters of the halftones, which range from $d_{avr\,(950W)}$ = 58,43 μm to $d_{avr\,(450W)}$ = 60,6 µm.

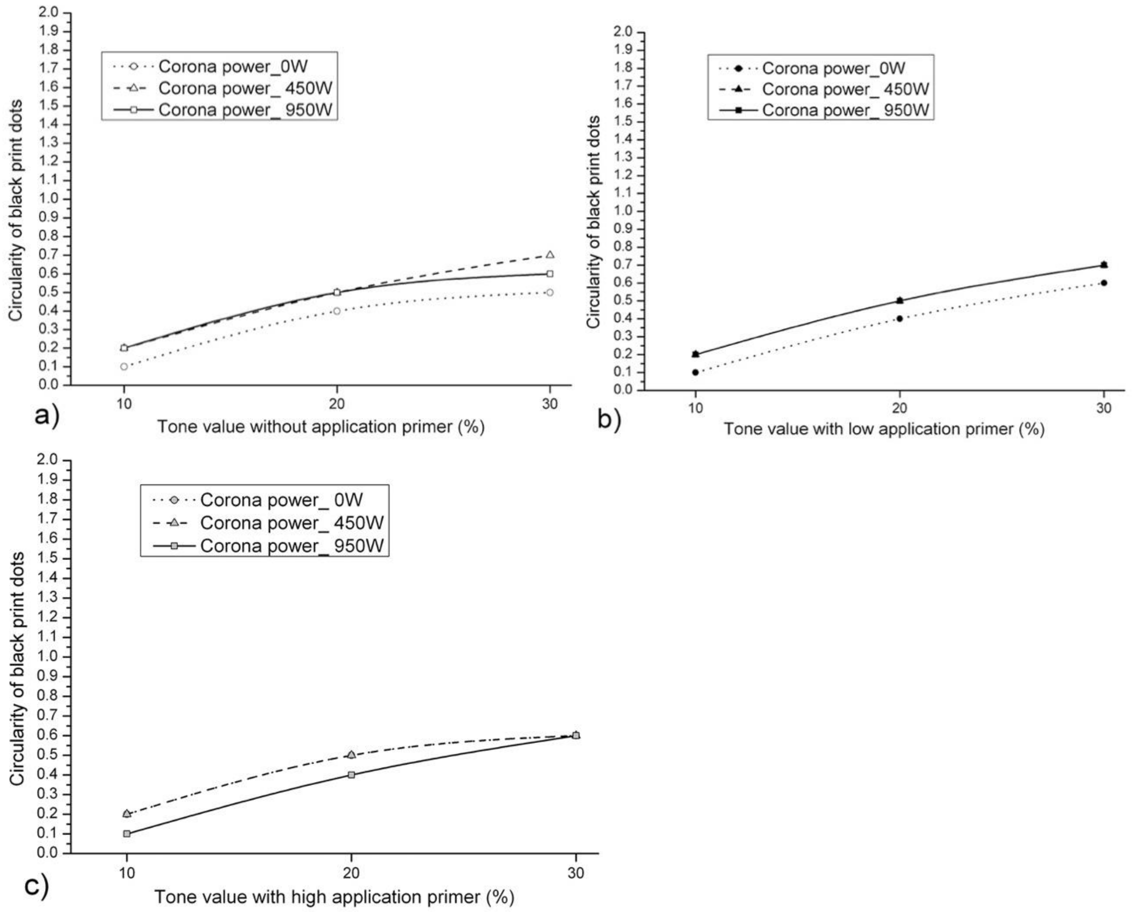

Figure 3: Curves of the dependence of the diameter of the halftones on the imprints are obtained by varying the corona power of 0 W; 450 W and 950 W, and application of the primer in a surface mass of a) 0 g/m^2; b) 0,5 g/m^2; c) 1 g/m^2

Figure 3c shows that a visible change in the dot diameter can be achieved with the maximum application of the primer. Simultaneously, the imprint without the corona power effect varies out from the other two curves. This is especially emphasized on the surfaces of 30% TV ($\Delta d_{30\%(0W-450W)}$ = 17,5 µm). The resulting dot deviations are very small, but still, the 450W corona treatment will achieve somewhat larger diameters of halftones in darker fields ($d_{avr(450W)}$ = 61,6 µm). The smallest diameters of black halftones were thus obtained on prints without the effect of the corona device ($_{(0W)}$=50,3 µm).
The deviation of the circularity obtained on the printing substrate without corona treatment is negligible ($\Delta C_{10\%(0W-450W)}$ = 0,1). In the darkest areas (30% of TV), the circularity of the elements is best on the substrate treated with a 450 W corona ($C_{30\%}$ = 0,7), while on the other two types of the substrate it is slightly worse, but not so much as to be significant ($C_{30\%\,(0W)}$= 0,5 and C30% (950W) = 0,6). By analyzing all reproduced black prints, a small average deviation of the circularity of the dot elements was observed, which amounts to $C_{avr(0W)}$ = 0,33 µm, $C_{avr\,(450W)}$ = 0,47 µm and $C_{avr\,K\,(950W)}$ = 0,43 µm. The similarity of the circularity of the halftones is also visible in Figure 5.
In the case of black imprints (Figure 4b), the circularity of the dot elements is the same on the printing substrate without treatment and the substrate treated with a 450 W corona. This applies to the analyzed values of TV. The deviations of the circularity of dot elements on the printing substrate treated with

950W corona are $\Delta C_{10\% (450W\text{-}950W)}$ = 0,1 and $\Delta C_{20\% (450W\text{-}950W)}$ = 0.1. In the area of 30% TV, the circularity obtained on all three processed printing substrates is the same and amounts to $C_{(0W,\ 450W,\ \text{and}\ 950W)}$ = 0,6. By calculating the average circularity of the dot elements, it was noticed that on the substrates without corona treatment and with corona treatment of power 450 W, the identical circularity of the dot elements is formed ($C_{\text{avr}\ (0W\ i\ 450W)}$ = 0,43). With the 950 W corona treatment, slightly more irregular dot elements were created ($C_{\text{avr}\ (950W)}$ = 0,37). This is also visible on the enlarged segments of the HP Indigo imprints in Figure 5.

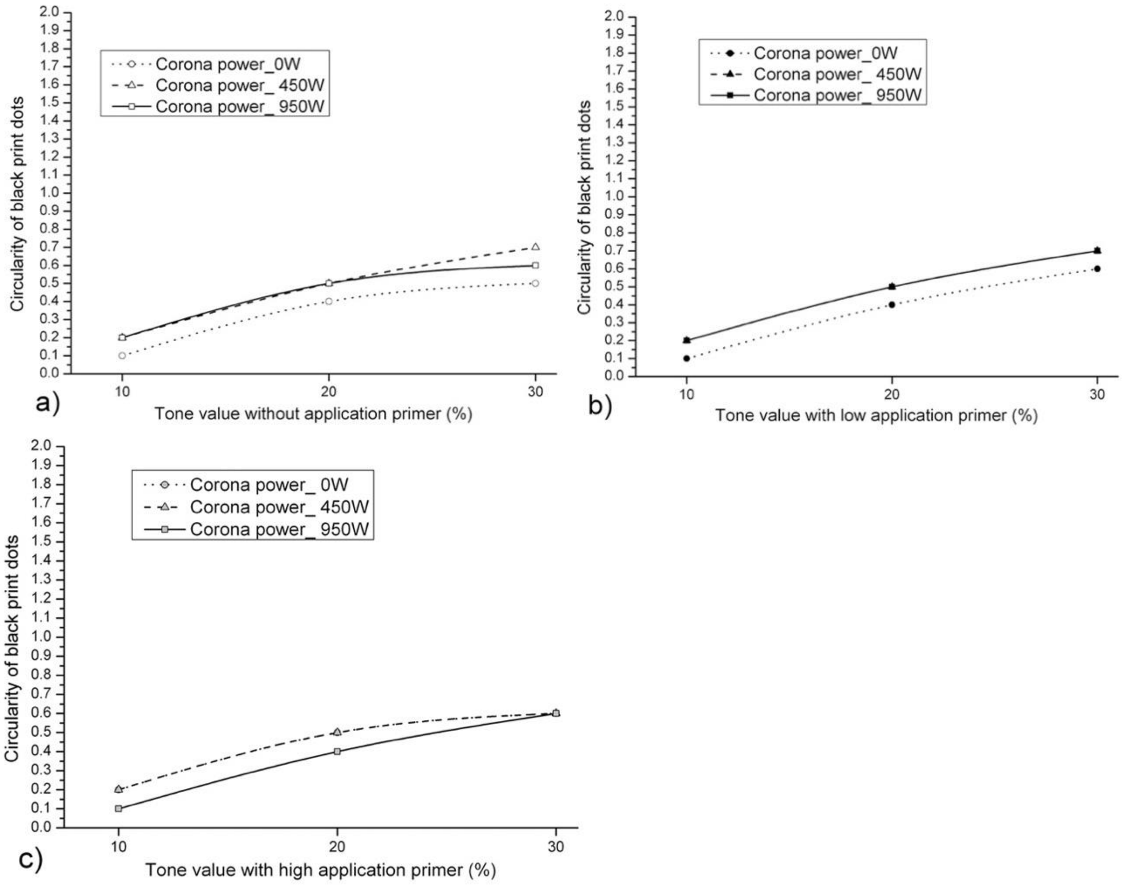

Figure 4: Curves of the dependence of the circularity of the halftones on the imprints are obtained by varying the corona power of 0 W; 450 W and 950 W, and application of the primer in a surface mass of a) 0 g/m²; b) 0,5 g/m²; c) 1 g/m²

On the substrates treated with 450W and 950W corona treatment (Figure 4c), it is visible that in all areas of the TV dot elements of identical circularity were formed ($C_{10\% (450W\ i\ 950W)}$ = 0,2, $C_{20\% (450W\ i\ 950W)}$ = 0,5 and $C_{30\% (450W\ i\ 950W)}$ = 0,7), and the values of the circularity of halftone elements formed on the substrate without corona treatment are lower on all TVs by ΔC = 0,1. For elements formed on the substrate without treatment, the average dot circularity is thus $C_{\text{avr}\ (0W)}$ = 0,37. For halftones formed on substrates treated with 450 W and 950 W coronas, the average circularity is the same, $C_{\text{avr}\ (450\ i\ 950W)}$ = 0,47 µm (Figure 5)

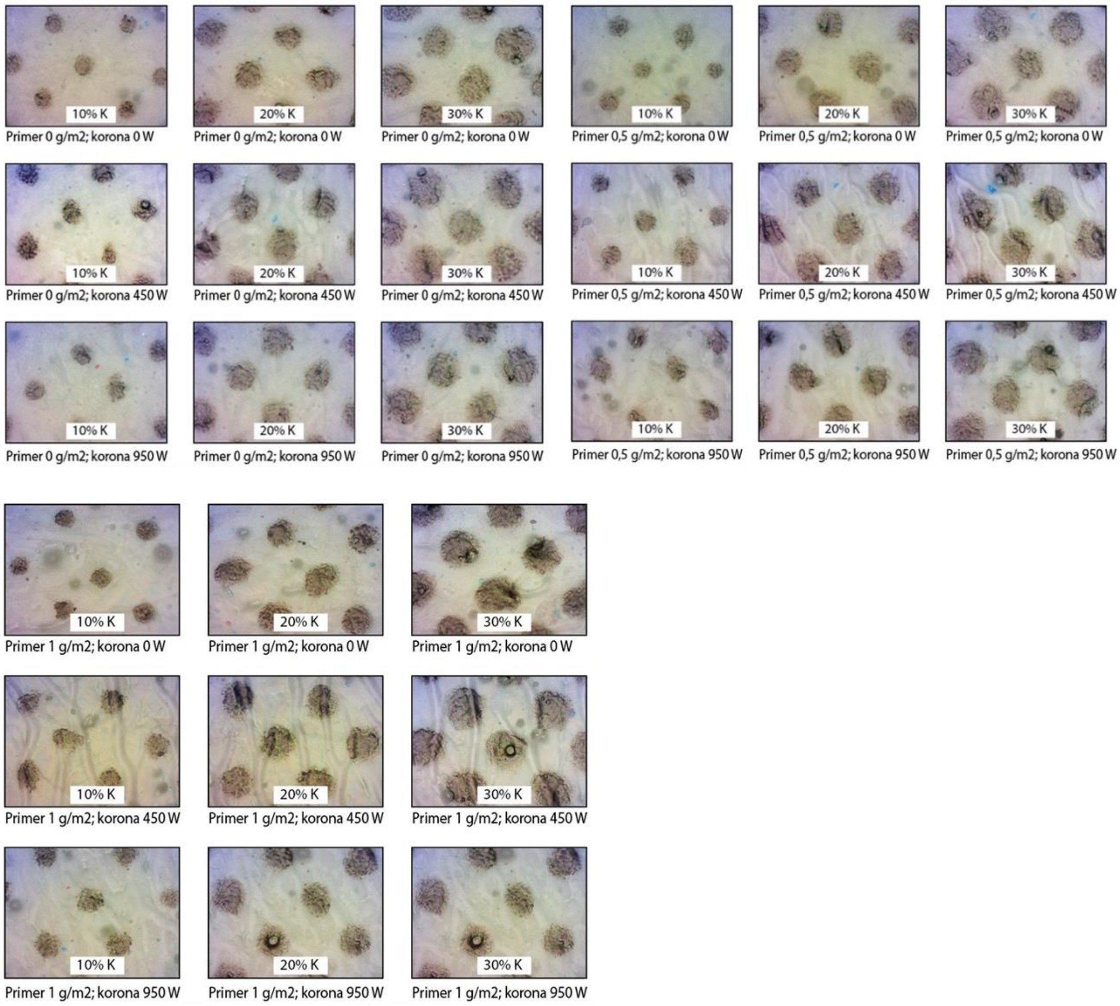

Figure 5: Magnified view of halftones of ElectroInk black ink realized with thicknesses of primers of 0 g/m^2, 0.5 g/m^2; 1 g/m^2, and corona power 0 W, 450 W, 950 W

4. CONCLUSIONS

The smallest halftones were found in the prints created without use of corona treatment and primer (standard prints). On a standard HP Indigo print, the corona treatment increases the diameter of the halftones. When the corona treatment is activated at 450W, larger halftones are realized in comparison with prints where the corona treatment was activated at 950 W, resulting in more articulated halftone dots.

Applying primer in the amount of 0,5 g/m^2 will not cause significant changes in the realized black halftones, and corona treatment will also produce microscopically visible (larger in diameter) halftone deformations. A larger application of primer (1 g/m^2) eliminates the action of the corona device.

If the corona device is not activated, black imprints without a primer will achieve the higher regularity of halftone elements (circularity). Using a primer to fine art paper makes halftones more rounded, which is more noticeable in higher tonal values (30% < TV). The optimal shape of the HP Indigo halftones will be obtained with an application of 1 g/m^2 primer and activation of the corona power of 950 W.

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STUDY OF THE COLOUR GAMUT VOLUMES AND OTHER REPRODUCTION QUALITY PARAMETERS OF ELECTROPHOTOGRAPHICAL DIGITAL PRINTING SYSTEMS

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Abstract: *The main purpose of this article is to study the various quality indicators of industrial electrophotographical digital printing systems. Several test forms with a large number of test charts and various control elements were printed on the aforementioned digital printing and media systems. For the purpose of the study, one of the most common print media was used - mat and glossy coated papers, uncoated papers, Brigh foil gold, Martele Blanc paper, MC Primecoat, PP Silver, etc. with standard colour profiles FOGRA 39 and FOGRA 51 and offset uncoated paper with standard colour profiles FOGRA 29 and FOGRA 52. Colour gamut (2D and 3D), colour volumes, colour differences, etc. were studied. ICC profiles for specific printing systems and materials have been generated and their 3D volumes, 2D areas of different sections in light, medium and dark tones have been studied. Other indicators of the quality of reproduction have been studied, such as - achieved colour differences in relation to the set / desired colour and ISO standards, accuracy of reproduction - colour and geometric, grey balance TVI, etc.*

Key words: ICC colour profiles, digital printing, printing quality, colour gamut, colour reproduction quality, grey balance, electrophotography

1. INTRODUCTION

Over the last decade, with the orders of small, and sometimes medium – sized circulations, the classic offset print in the commercial and packaging printing has been replaced by the high definition electrophotographical print, which allows the obtainment of a rich product set, such as: brochures, books, posters, labels, cardboard packages, some types of flexible packaging, personalized products and many more.

In reality, there aren't any traditional printing houses, which avoids supplementing its traditional printing techniques with industrial grade electrophotographical printing machines. Practice shows, that clients hold high expectations towards digital print quality, comparing it with the conventional printing in regards to the standard parameters, guaranteeing colour reproduction accuracy, lack of colour variation in printing run, the achievement of Pantone colours, etc. At this point in time the market is saturated with an immense number of digital (electrophotographical) printing machines from the premium and mid-price segments, which, if one was to judge on technical specifications only, must meet the aforementioned quality criteria in full. Experience in the field so far tells a different story, revealing that most of the digital printing systems from the industrial class suffer severe problems and deviations in relation to several quality criteria. This article is a part of a series of works, based on a pure and objective scientific approach and unique methodology, both based on the measurement and assessment of assorted characteristics, definitive of the term print quality. The method offered herein is based on the unbiased measurement and assessment of densitometric and colorimetric parameters, as well as their quantitative correlation to the particularities of human perception and the fundamentals of print quality, as set in the ISO-standards of graphic technology (TC 130).

The methodology, developed and described herein is based on the measurement, analysis and assessment of:

- Colorimetric parameters analysis in the case of single, double, triple, etc. ink overlays (Kašiković et al., 2018). Calculation of colour differences, compared to set desired values and international standards, characteristization data, etc.
- Analysis of the capacity of digital printing system to simulate PANTONE colour and obtained colour differences.
- Complete accuracy analysis of colour and tone reproduction quality of particular digital printing machine (Kašiković et al., 2017).

- Analysis of densitometric parameters in digitally printed images – optical densities, reproduction accuracy of tone values, simulation with Tone Value Increase, etc.
- Assessment and analysis of the volume in 3D and 2D colour gamut of the tested digital printing machine during printing over different media. Comparison of the obtained ranges against the FOGRA standards.
- Research and assessment of colour variation while producing an edition, as well as analysis of colour variance as function of time – printing the same image (complete edition) over a predefined period of time.
- Analysis and comparison of the capabilities to obtain similar colour parameters between the tested digital printing system and a conventional machine – an item of particular importance when the first edition is in offset, for example, and is then supplemented using digital printing machines.
- Generating of ICC profiles for the digital printing system over different media and assessment of the complete reproduction specifications, comparison over standard profiles, research of stability over time, etc.

2. EXPERIMENTAL

For the purposes of the experiment we have modelled special test forms with specialized testcharts and control elements for:

- Colorimetric analysis of colour characteristics for a digitally printed image.
- Densitometrical analysis – optical density of solids, TVI (Tone Value Increase), Print Contrast (Spiridonov & Shopova, 2013), etc.
- Charts to generate ICC profiles
- Images with distinct colours
- Precision control scales for colour reproduction, gradient precision, etc.
- Colorimetric tests and assessment of colour characteristics of stock PANTONE colours.

The fundamental task in building a colour profile is the at-most precise reproduction of the digital original. To complete the test, we have used a premium electrophotographical printing system, as offered by one of the segment-leading brands. The derived ICC profiles, on the basis of which we have tested the Fogra 51, Fogra 52, Fogra 29 and Fogra 39 ranges are rooted on the characterization data, as published on the FOGRA website (Fogra, 2022). The profiles are generated with optimal colour separation conditions as per ISO 12647-2/2004/2013 (International Organization for Standardization, 2013).

- Fogra 51 – glossy/matte coated paper
- Fogra 52 – offset uncoated paper
- Fogra 29 – offset uncoated paper
- Fogra 39 – glossy/matte coated paper

Part of the scales used are presented in figure 1.

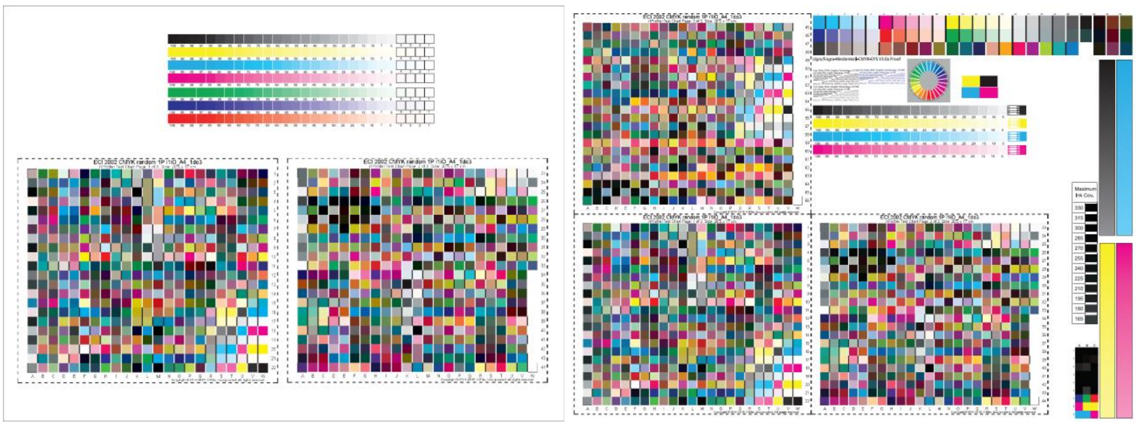

Figure. 1: Part of the testing forms used during experiments

The testing forms are printed with settings for different resulting ICC profiles. Before printing the test editions all machines are calibrated according to manufacturer's instructions with the aid of spectrophotometer.

2.1 Test materials

We have used two types of printing media. They are one of the most common stocks in printing houses and come with good printing specifications (whiteness, opacity, mechanical properties, etc.), as well as with great price/quality ratio.

1. Coated paper
2. Uncoated paper

In this case the main goal we set is to observe the colour gamut of used digital systems while working with the used printing stocks.

In order to perform a comparison of the colour range for the used materials in the used digital machines, it is necessary to get both 2D and 3D visualization with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and FOGRA 51 for coated papers, so that one can gain visual idea of available colour ranges. To get the 2D and 3D visualizations of the ICC colour profiles we have used the PROFILE MAKER5.0 and ColorThink Pro 3.0.3 software products.

Test conditions include the use of three electrophotographical printing systems from the mid and high price tiers with identical print stocks. This article is based on widely used machines, which are in fact preferred in polygraphy printing, well-established as auxiliary printing systems in offset printing houses and as main digital printing systems. Other articles from this series focus on different contenders in these price brackets, ink-jet systems and others.

2.2 The test completion comprehends the following parameters:

- Testing and comparing the volume and shape of 3D colour gamutof CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800 against Fogra standards.
- Calculation and comparison of the colour gamut volume – ΔE (Spiridonov, Shopova & Boeva-Spiridonova, 2012).
- Testing and comparing the 2D cross sections of colour gammuts CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800 against Fogra standards.

3. RESULTS AND DISCUSSION

To test and compare the volume of colour gamut we have combined several specialized ΔE^3 software products, which yielded generally more accurate result representation. Please note that this is the maximal colour ranges, which is reproducible by the digital printing systems CANON imagePRESS C750, Xerox Versant 180 Press and HP Indigo WS 6800. This is why colour volume is one of the cornerstone specifications. With the aid of the different software products we were able to calculate the colour volumes from the printing results for the used substrate and to compare them against the reference values for the corresponding Fogra standard.

This research and graphic representation of 2D cross-sections and 3D volumes of colour gamut is aided by these specialized software products: X-Rite Profile Editor 5.0 and ColorThink Pro 3.0.3.

To test and compare the volume of colour volumes, we have made use of two specialized ΔE^3 software products - CHROMIX ColorThink 3.0.3 and Gamut Vision 1.4.

3.1 Investigation of colour gamut volumes and comparison of 2D and 3D colour gamut of different digital printing systems

One important function, which is used to visualise the colours, as reproduced by any given machine, is the 2D and 3D representation of the respective colour gamut. This paper also uses 2D and 3D representations. The 2D representation of colour gamut with different cross-sections along the L-axis of the CIE Lab colour space allows for good visual comparison of colours in light, mid and dark tones, as well as comparison of a large number of colour gamut at once. The 3D representation of colour gamut allows a complex visual assessment for the 3D body of the colour gamut. It is appropriate for the visualisation and comparison of ore or two-coloured gamut's.

In order to perform the comparison for the colour gamut of the examined prints from the corresponding digital printing presses – CANON imagePRESS C750, XEROX Versant 180 Press and HP Indigo WS 6800 it is necessary to provide a 3D visualisation with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and Fogra51 for coated papers with the ultimate goal to achieve visual representation for the colour gamut. The 3D visualisation of the ICC colour profiles was performed using the software X-Rite Profile Editor 5.0.
To compare the colour gamut on offset uncoated paper, a standard ICC profile was used FOGRA 29 and FOGRA 52.

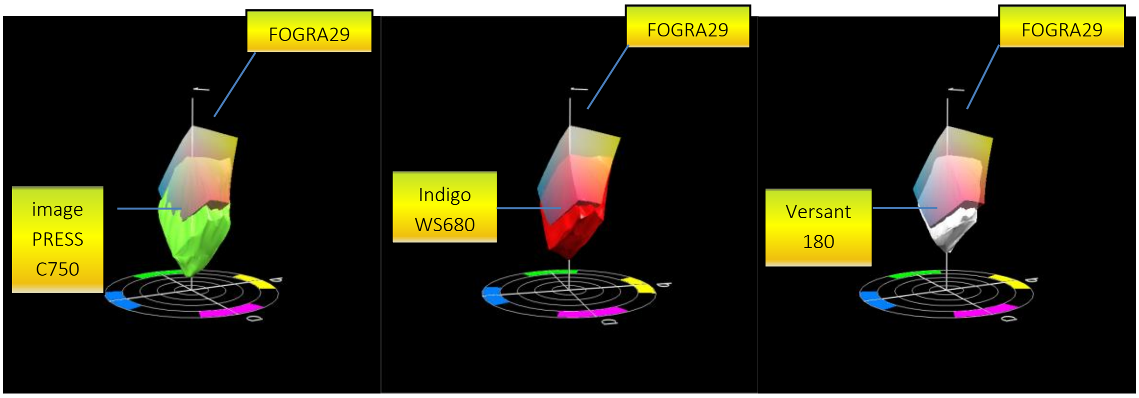

Figure 2: 3D visualisation (Lab system) of an ICC profile of offset paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA29

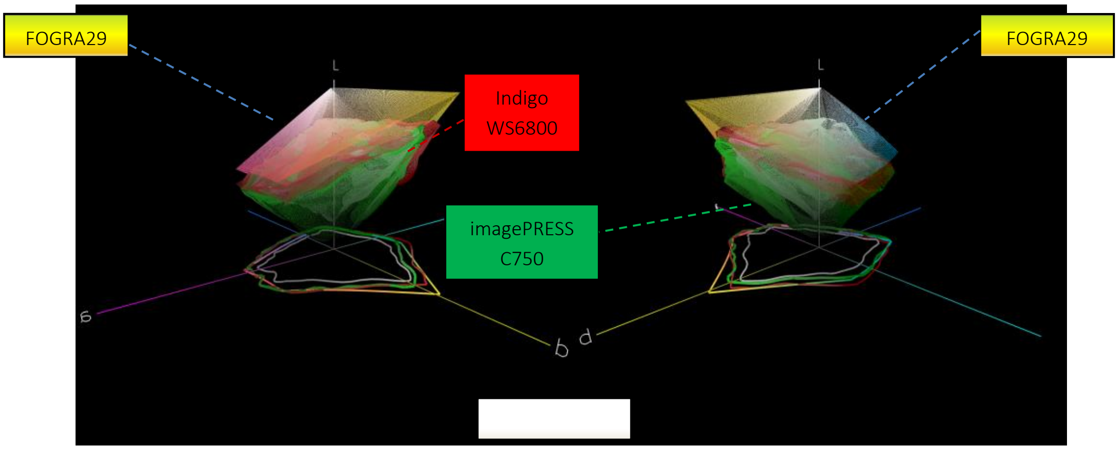

Figure 3: 3D visualization (lab system) of ICC profile of offset paper printed by all printing systems compared to FOGRA29

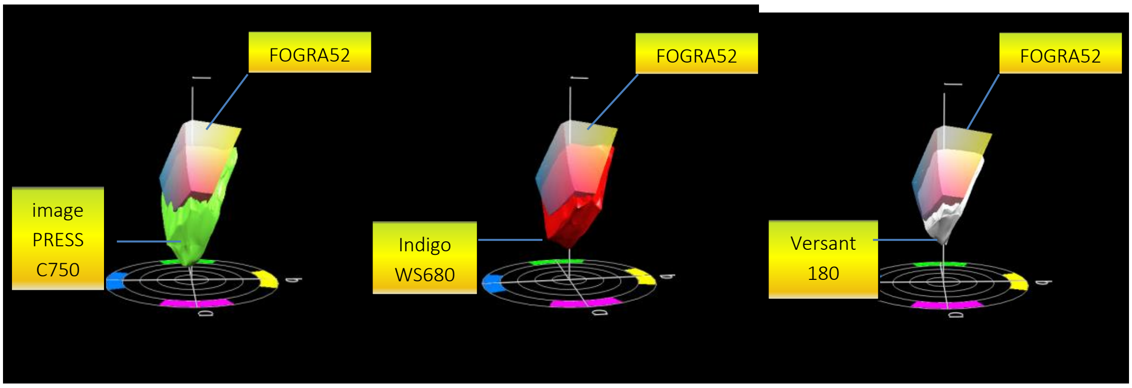

Figure 4: 3D visualisation (Lab system) of an ICC profile of offset paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA52

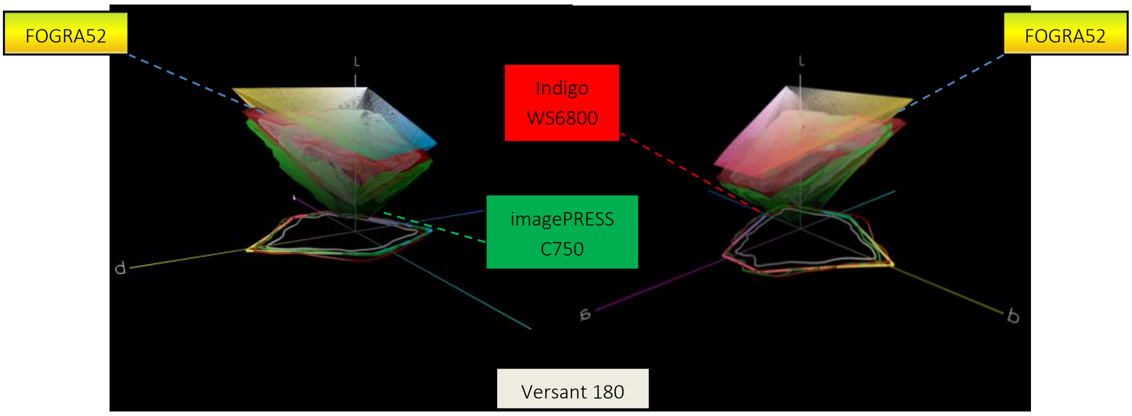

Figure 5: 3D visualization (lab system) of ICC profile of offset paper printed by all printing systems compared to FOGRA52

From figures 2, 3, 4 and 5 one can observe that the colour range of FOGRA29, as well as the one of FOGRA52 are considerably larger (in the conditions of conducted experiment) in the lighter tones in offset paper, which has been printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Also one can observe, that certain regions of the colour range, for the printing systems tested, there is reproduction which is unattainable for FOGRA29 and FOGRA52. It is also clear, that offset paper generally yields better colour reproduction in lighter tones. With FOGRA29 and FOGRA 52, however one observes better reproduction in the lighter hues.
As a comparison platform for the colour gamut of coated paper the ICC FOGRA39 and FOGRA51 profile has been used:

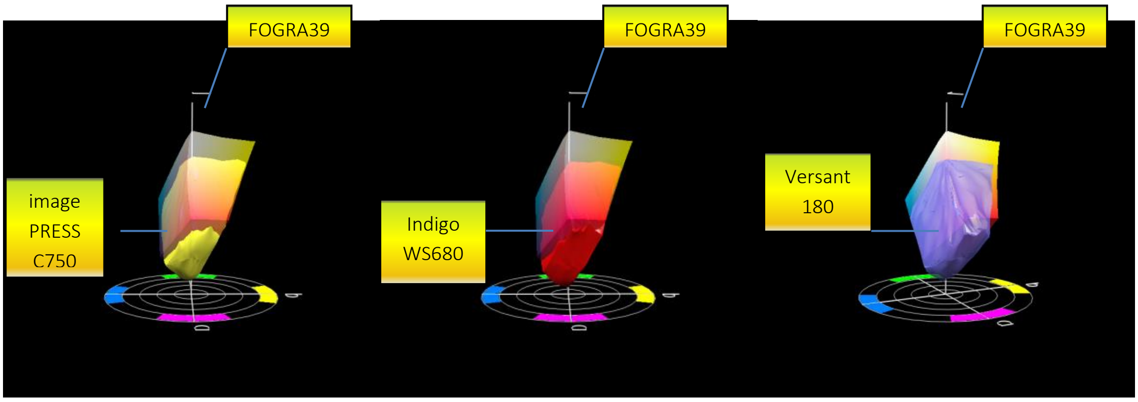

Figure 6. 3D visualisation (Lab system) of an ICC profile of coated paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA39

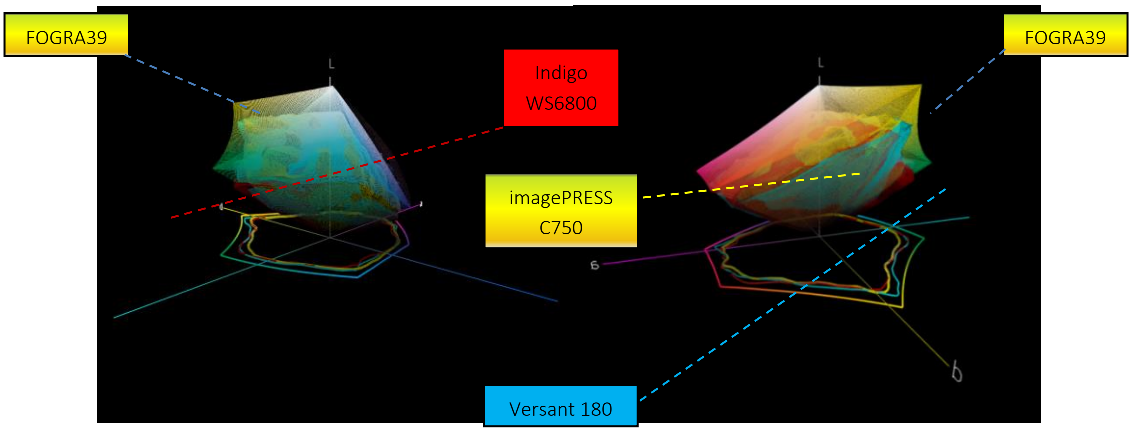

Figure 7: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA39

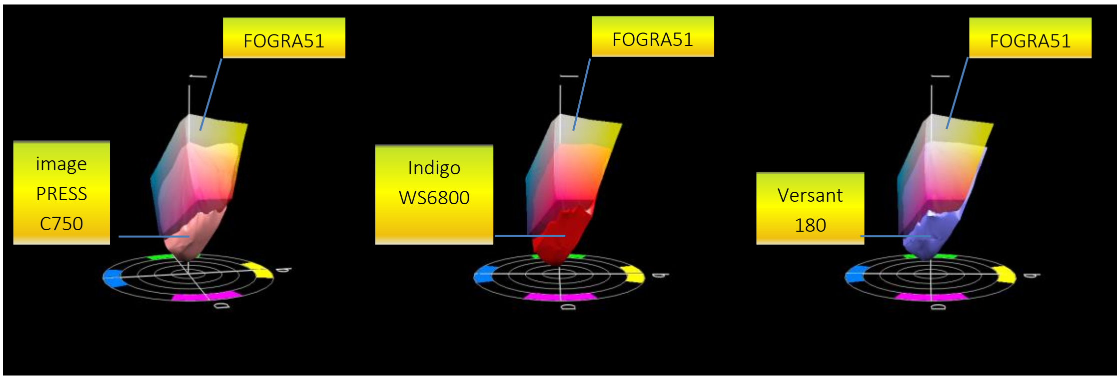

Figure 8: 3D visualisation (Lab system) of an ICC profile of coated paper printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press and FOGRA51

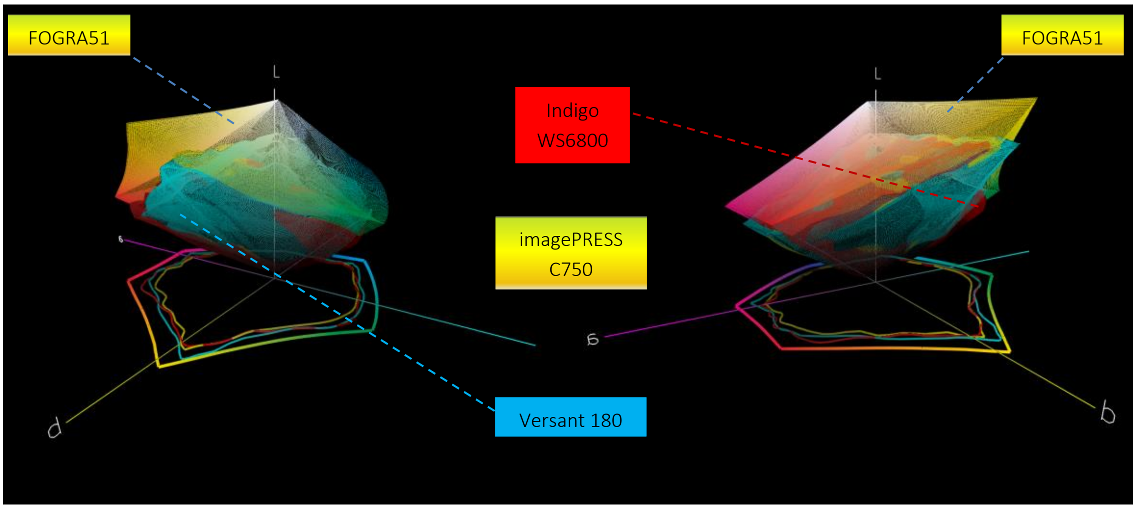

Figure 9: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA51

Figures 6, 7, 8 and 9 show that the colour gamuts of FOGRA39 and FOGRA51 are considerably larger (in the conditions of conducted experiment), compared to coated paper, again printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Also one can observe, that certain regions of the colour gamut, for the printing systems tested, there is reproduction which is unattainable for FOGRA39 and FOGRA51. It is also clear that the coated paper aids better colour reproduction of the lighter nuances of yellow-green and blue-red regions. With FOGRA39 and FOGRA 51 a better reproduction of lighter hues has been noted.
The visualization of 2D cross-sections with different values of L yields a rich fact set on how the colour gamut varies, with the media used, against the reference values as per the corresponding FOGRA standard. This allows for a deeper insight into the colour volume and also aids tracking the corresponding values of L, which can be in the range 0 to 100. The next figures show the comparison of 2D cross-sections across different media, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press, compared with the corresponding FOGRA standard.

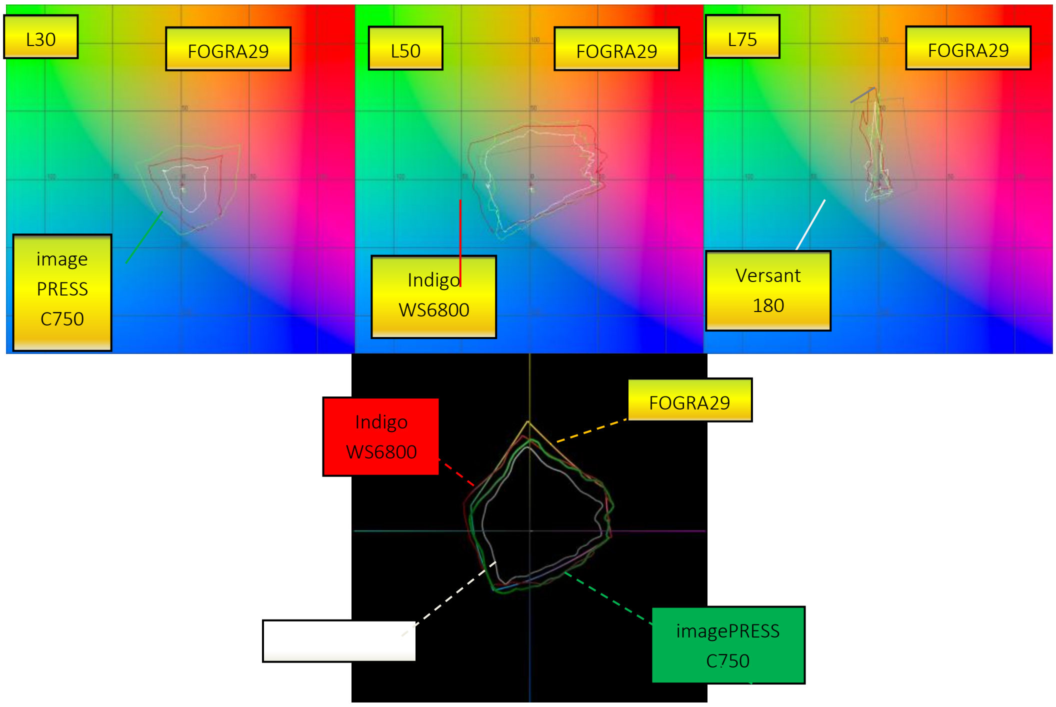

Figure 10: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA29

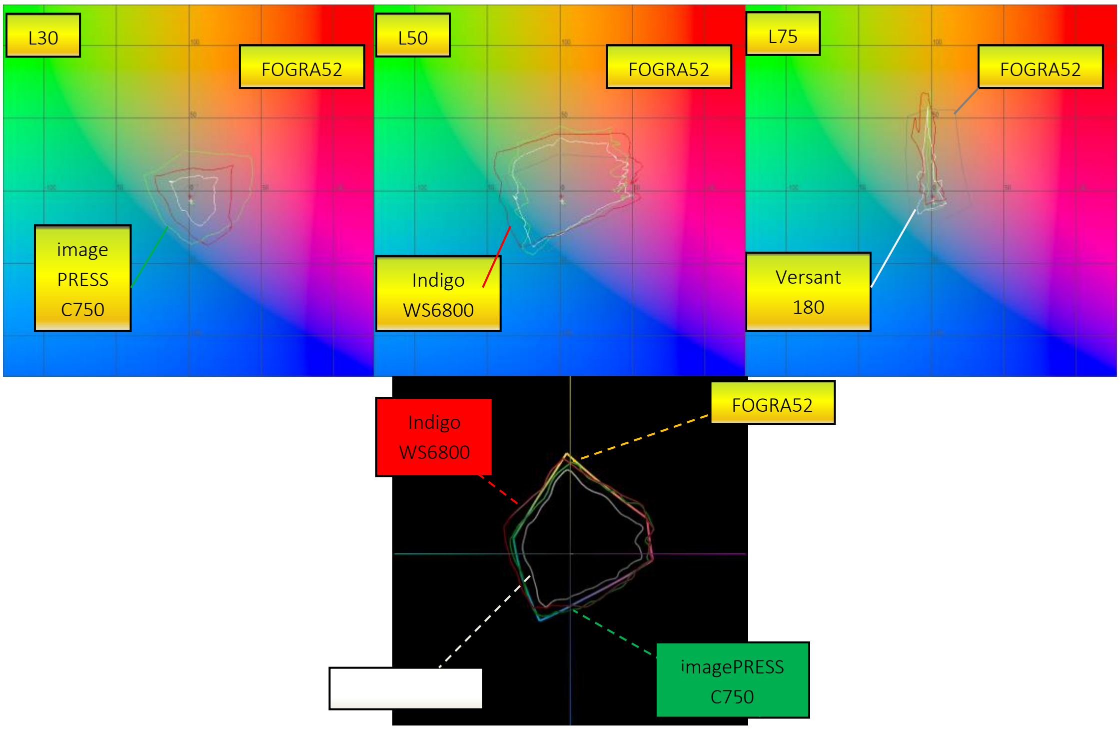

Figure 11: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA52

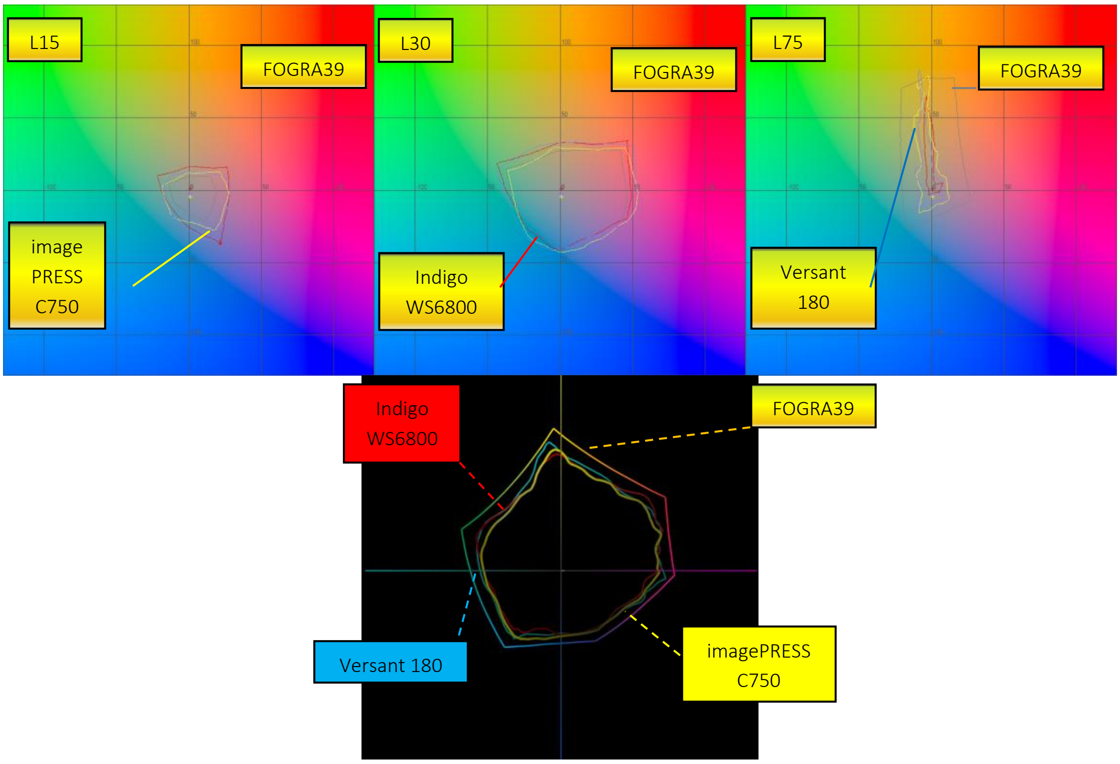

Figure 12: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA39

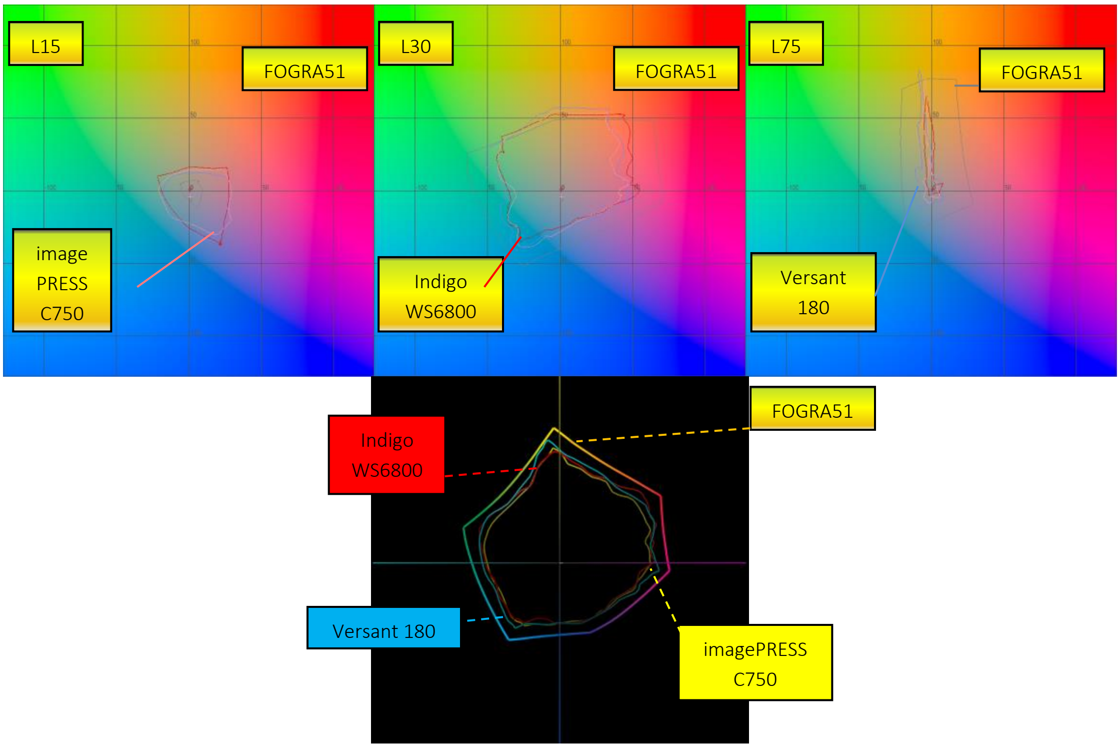

Figure 13: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with reference values as per FOGRA39

Figures 10 to 13 show the 2D visualisation of colour gamut over the tested media, as printed with CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press. Data shows that the most precise

tone and colour reproduction is showing with coated papers as the latter match with the references in almost all regions. the smallest colour range is obtained with offset uncoated papers, used with the same systems.
Tables 1 and 2 show the calculated values of the received ICC profiles for the media printed through CANON imagePRESS C750, HP Indigo WS 6800 and Xerox Versant 180 Press compared with the reference values as per the corresponding FOGRA standard. Two specific software products have been used to calculate the volume of the colour range. Each of them has a proprietary algorithm to calculate ΔE^3, which accounts for the difference between the two software products.

Table 1: Colour gamut volume ΔE^3 for Uncoated Paper

Uncoated Paper ΔE^3					
	FOGRA 29	FOGRA 52	CANON imagePRESS C750	HP Indigo WS 6800	Xerox Versant 180 Press
Color Think 3.0.3	181382	163565	184096	174144	109143
Gamut Vision 1.4	187079	162620	285724	315783	197341

Table 2: Colour gamut volume ΔE^3 for Coated Paper

Coated Paper ΔE^3					
	FOGRA 39	FOGRA 51	CANON imagePRESS C750	HP Indigo WS 6800	Xerox Versant 180 Press
Color Think 3.0.3	402279	386692	271565	264155	285899
Gamut Vision 1.4	444027	448088	458882	501624	491149

According these results, one can obtain the graphics as shown in figures 14 and 15.

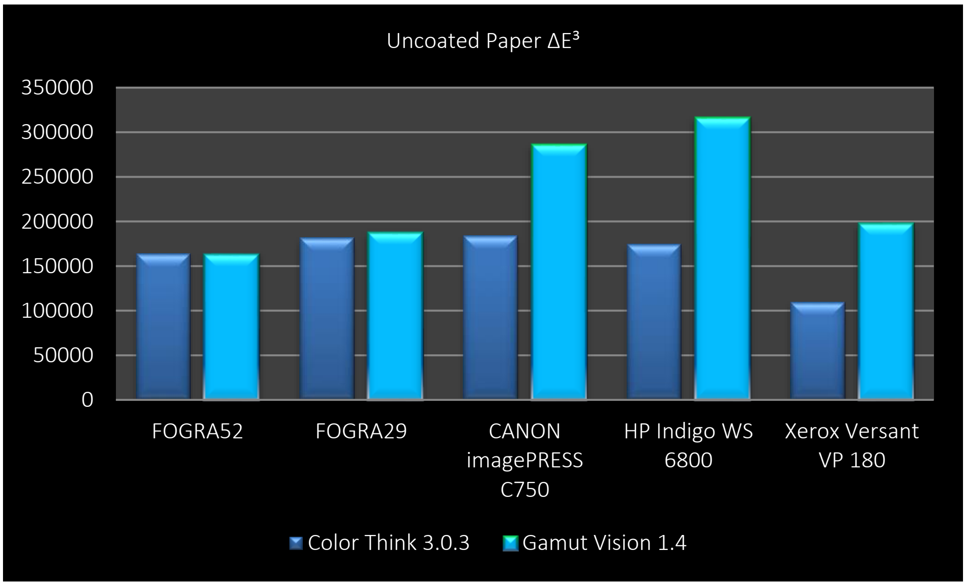

Figure 14: Graphic representation of the colour gamut ΔE^3 for Uncoated Paper as printed by CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

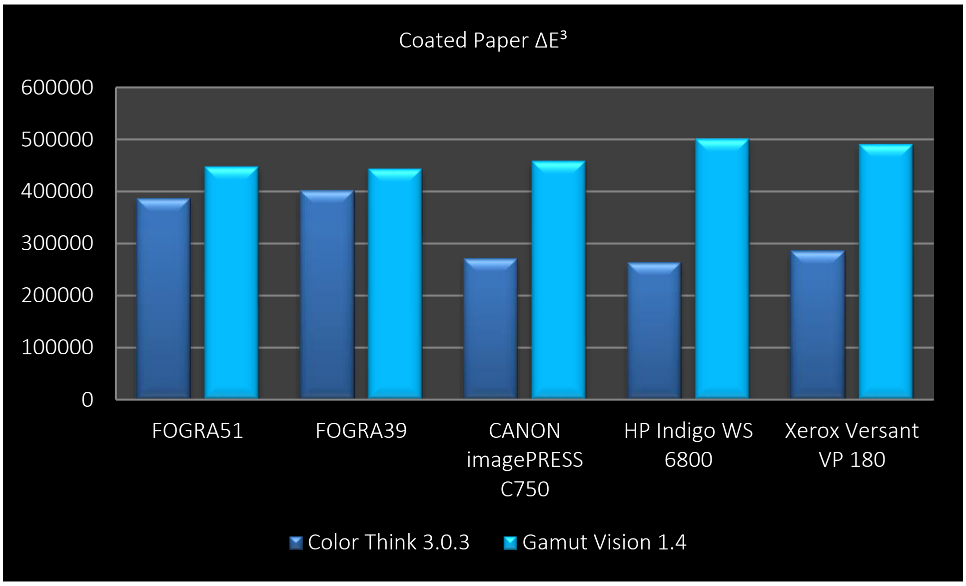

Figure 15: Graphic representation of the colour gamut ΔE^3 for Coated Paper as printed by CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

4. CONCLUSIONS

From the tests performed in relation to this article, we have arrived at the following conclusions:

1. It is suggested complete method to evaluate digital print quality, based on scientific approach and unbiased analysis of a great number of colorimetric and densitometric parameters for the printed image such as: achieved colour differences in relation to the set / desired colours and ISO standards, accuracy of reproduction - colour and geometric, grey balance, TVI, Colour Gamut, etc. The color gamut volume and 3D and 2D cross section surface analysis part of complete methodology is included in this article.
2. In real-world conditions, using widespread printing media, we have tested some of the wide used electrophotographical digital printing systems, as the obtained unbiased results have been dully compared with the FOGRA standards.
3. All of obtained results for color gamut volumes, 3D and 2D cross section surface analysis are valid for the studied printing conditions and used materials. The authors do not claim general evaluations of the investigated digital presses.
4. From the obtained 3D visualizations with generation of ICC colour profiles and comparing them to the FOGRA 29 and FOGRA 52 standards (for uncoated media) and FOGRA 39 and FOGRA 51 (for coated media), as printed by the tested electrophotographical printing machines, and using all mentioned media, we have established that CANON imagePRESS C750, HP Indigo WS 6800 and XeroxVersant 180, we have better colour reproduction in lighter and medium hues, compared to FOGRA 29 and FOGRA 52. The darker tones of the colour profiles for the tested electrophotographical printing systems go beyond the scope of the standard profiles as per FOGRA 29 and FOGRA 52. Data shows that when uncoated media is used, the best results against FOGRA 29 and FOGRA 52 belongs to XeroxVersant 180, followed by HP Indigo WS 6800 and CANON imagePRESS C750. From the results of the 3D volume range for coated paper (gloss, matte), as printed with the tested machines, we can establish that FOGRA 39 and FOGRA 51 standards have bigger colour scale in lighter hues, compared to the prints as done with the tested machines. Better colour reproduction is observed with coated media, especially in colour transmission for green-blue and blue-red regions.
5. From the 2D visualization we have made certain cross-sections of colour gamut over tested media with different values of L and it is clearly visible that with L=30, for uncoated paper, the greatest colour range belongs to CANON imagePRESS C750, and the smallest to XeroxVersant 180. With L=50 all three tested machines show similar results, as greater colour range is observed with the green-yellow and yellow-red regions as compared with FOGRA 29 and FOGRA

52 standards. With L=75 the lowest colour range belongs to CANON imagePRESS C750, as it is worth noting, that all three tested machines show circa two-fold smaller colour gamutcompared with FOGRA 29 and FOGRA 52. For coated paper (matte, gloss), and with L=15, CANON imagePRESS C750 and HP Indigo WS 6800 show greater colour ranges, compared with XeroxVersant 180 and the FOGRA 39 and FOGRA 51. With L=30 all three machines show similar colour ranges, which are smaller than the colour range per FOGRA. With L=75 again all three machines yield out a colour range which is about two-three-fold smaller than FOGRA 39 and FOGRA 52 ranges.

6. We have made use of two specialized software solutions to obtain the colour volume. Each of them uses its own ΔE^3 algorithm, due to which one sees variance in the calculated values.

Colour gamut's and their volume are of special significance when the print quality is defined. Calculating ΔE^3 using CHROMIX Color Think 3.0.3 showed the following result:

- For uncoated paper the largest colour gamut was obtained with CANON imagePRESS C750 (ΔE^3 =184096), followed from HP Indigo WS 6800 ΔE^3 =174144) and XeroxVersant 180 Press (ΔE^3 =109143). The standard colour gamut's of FOGRA29 (ΔE^3 =181382) and FOGRA52 (ΔE^3 =163565) were best met by the CANON imagePRESS C750 Press (1,5% > ΔE^3 FOGRA29 and 11% > ΔE^3 FOGRA52), followed by HP Indigo WS 6800 Press (4% < ΔE^3 FOGRA29 and 6,5% > ΔE^3 FOGRA52) and XeroxVersant 180 Press (40% < ΔE^3 FOGRA29 and 33% < ΔE^3 FOGRA52).

- For coated paper the largest colour gamut was obtained with XeroxVersant 180 Press (ΔE^3 =285899), followed from CANON imagePRESS C750 (ΔE^3 =271565) and HP Indigo WS 6800 (ΔE^3 =264155). The standard colour gamut's of FOGRA39 (ΔE^3 =402279) and FOGRA51 (ΔE^3 =386692) were best met by the XeroxVersant 180 Press (29% < ΔE^3 FOGRA39 and 26% < ΔE^3 FOGRA51), followed by CANON imagePRESS C750 (33% < ΔE^3 FOGRA39 and 30% < ΔE^3 FOGRA51) and HP Indigo WS 6800 (34% < ΔE^3 FOGRA39 and 32% < ΔE^3 FOGRA51).

Calculating ΔE^3 using Gamut Vision 1.4 showed the following result:

- For uncoated paper the largest colour gamut was obtained with HP Indigo WS 6800 (ΔE^3 =315783), followed from CANON imagePRESS C750 (ΔE^3 =285724) and XeroxVersant 180 Press (ΔE^3 =197341). The standard colour gammuts of FOGRA29 (ΔE^3 =187079) and FOGRA52 (ΔE^3 =162620) were best met by the HP Indigo WS 6800 (41% > ΔE^3 FOGRA29 and 49% > ΔE^3 FOGRA52), followed by CANON imagePRESS C750 (35% > ΔE^3 FOGRA29 and 43% > ΔE^3 FOGRA52) and XeroxVersant 180 Press (3% > ΔE^3 FOGRA29 and 18% > ΔE^3 FOGRA52).
- For coated paper the largest colour gamut was obtained with HP Indigo WS 6800 (ΔE^3 =501624), followed from XeroxVersant 180 Press (ΔE^3 =491149) and CANON imagePRESS C750 (ΔE^3 =458882). The standard colour gammuts of FOGRA39 (ΔE^3 =444027) and FOGRA51 (ΔE^3 =448088) were best met by the HP Indigo WS 6800 (22% > ΔE^3 FOGRA39 and 11% > ΔE^3 FOGRA51), followed by XeroxVersant 180 Press (10% > ΔE^3 FOGRA39 and 9% >ΔE^3 FOGRA51) and CANON imagePRESS C750 (3% > ΔE^3 FOGRA39 and 2% > ΔE^3 FOGRA51).

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INVESTIGATION OF THE COLOUR REPRODUCTION QUALITY OF INKJET DIGITAL PRINTING MACHINES

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Abstract: *Industrial digital inkjet printing machines are increasingly entering commercial printing, label, packaging, etc. The quality of printing and the speed of inkjet printing machines are constantly increasing, but in a number of industries such as packaging, labels, etc. there are increased requirements for colour reproduction quality, which requires additional and in-depth research. The main purpose of this article is to study the different quality indicators of the most widely used digital inkjet systems. For the purposes of the experiment were used from the most commonly used in practice materials such as – regular matte and glossy coated paper, uncoated white paper, Jetcoat paper, photo paper - gloss, self-adhesive film - gloss, etc. with standard colour profiles FOGRA 39 and FOGRA 51 and offset uncoated paper with standard colour profiles FOGRA 29 and FOGRA 52. Several test forms with a large number of test charts and various control elements are printed on the aforementioned digital printing presses on different media. Colour gamut (2D and 3D), colour volumes, colour differences, etc. were studied. ICC profiles for the specific printing systems and materials have been generated and 2D visualization and comparison of the colour gamut of the studied media at different values of L and 3D visualization and comparison of the colour gamut of the studied media with standard ICC profile FOGRA.*

Key words: colour reproduction quality, Inkjet printing, ICC profiles, digital printing, substrate, colour gamut

1. INTRODUCTION

The past few years ought to be considered as booming for digital printing. In these novel times every user demands his items delivered in the shortest time conceivable. This, naturally, introduced the need to provide printing on demand. Manufacturing brochures, books, posters, labels, some types of flexible packaging, personalized items, security printing etc. is also flourishing (Bozhkova, Spiridonov & Shterev, 2017). Besides all that, from the users' perspective, there is an ever growing and active demand to provide for ecologically sustainable options. Digital printing is a perfect candidate to tackle this problem as it produces less emissions and waste. Furthermore, digital technologies rely on more robust materials, which could in turn be more beneficial for the end user. Digital technology allows for greater flexibility when compared to conventional techniques, which is a must if one aims to provide high-quality production, which could be customized or delivered within the briefest timeframe without the addition of unnecessary expenditures. Therefore, it is impossible to find a contemporary printing house to stray away from complementing its traditional printing techniques with industrial-grade digital inkjet printers. Inkjet printing systems represent one of the most popular solutions for industrial printing. In theory (even though this is not true for each model) they use contactless deposition method, which is relatively universal, and allows to apply inks of various chemical composure (most of them are water-based) over almost any kind of surface in a wide variety of scales. Practice has shown that customers come in bearing high expectations with regard to digital printing, anticipating it to be on par with conventional techniques as far as standard colour reproduction accuracy factors, the lack of colour variation in a printing run, the reproduction of Pantone colours, colour proof etc. are concerned (Spiridonov & Shopova, 2013). Judging by the technical specifications, originating from the wide variety of top-tier inkjet printing systems, one must conclude that that these products are bound to satisfy the aforementioned criteria. However, reality is different and shows that this is not true and that many such industrial grade systems display significant deviations and problems regarding several quality parameters. This article is a part of a series, offering a purely objective scientific approach and proprietary methodology, based on the measurement and analysis of a range of factors, used to determine print quality. The methodology offered is based on unbiased measurement and assessment of densitometric and colorimetric factors, as well as their quantitative binding to the particularities of human perception and the fundamentals of print quality, as set by the graphic technology ISO standards suite (TC 130).

The original methodology, suggested by authors and described herein is based on the measurement, analysis, and assessment of:

1. Assessment and analysis of the volume in 3D and 2D colour gamut of the tested digital printing machine during printing over different media. Comparison of the obtained ranges against the FOGRA standards.
2. Generating of ICC for the digital printing system over different media and assessment of the complete reproduction specifications, comparison over standard profiles, investigation og icc profiles quality, research of colour stability over time, etc.
3. Complete accuracy analysis of colour and tone reproduction from a particular digital inkjet printing machine.
4. Research and assessment of colour variation during printing run, as well as analysis of colour variance as function of time – printing the same image (complete edition) over a predefined time period, reparability in different printing runs.
5. Analysis and comparison of the capabilities to obtain similar colour parameters between the tested digital printing system and conventional presses – an item of particular importance when the first edition is in offset, for example, and is then supplemented using digital printing machines. Analysis of the capacity of investigated inkjet printing systems to simulate PANTONE colours and determination of colour differences.
6. Colorimetric parameters analysis in the case of single, double, triple, etc. ink overlays. Calculation of colour differences, compared to reference values and international standards, characteristization data, etc.
7. Analysis of densitometrical parameters in digitally printed images – optical densities of solids, reproduction accuracy of tone values, simulation of tone value increase, etc.

2. EXPERIMENTAL

For the purposes of the experiment we have modelled special test forms with specialized scales and control elements for:

a) Colourimetric tests and assessment of colour characteristics of simulated PANTONE colours on inkjet digital printing presses.
b) Test charts to generate ICC profiles.
c) Charts for colourimetric analysis of colour characteristics for a digitally printed image (Kašiković et al., 2015).
d) Images with distinct colours.
e) Precision control scales for estimation of colour reproduction accuracy, gradient precision, etc.
f) Densitometric analysis patches – for estimating of density of solids, TVI (Tone Value Increase), Print Contrast etc.

To complete the test, we have used a premium inkjet printing system, as offered by one of the segment-leading brands. The fundamental task in building a colour profile is the at-most precise reproduction of the digital original. The derived ICC profiles, on the basis of which we have tested the Fogra 51, Fogra 52, Fogra 29 and Fogra 39 ranges are rooted on the characterization data, as published on the FOGRA website (Fogra, 2022). The profiles are generated with optimal colour separation conditions as per ISO 12647-2/2004/2013 (International Organization for Standardization, 2013).
Part of the scales used are presented in figure 1. The testing forms are printed with settings for different resulting ICC profiles. Before printing the test editions all machines are calibrated according to manufacturer’s instructions with the aid of spectrophotometer.

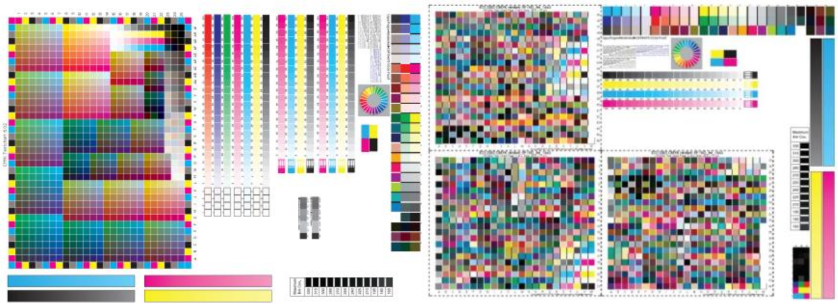


Figure 1 (part 1): Part of the testing forms used during experiments

Figure 1 (part 2): Part of the testing forms used during experiments

2.1 Test materials

We have used two basic types of printing media – different brands of coated papers and uncoated papers. They are one of the most common stocks in printing houses and come with good printing specifications (whiteness, opacity, mechanical properties, etc.), as well as with great price/quality ratio (Ozcan et al., 2020). In this case the main goal we set is to observe the colour gamut of used inkjet systems while working with the used printing stocks. In order to perform a comparison of the colour gamut for the used materials in the used inkjet digital machines, it is necessary to get both 2D and 3D visualization with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and FOGRA 51 for coated papers, so that one can gain visual idea of available colour gamut. To get the 2D and 3D visualizations of the ICC colour profiles we have used the PROFILE MAKER5.0 and ColorThink Pro 3.0.3 software products.

For the purpose of testing a total of three inkjet printing systems (from the mid and high price tier) have been used on different printing media. This article is based on machines, used in different areas of polygraphy as core digital printing systems. Other articles of this series offer insights investigation of the rest of printing quality parameters of suggested methodology, also another printing systems from this class, electrophotographical systems and others.

2.2 The test completion comprehends the following parameters:

1. Testing and comparing the 2D cross sections of colour gammuts Durst TAU RSC 330, Gallus Labelfire 340 и HP DesignJet Z6800 against FOGRA standards.
2. Testing and comparing the volume and shape of 3D colour gamut of Durst TAU RSC 330, Gallus Labelfire 340 и HP DesignJet Z6800 against FOGRA standards.
3. Calculation and comparison of the colour gamut volume ΔE^3.

3. RESULTS AND DISCUSSION

To test and compare the volume of colour gamut we have combined several specialized ΔE^3 software products, which yielded generally more accurate result representation. Please note that this is the maximal colour ranges, which is reproducible by the digital printing systems Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800. This is why colour volume is one of the cornerstone specifications.

With the aid of the different software products, we were able to calculate the colour volumes from the printing results for the used substrate and to compare them against the reference values for the corresponding FOGRA standard. This research and graphic representation of 2D cross-sections and 3D volumes of colour gamut is aided by these specialized software products: X-Rite Profile Editor 5.0 and ColorThink Pro 3.0.3.

3.1 Investigation of colour gamut volumes and comparison of 2D and 3D colour gammuts of different digital inkjet printing systems

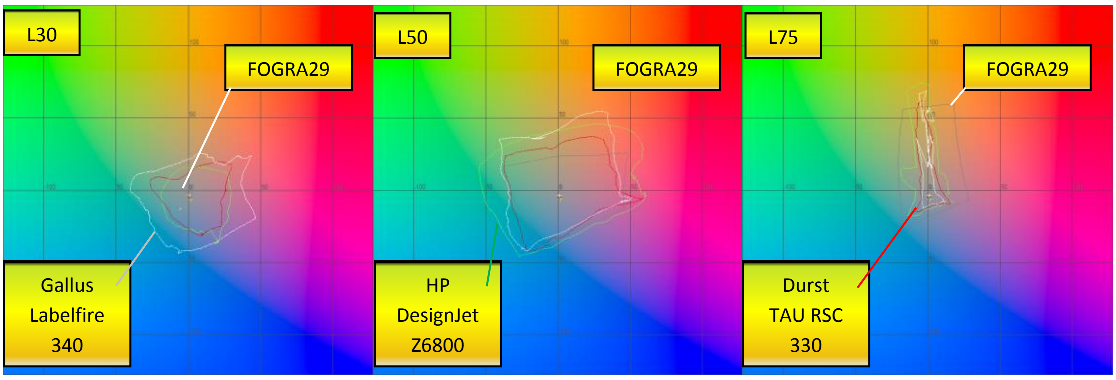
One important function, which is used to visualise the colours, as reproduced by any given machine, is the 2D and 3D representation of the respective colour gammuts. This paper also uses 2D and 3D representations. The 2D representation of colour gammuts with different cross-sections along the L-axis of the CIE Lab colour space allows for good visual comparison of colours in light, mid and dark tones, as well as comparison of a large number of colour gammuts at once. The 3D representation of colour gammuts allows a complex visual assessment for the 3D body of the colour gammut. It is appropriate for the visualisation and comparison of ore or two colour gammuts.

In order to perform the comparison for the colour gammut of the examined prints from the corresponding digital printing presses – Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800 it is necessary to provide a 3D visualisation with a standard ICC profile FOGRA 29 and FOGRA 52 for uncoated papers and FOGRA 39 and Fogra51 for coated papers with the ultimate goal to achieve visual representation for the colour gammuts.

The visualization of 2D cross-sections with different values of L yields a rich fact set on how the colour gamut varies, with the media used, against the reference values as per the corresponding FOGRA standard. This allows for a deeper insight into the colour volume and also aids tracking the corresponding values of L, which can be in the range 0 to 100.

The next figures show the comparison of 2D cross-sections across different media, as printed with Durst TAU RSC 330, Gallus Labelfire 340 and HP DesignJet Z6800, compared with the corresponding FOGRA standard.

Figures 2 to 5 show 2D visualization of colour ranges over tested media with the use of Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330.



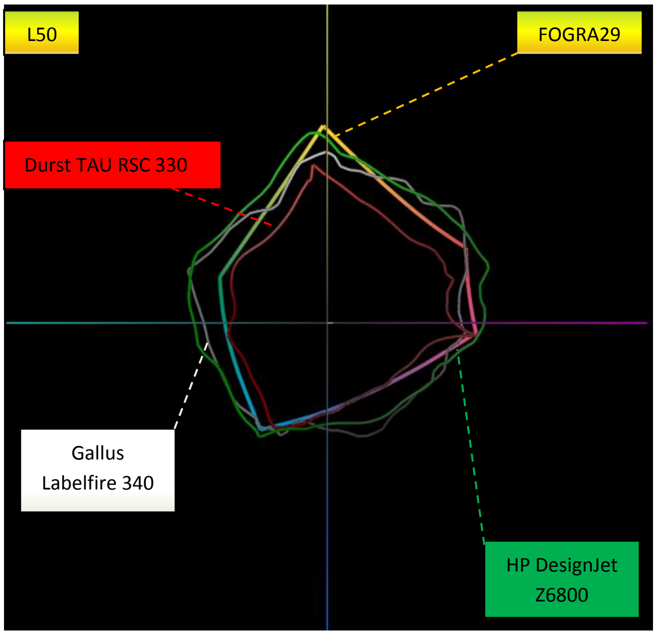
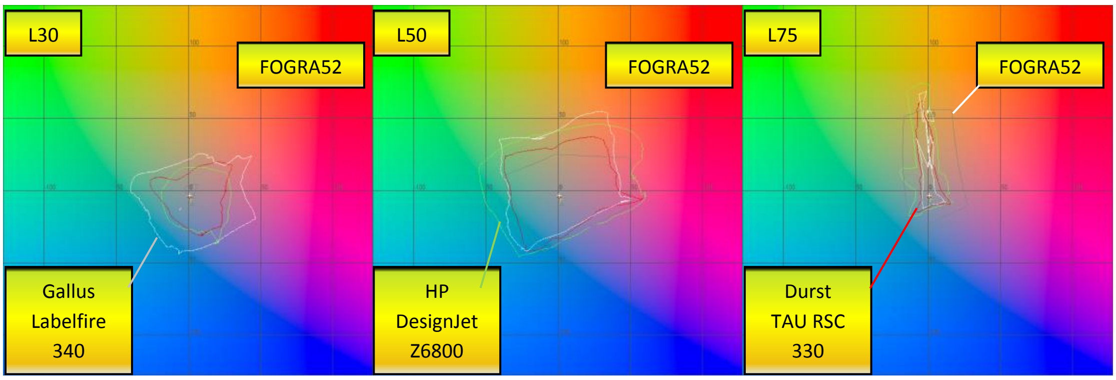


Figure 2: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed with Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA29

Data shows that the most accurate reproduction of tone and hue, as compared to FOGRA standards, is observed with coated (matte or glossy) and uncoated (offset) papers in mid tones for L=50. With dark tones L=30 (FOGRA29, FOGRA52) for uncoated papers and L=10 (FOGRA39), respectively L=15(FOGRA51) for coated papers, the colour range derived from the test is comparatively larger, than FOGRA standards. In light tones for L=75 the colour range of tested papers, as printed with the corresponding inkjet digital machines is considerably smaller in comparison to the FOGRA standards.
To compare the colour gamut on offset uncoated paper, a standard ICC profile was used FOGRA 29 and FOGRA 52.



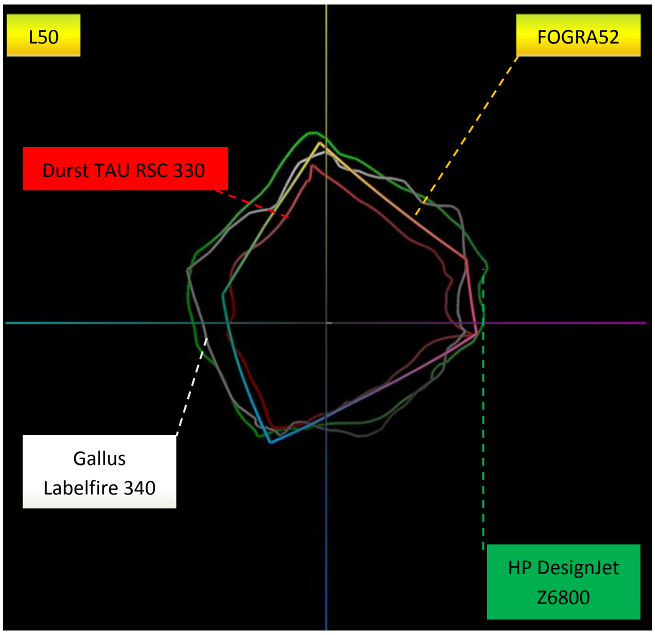


Figure 3: Graphic representation and comparison of 2D colour gamut with different values of L over uncoated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA52

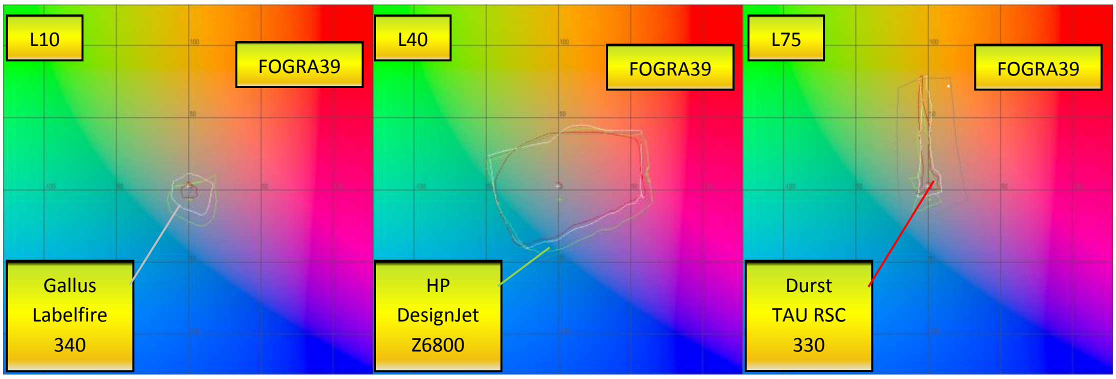


Figure 4 (part 1): Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

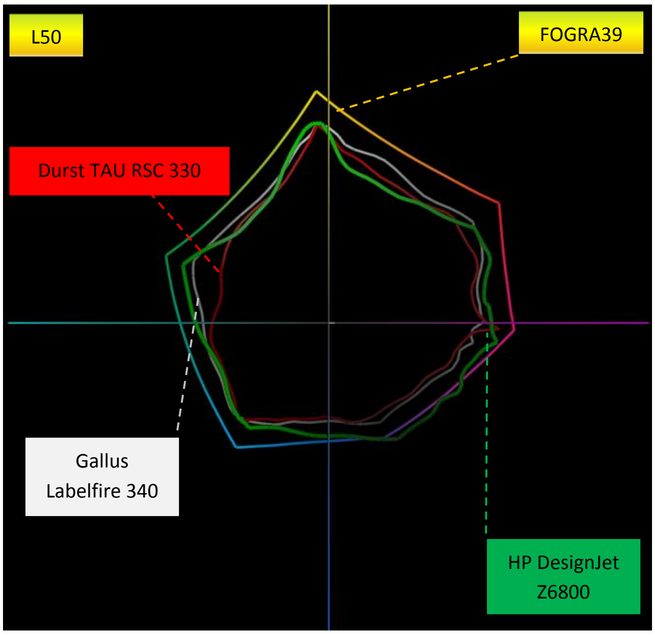


Figure 4 (part 2): Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

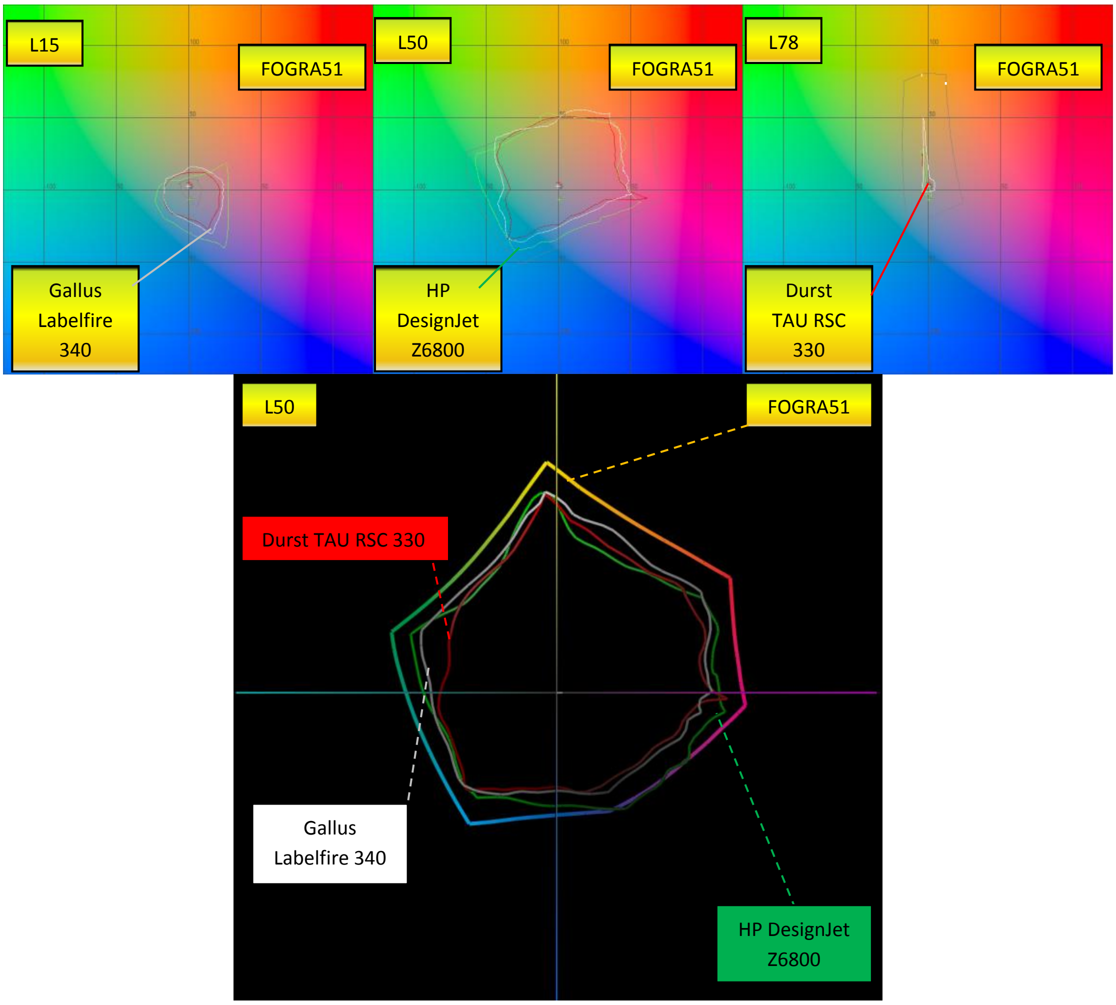


Figure 5: Graphic representation and comparison of 2D colour gamut with different values of L over coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA39

From figures 6, 7, 8 and 9 one can observe that the colour range of FOGRA29, as well as FOGRA52 is considerably larger in light tones compared to the offset paper printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330. It is also apparent that in certain regions the colour range of all tested printing systems, material can reproduce colours, which FOGRA29 and FOGRA52 cannot, but this is mostly limited to dark tones. In mid tones there is a large resemblance between the test print and the FOGRA29/52 prints.

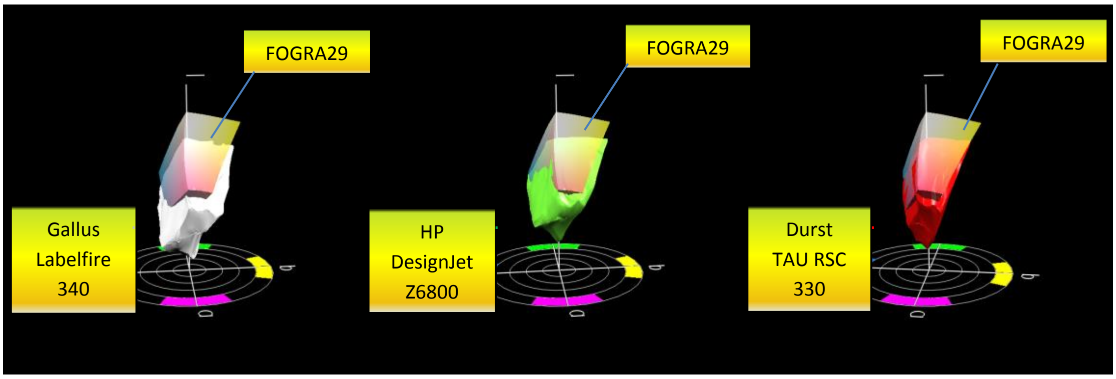


Figure 6: 3D visualisation (Lab system) of an ICC profile of offset paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA29

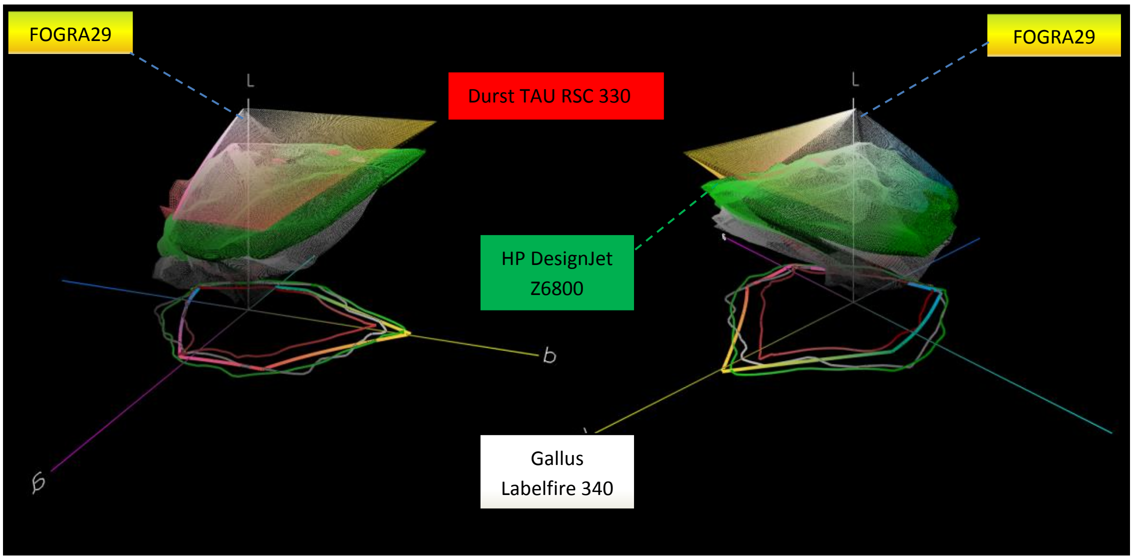


Figure 7: 3D visualization (lab system) of ICC profile of uncoated paper printed by all printing systems compared to FOGRA29

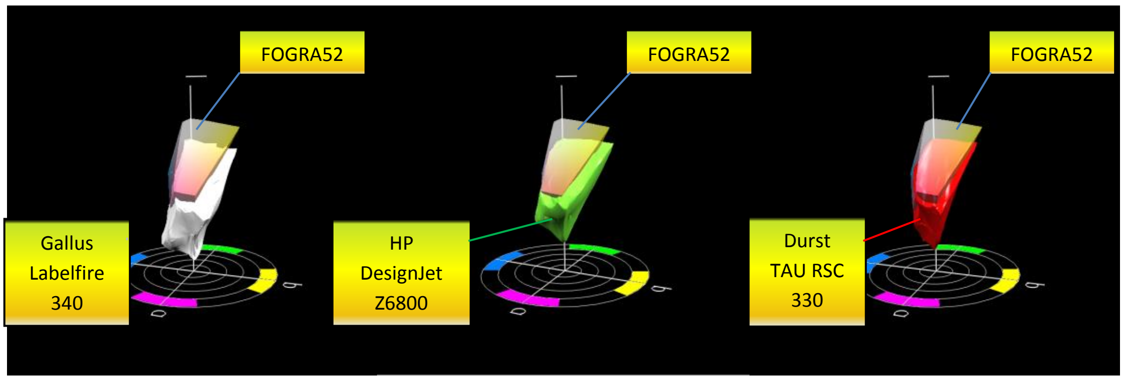


Figure 8: 3D visualisation (Lab system) of an ICC profile of uncoated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA52

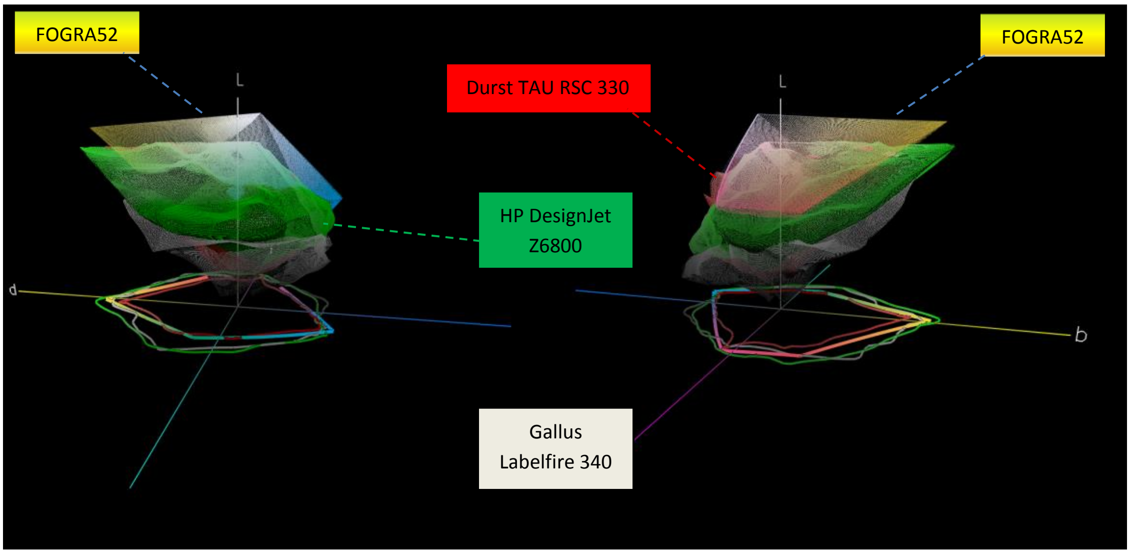


Figure 9: 3D visualization (lab system) of ICC profile of uncoated paper printed by all printing systems compared to FOGRA52

As a comparison platform for the colour gamut of coated paper the ICC FOGRA39 and FOGRA51 profile has been used:

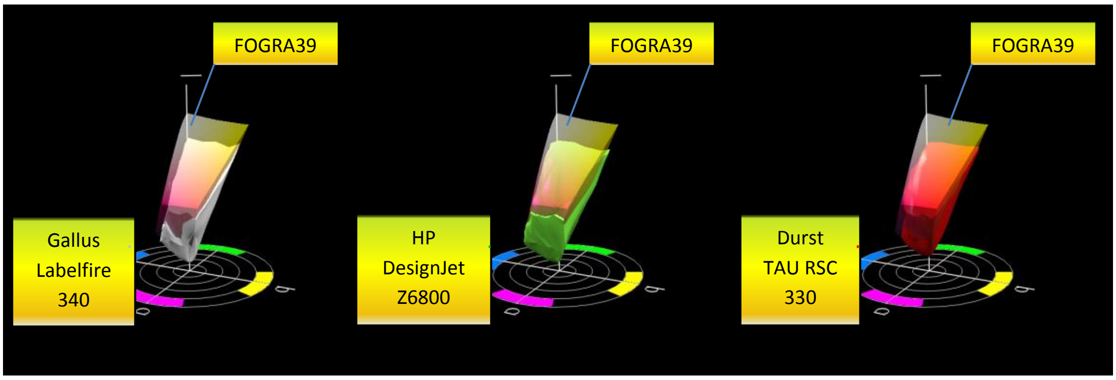


Figure 10: 3D visualisation (Lab system) of an ICC profile of coated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA39

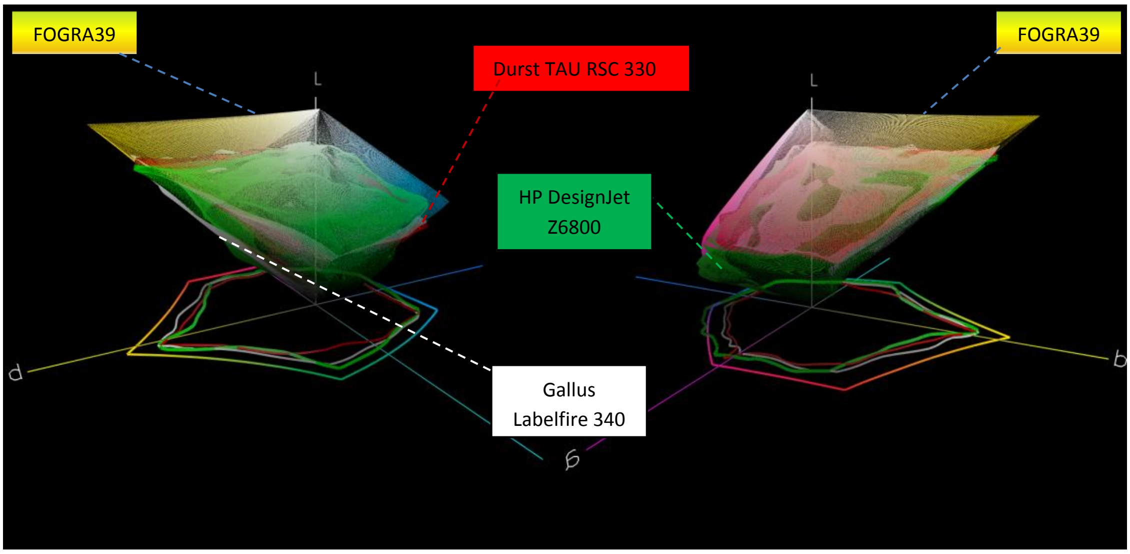


Figure 11: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA39

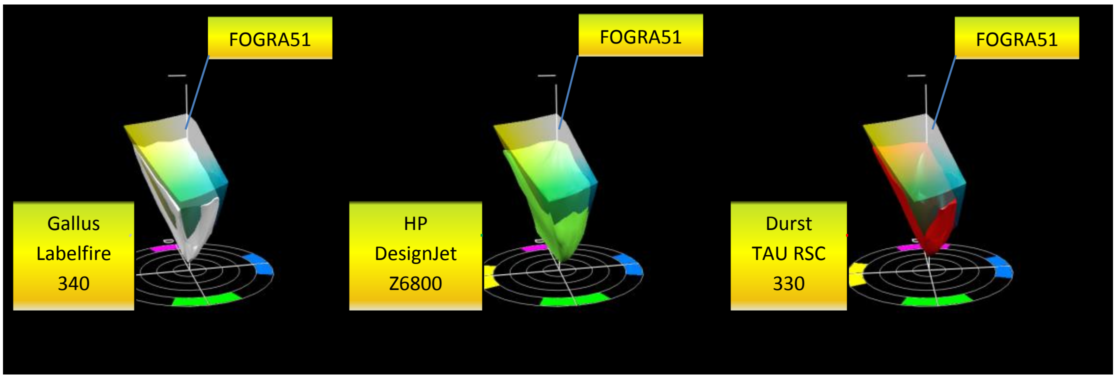


Figure 12: 3D visualisation (Lab system) of an ICC profile of coated paper printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 and FOGRA51

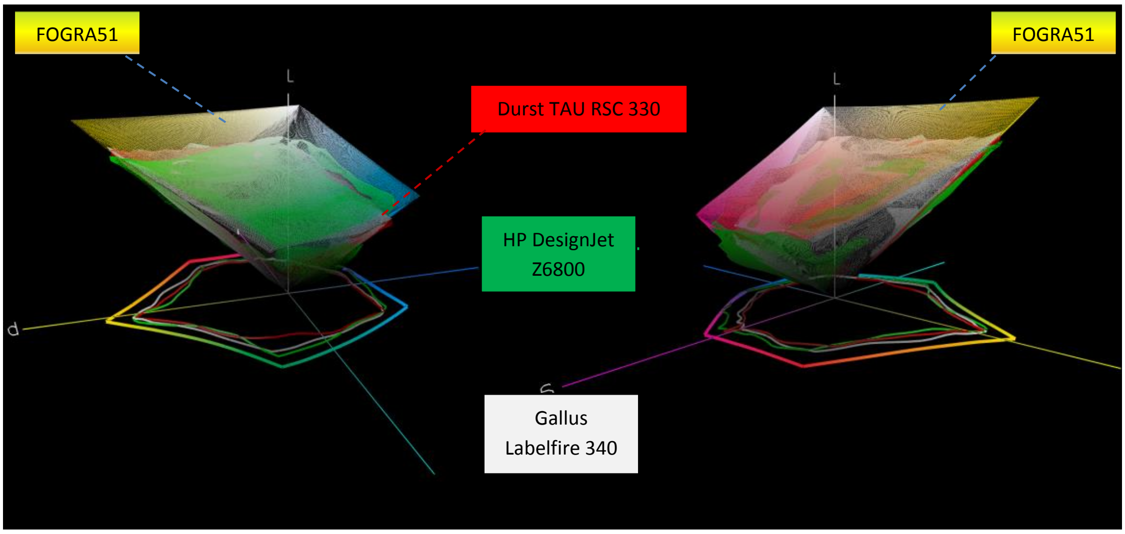


Figure 13: 3D visualization (lab system) of ICC profile of coated paper printed by all printing systems compared to FOGRA51

Figures 10, 11, 12 and 13 show that the colour range of FOGRA39 and FOGRA51 is considerably larger in yellow-green, blue-red and green-blue areas in light tones of coated paper, as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330. Also it is visible that certain areas of the colour scale of tested printing machines, the material is able to reproduce colours mostly in the dark tones, which FOGRA39 and FOGRA51 can't. In mid tones we see good results for all tested machines and substrates, which come very close to FOGRA standards. With FOGRA39 and FOGRA 51, however, there is better colour reproduction in the lighter hues.
Tables 1 and 2 show the calculated values of the received ICC profiles for the media printed through Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with the reference values as per the corresponding FOGRA standard. Two specific software products have been used to calculate the volume of the colour range. Each of them has a proprietary algorithm to calculate ΔE^3, which accounts for the difference between the two software products.

Table 1: Colour gamut volume ΔE^3 for Uncoated Paper

Uncoated Paper ΔE^3					
	FOGRA 29	FOGRA 52	Gallus Labelfire 340	HP DesignJet Z6800	Durst TAU RSC 330
Color Think 3.0.3	181382	163565	207411	228134	141819
Gamut Vision 1.4	187079	162620	304569	395050	206122

Table 2: Colour gamut volume ΔE³ for Coated Paper

Coated Paper ΔE^3					
	FOGRA 39	FOGRA 51	Gallus Labelfire 340	HP DesignJet Z6800	Durst TAU RSC 330
Color Think 3.0.3	402279	386692	249767	298815	223135
Gamut Vision 1.4	444027	448088	477068	476522	393221

According these results, one can obtain the graphics as shown in Figures 14 and 15.

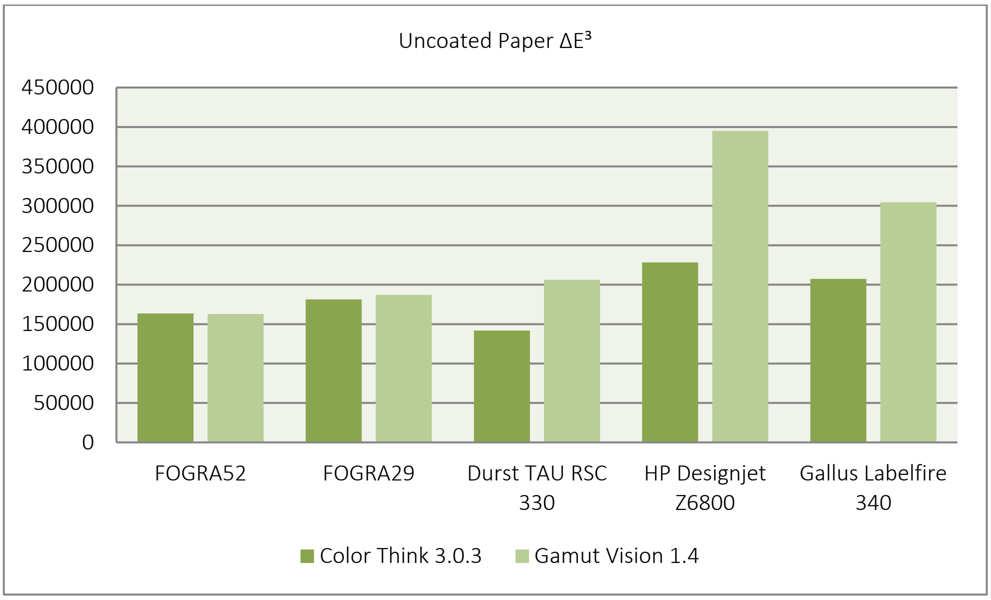


Figure 14: Graphic representation of the colour gamut ΔE³ for Uncoated Paper as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

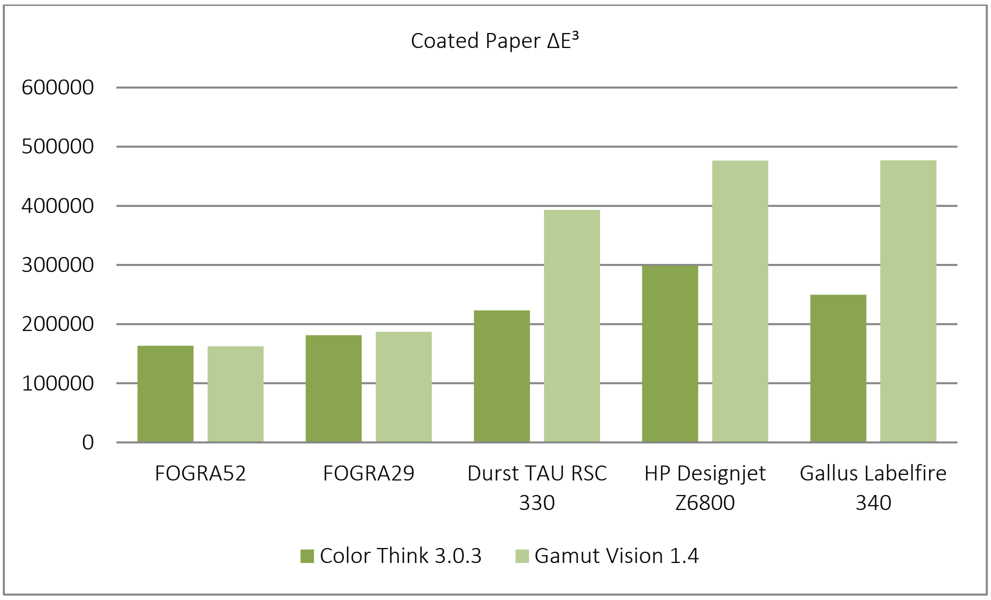


Figure 15: Graphic representation of the colour gamut ΔE³ for Coated Paper as printed by Gallus Labelfire 340, HP DesignJet Z6800 and Durst TAU RSC 330 compared with reference values as per FOGRA calculated with CHROMIX Color Think 3.0.3 and Gamut Vision 1.4

4. CONCLUSIONS

From the tests performed in relation to this article, we have arrived at the following conclusions:

1. This research is a part of complete method to evaluate digital print quality, based on scientific approach and unbiased analysis of a great number of colorimetric and densitometric parameters for the printed image such as: achieved colour differences in relation to the set / desired colours and ISO standards, accuracy of reproduction - colour and geometric, grey balance, TVI, Colour Gamut, etc.
2. In real conditions, over widely used media, we have examined some of the most used industrial grade inkjet digital printing systems as the results are compared against FOGRA standards.
3. All of obtained results for colour gamut volumes, 3D and 2D cross section surface analysis are valid for the studied printing conditions and used materials. The authors do not claim general evaluations of the investigated digital presses.
4. From the 2D visualization we have made cross-sections of colour ranges of tested media, with different values of L, we have observed that with L=30 over uncoated paper, the largest colour range belongs to Gallus Labelfire 340, followed by HP DesignJet Z6800 and Durst TAU RSC 330 with overlapping ranges. With these values of L=30 (dark tones), colour ranges of tested inkjet printing systems are considerably larger, compared to the FOGRA 29/52 standards. With L=50 all three systems tested show larger colour range in green-yellow and yellow-red areas, compared to the FOGRA 29 and FOGRA 52. With L=75 the smallest colour range is observed with Gallus Labelfire 340, as all three digital systems display circa two-fold smaller colour ranges, compared to FOGRA 29 and FOGRA 52. For coated paper (matte, glossy) with L=10 (FOGRA39) and L=15 (FOGRA52) HP DesignJet Z6800 and Gallus Labelfire 340 show larger colour ranges, compared to Durst TAU RSC 330 and the FOGRA 39 and FOGRA 51 standards. With L=40 (FOGRA39) colour ranges for all machines are comparable and almost cover the FOGRA39 standard. With L=75 (FOGRA39) and L=78 (FOGRA51) we have observed, yet again, circa two-fold smaller colour range as compared to the FOGRA standard.
5. From the 3D visualization with ICC colour profile generation and the comparison between the latter and FOGRA 29 and FOGRA 52 (for uncoated media) and FOGRA 39 and FOGRA 51 (for coated media) for the tested inkjet printing machines and the tested media, we have established that Gallus Labelfire 340 followed by HP DesignJet Z6800 and Durst TAU RSC 330, we have better colour reproduction in the dark and mid tones, compared to FOGRA 29 and FOGRA 52. In the dark tones, the colour profiles of all tested inkjet printing systems go beyond the scope of standard FOGRA 29 and FOGRA 52 profiles. Data shows that when using uncoated media, best results, compared with FOGRA 29 and FOGRA 52, belong to Durst TAU RSC 330 followed by Gallus Labelfire 340 and HP DesignJet Z6800. From the results obtained regarding the 3D volume range over coated paper (glossy, matte), printed via the tested digital printing machines, it is visible that the FOGRA 39 and FOGRA 51 standards have larger colour gammut in lighter hues, compared to the prints as produced by all tested machines. Better colour reproduction is observed with coated media, especially in colour reproduction over mid hues in blue-green, green-red and red-yellow areas.
6. We have made use of two specialized software solutions to obtain the colour volume. Each of them uses its own ΔE^3 algorithm, due to which one sees variance in the calculated values.
   Colour gamut's and their volume are of special significance when the print quality is defined. Calculating ΔE^3 using CHROMIX Color Think 3.0.3 showed the following result:

   - For uncoated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =228134), followed from Gallus Labelfire 340 (ΔE^3 =207411) and Durst TAU RSC 330 (ΔE^3 =141819). The standard colour gammuts of FOGRA29 (ΔE^3 =181382) and FOGRA52 (ΔE^3 =163565) were best met by the HP DesignJet Z6800 (26% > ΔE^3 FOGRA29 and 39% > ΔE^3 FOGRA52), followed by Gallus Labelfire 340 (14% > ΔE^3 FOGRA29 and 27% > ΔE^3 FOGRA52) Durst TAU RSC 330 (22% < ΔE^3 FOGRA29 and 13% < ΔE^3 FOGRA52).
   - For coated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =298815), followed from Gallus Labelfire 340 (ΔE^3 =249767) and Durst TAU RSC 330 (ΔE^3 =223135). The standard colour gammuts of FOGRA39 (ΔE^3 =402279) and FOGRA51 (ΔE^3 =386692) were best met by the HP DesignJet Z6800 (26% < ΔE^3

FOGRA39 and 23% < ΔE^3 FOGRA51), followed by Gallus Labelfire 340 (38% < ΔE^3 FOGRA39 and 35% < ΔE^3 FOGRA51) and Durst TAU RSC 330 (44% < ΔE^3 FOGRA39 and 42% < ΔE^3 FOGRA51).

Calculating ΔE^3 using Gamut Vision 1.4 showed the following result:

- For uncoated paper the largest colour gamut was obtained with HP DesignJet Z6800 (ΔE^3 =395050), followed from Gallus Labelfire 340 (ΔE^3 =304569) and Durst TAU RSC 330 (ΔE^3 =206122). The standard colour gammuts of FOGRA29 (ΔE^3 =187079) and FOGRA52 (ΔE^3 =162620) were best met by the HP DesignJet Z6800 (111% > ΔE^3 FOGRA29 and 143% > ΔE^3 FOGRA52), followed by Gallus Labelfire 340 (63% > ΔE^3 FOGRA29 and 87% > ΔE^3 FOGRA52) and Durst TAU RSC 330 (10% > ΔE^3 FOGRA29 and 27% > ΔE^3 FOGRA52).

- For coated paper the largest colour gamut was obtained with Gallus Labelfire 340 (ΔE^3 =477068), followed from HP DesignJet Z6800 (ΔE^3 =476522) and Durst TAU RSC 330 (ΔE^3 =393221). The standard colour gammuts of FOGRA39 (ΔE^3 =444027) and FOGRA51 (ΔE^3 =448088) were best met by the Gallus Labelfire 340 (7% > ΔE^3 FOGRA39 and 6% > ΔE^3 FOGRA51), followed by HP DesignJet Z6800 (7% > ΔE^3 FOGRA39 and 6% >ΔE^3 FOGRA51) and Durst TAU RSC 330 (11% < ΔE^3 FOGRA39 and 12% < ΔE^3 FOGRA51).

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NOVEL TECHNOLOGIES

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INVESTIGATION OF THE EFFECT OF SPEED AND PRESSURE ON CONDUCTIVITY IN INKJET PRINTED ELECTRONIC DEVICES

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Abstract: *We can define printed electronics as the application of printing on a material by means of semiconductor, dielectric and electronic components. This process basically takes place by adding materials that will provide conductivity properties into the printing inks. In addition to printing with traditional printing systems, drop-on demand inkjet printing provides an important advantage in this field thanks to its non-contact and digital patterning capabilities. Therefore, the demand for inkjet printing printable inks based on high-performance electronics is also increasing to expand the scope of possible applications for printed electronics. In recent years, inkjet printing technology has become more and more popular due to its use in various applications such as photovoltaic cells, light-emitting diodes (LED), organic thin-thin transistors, displays, radio frequency identification devices (RFID), smart clothing and sensors. For these applications, the unique feature of inkjet printing technology is that it can print on a wide range of materials and is a digital, contactless and plateless system. We can count other advantages of this technology as low cost and savings from waste. These properties make the inkjet printing technique particularly suitable for printing conductive patterns on a variety of flexible substrates in the manufacture of electronic circuits or devices. The electrical conductivity on the printed material may vary depending on the substrate, printing speed and pressure. For this purpose, a specially prepared test scale with lines of different thicknesses was printed on the polyethylene film material with BENTSAI BT-HH6105B1 Portable Handheld Mobile inkjet printing machine. The effect of machine speed and pressure values on conductivity was observed in the prints made with silver-based conductive inks. As a result, it was concluded that the conductivity value increased as the printing pressure increased at constant speed, and on the other hand, the conductivity value increased as the printing speed decreased when the pressure was fixed.*

Keywords: conductivity, inkjet, printed electronics, printability, conductive ink

1. INTRODUCTION

The world is developing and changing according to our wants, needs, and everything change. Consequently, the need for advanced technological products is increasing. To respond to this increase, we must produce more and. Although the need for printed products, such as books and newspapers, has decreased, it can be said that there is an increase, not a decrease, when the printing industry are examined. The reason for this is packaging, labels, and high-technology printable products. In other words, the printing industry is not shrinking; on the contrary, it is growing daily and changing its shape. At this point, the use of printed electronics to produce new technologies has emerged as an option. This technology can be used in areas such as sensors, health products, displays, solar panels, wearable technologies, and VR games (Wang & Liu, 2016). When the products mentioned are examined and traditional production techniques are used, both time and conductive materials are lost. They are also difficult to manufacture. However, with printing systems, these products can be produced more easily and cheaper using less ink. Printed electronics are products that are easy to manufacture, inexpensive, shorter in time, and generally exhibit high performance. Owing to these advantages, it is used in many areas and there are new areas of use by day (Wu, 2017).
Printed electronics can be defined as the transfer of a conductive ink to the substrate of an electronic circuit element by means using a plate. This is similar to the traditional printing processes. According to the Organic Electronics Association, printed electronics are defined as "thin, light, flexible, and low-cost electronics" (Organic and Printed Electronics Association, 2022). As printed electronics evolve, this opens new doors to technology. These include smart packaging applications, smart transport systems, smart textiles, lighting and panel systems, and flexible displays. Depending on customer demand, it is used in many areas from the packaging industry to the automotive industry, from the pharmaceutical industry to the construction industry, and the health sector (Figure 1). In addition, wearable health products such as smaller scale games and augmented reality applications, smart roads and cars, and diabetes sensors can be produced with the help of printed electronics (Kantola et al., 2009). Many studies show that it will

enter our daily lives in many new areas such as invisibility, foldable and wearable screens, body integrated communication systems, and printed electronic products in the future.

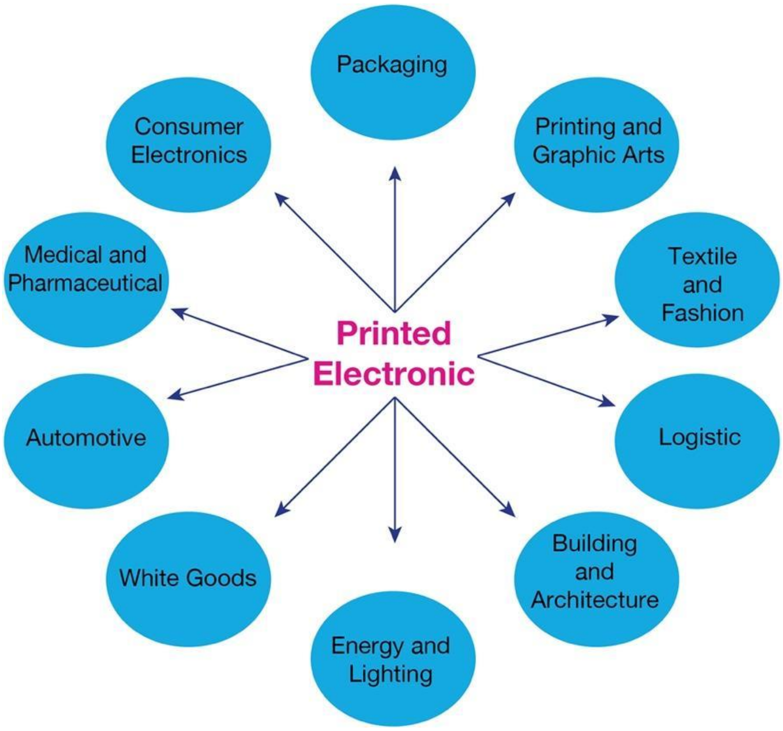

Figure 1: Printed electronics usage areas

The most important element of all electronic devices is the conductive structure of the metals that connect various components in the circuit. Conventional electronic systems are produced using photolithography, a complex and time-consuming multi-step process that requires expensive facilities and a variety of tools that generate large volumes of environmentally damaging hazardous waste. Vacuum deposition is also used in the manufacture of electronic devices. This process is not as costly as photolithography, but requires a large amount of energy to perform. In addition, the process is difficult to control over small areas, therefore, it is not suitable for high resolution patterns.

The global market demands high-quality and low-cost production methods for electronic devices that are both faster and cheaper than traditional production methods. There has been a worldwide effort to make these processes commercially available, and some have already been successfully commercialized. Printed electronics bring together two different fields; printing and electronics. Using traditional printing processes, inks based on metal nanoparticles (NPs) and metallo-organic complexes (MC) are used to produce building blocks of electronic products, such as transistors and diodes (Rao et al., 2022). The biggest advantage of printed electronics in the production of these components is the significant reduction in the cost of the electronic devices. Applications of printed electronics have previously been demonstrated in the manufacturing of batteries, LEDs, displays, speakers, sensors, and fully printed RFID tags. Flexible electronic devices are manufactured by placing single or multiple layers of functional materials, including paper, on polymer substrates.

The most important challenge in printed electronics is the formulation of functional inks. The formulation of functional inks is similar to that of printing inks; however, in order to be compatible with flexible surfaces, the printed pattern must provide good printability, good compatibility with the substrate, and low temperature processing (Patil, 2015), which is only possible with fluid or semi-fluid ink (Dang et al., 2014). Therefore, the dimensions of the metals used in this study should be reduced. However, in this manner, it is possible to produce ink from metals. Thus, these metals exhibit properties different from those of their normal sizes (Elzey & Grassian, 2010). To increase the effectiveness of the ink, the surface of the nanometal was modified with organic molecules. The metal obtained here can not only be called a pigment, but the product obtained is a functional ink (Schlisske et al., 2021).

Conductive inks consist of silver, copper or organic semiconductor materials. Many printing systems, such as inkjet, flexo, screen printing, and intaglio printing, are used in the production of printed electronics.

The ink rheology, viscosity, wettability, surface energy, and morphology of the substrate are effective for printing ink on the surface, as designed. These parameters play a significant role in the high resolution of printed electronics products. Therefore, these criteria should not be ignored when selecting the substrates. These substrates have also been used in the packaging industry. This allows for the production of low-priced, easily produced and easily accessible products. In addition, fibre materials such as polyesters are used in wearable devices (Cui, 2016).

Currently, the printed electronics market is dominated by nanosilver-based inks. Printed electronics is a highly material-oriented field. Inks must operate stably with the viscosity and surface tension values required for printing, and charge transfer via interconnected molecules or particles in the transferred ink film, which provide the necessary electronic functionality (Patil, 2015). The challenge in meeting these requirements is the correct formulation of conductive inks. In inks using metallic nanoparticles, the nanoparticles are closed with a protective shell (encapsulation) to obtain a stable distribution of particles (Choi, 2012). Graphene-based inks offer high conductivity, flexibility, high speed printing, and low temperature curing properties.

When the materials used for printed electronics are examined, one of the important parameters affecting the final product feature is the substrate material. The mechanical properties and different surface properties of the substrate affect the printability and print quality. Printed electronic applications on flexible surfaces determine the cost and production technique of the final product. Smooth, low porosity and high surface energy substrates are preferred for most printable electronics applications. When the printing materials used in printed electronics are examined, we can begin with low-priced and widely used paper. In addition to these advantages, this study is thermally stable. However, indentations and protrusions on paper surfaces create problems for printed electronics. For this reason, by applying surface smoothing processes such as sizing, coating or calendering on the surface of the paper, these indentations can be reduced, the surface can be modified, the porosity can be reduced and surface wetting can be achieved, thus higher resolution electronic applications can be made (Hoeng, Denneulin & Bras, 2016). Other materials used in printed electronics include polyimide films, and various plastic and steel films. For special applications, high purity film materials meet these requirements. Polyethylene terephthalate is the most commonly used substrate in the printed electronics industry (MacDonald, 2007). In addition, many polymeric film materials satisfy the requirements of printed electronics. However, surface modification and applications may be required to increase the interest in these film materials in functional inks (Cummins & Desimulliez, 2012). For example, polyethylene terephthalate films require thermal stabilization.

The ease of creating the desired pattern in the screen printing technique, which is the most widely used in the field of printing electronics, allows it to be used frequently in the field of electricity and electronics. The sieves can be either flat or rotary. In the screen printing process, conductive, dielectric, and highly functional materials other than carbon can be printed. Screen printing is a very suitable tool in terms of possibilities such as printing thickness and repetition required for textile antenna production.

Inkjet printing technology is very promising today, especially in the production of low-cost and disposable electronics for various applications such as displays and RFID tags. In recent years this technology has been adapted to a number of technology areas as a manufacturing tool such as displays, plastic electronics, tissue engineering and 3D printing. The major advantage of inkjet printing is its ability to produce consistent drop volumes in a desired location. Another of the greatest advantages of the inkjet printing system is that it enables us to print data that can be changed. Thus, it is possible to produce many different circuit elements in a short time.

In the study, the effect of speed and pressure change on the conductivity value in inkjet printing was determined by printing at different speeds and different pressures in a handheld printer inkjet printing machine with specially prepared conductive ink.

2. METHODS

Conductive ink for use in prints is prepared as follows, it will be mixed with 0.01 M $NaBH_4$ and 0.01 M polyvinyl pyrrolidone (PVP). Then, 0.1 M $AgNO_3$ was added dropwise to this mixture. The colourless mixture was stirred until it turned dark brown. This colour indicates the formation of silver nanoparticles. Then, glycerol was added to the mixture as a stabilizer, and the mixture was mixed for 15 min to obtain silver nanoparticles. Using the obtained silver nanoparticles, inkjet ink with the ratios in Table 1 was prepared. For this, first the resin was fluidized using a solvent, then solid silver nanoparticles were added and after its viscosity was adjusted with the remaining solvent, it was homogenized in an ultrasonicator and printed quickly.

Table 1: Conductive ink formulation

Contents	Ratio
Ag Nanoparticles	25
Vinyl Choloride/Vinyl Acetate Copolymer	15
Ethylene Glycohol	60
Total	100

In the study, prints were carried out at different speeds of 300, 500, 700, and 900 m/s and at different pressures of 90, 120, 150, and 180 bar on a handheld printer inkjet printing machine with specially prepared conductive ink. With these pressures, the effect of speed and pressure change on the conductivity value was determined. In addition, it has been observed whether there is a change in conductivity according to the change of line thickness by using lines of different thickness in the special scale created for the test print.
Bentsai bt-hh6105b2 thermal inkjet digital printer (Figure 2) was used as the printing machine in the study. Polyethylene film material was used as the substrate material. Polyurethane binder conductive ink containing silver nanoparticles was produced and used. The images of the printed conductive lines were taken with the Leica S8 APO microscope and it was examined whether the prints were carried out optimally or not. After printing, conductivity measurements were made with a multimeter.

Figure 2: Bentsai bt handheld thermal inkjet digital printing machine

3. RESULTS AND DISCUSSION

Silver nanoparticle and inkjet ink were prepared successfully. It was determined that the silver ink remained homogeneous for 4 hours and inkjet prints were carried out without any problems.
As a result of the printing, the conductivity measurement results obtained at a constant speed of 300 m/s (Figure 3), 500 m/s (Figure 4), 700 m/s (Figure 5) and 900 m/s (Figure 6) are given. In addition, conductivity measurement results obtained at constant pressure of 90 bar (Figure 7), 120 bar (Figure 8), 150 bar (Figure 9) and 180 bar (Figure 10) are given.
As seen in the figures, when the conductivity values of the prints made at constant speeds of 300, 500, 700 and 900 m/s at 90, 120, 150 and 180 bar pressures are examined, the conductivity value increases as the pressure increases at constant speed.

In addition, an increase in conductivity was observed in parallel with the increase in line thickness. Depending on the increased printing pressure, the amount of transmitted ink also increased and this caused an increase in conductivity.

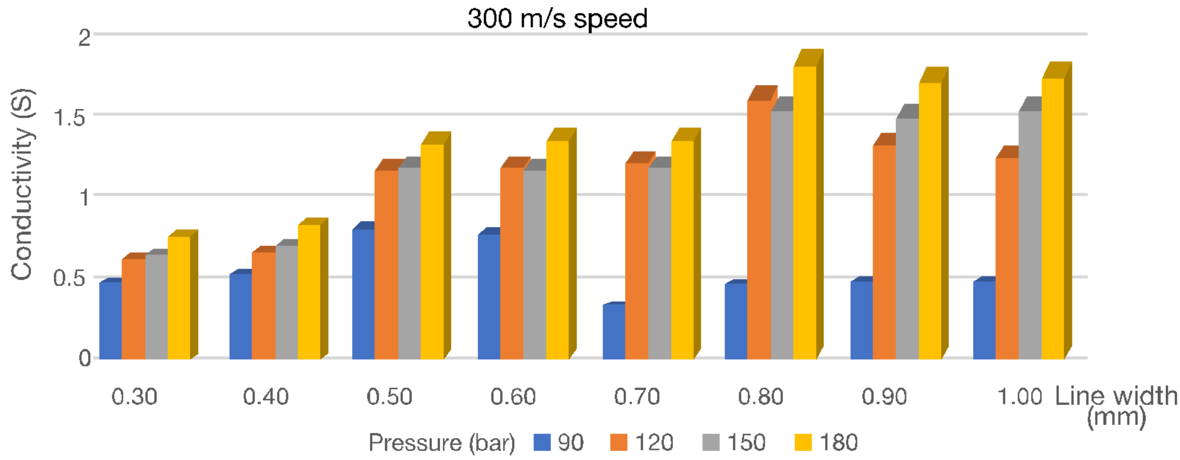

Figure 3: Conductivity values of lines printed under different pressure at a constant speed of 300 m/s

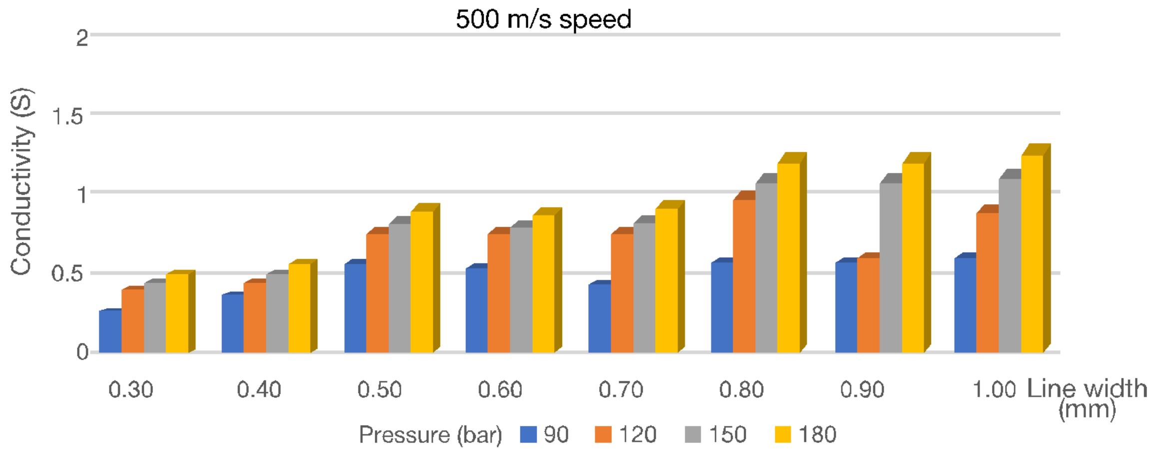

Figure 4: Conductivity values of lines printed under different pressure at a constant speed of 500 m/s

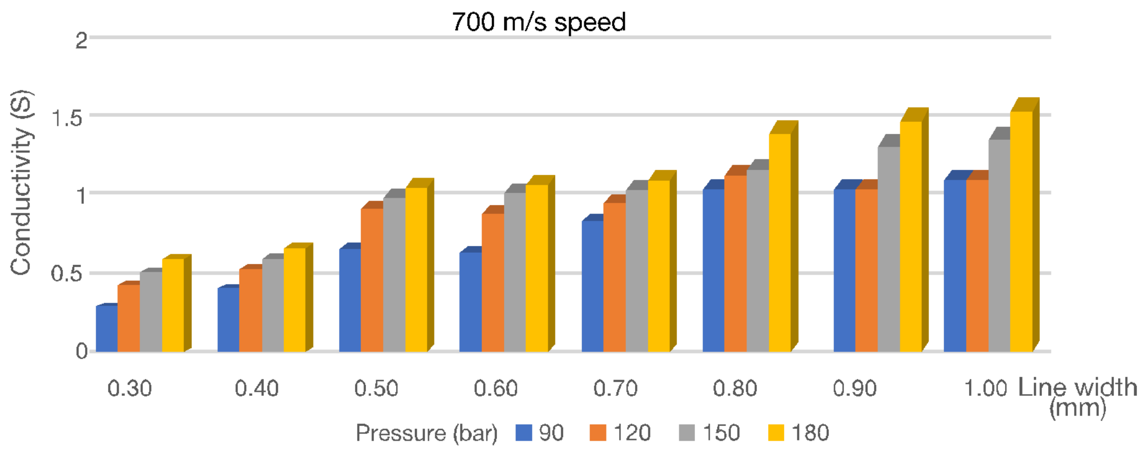

Figure 5: Conductivity values of lines printed under different pressure at a constant speed of 700 m/s

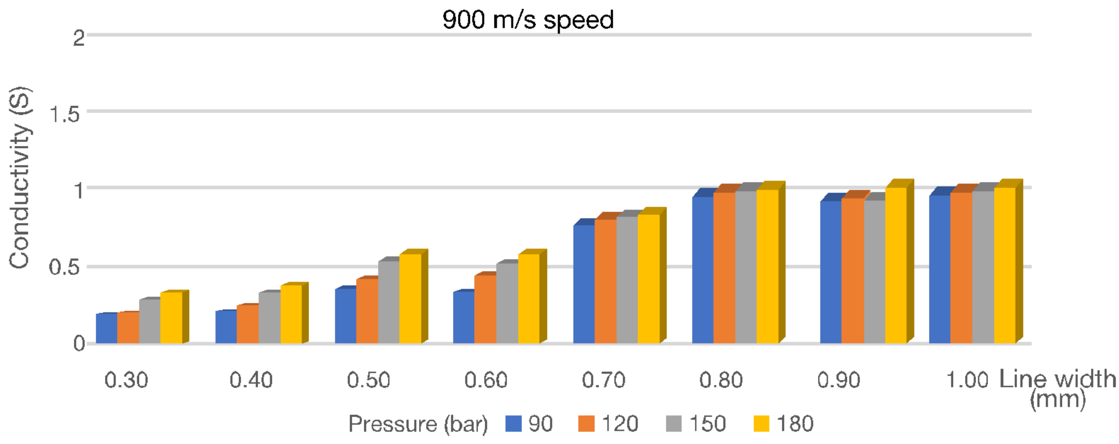

Figure 6: Conductivity values of lines printed under different pressure at a constant speed of 900 m/s

When the conductivity values obtained from the prints made at different speeds under constant pressure are examined (Figure 7, Figure 8, Figure 9, and Figure 10), it has been determined that the conductivity value decreases as the speed increases at constant pressure. In addition, the increase in line thickness also increased the conductivity value.

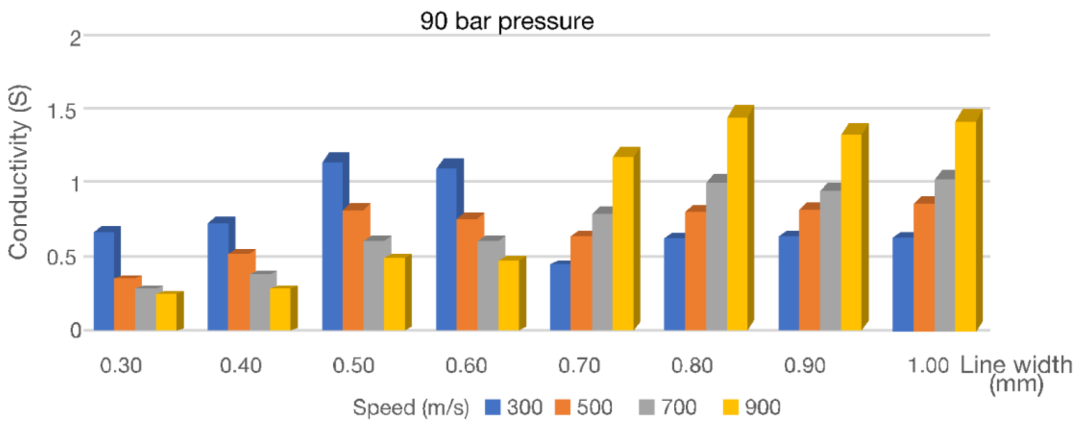

Figure 7: Conductivity values of lines printed at different speeds under 90 bar constant pressure

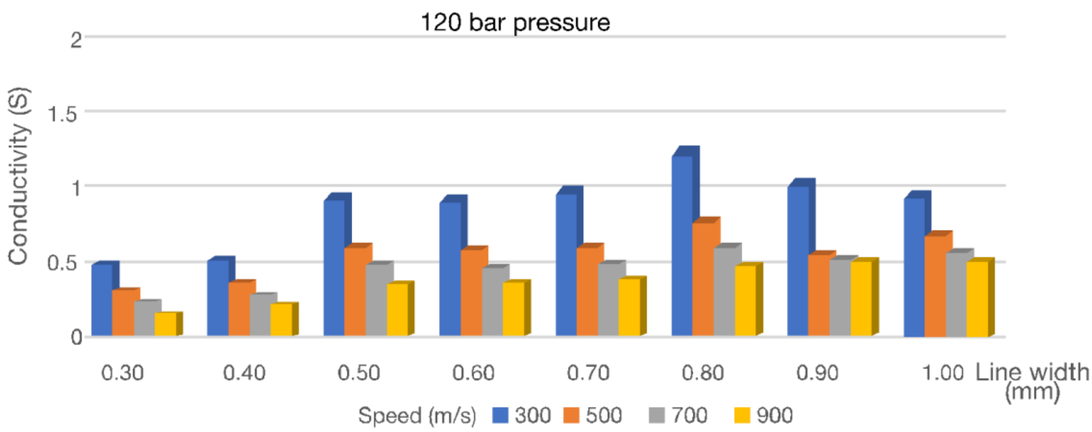

Figure 8: Conductivity values of lines printed at different speeds under 120 bar constant pressure

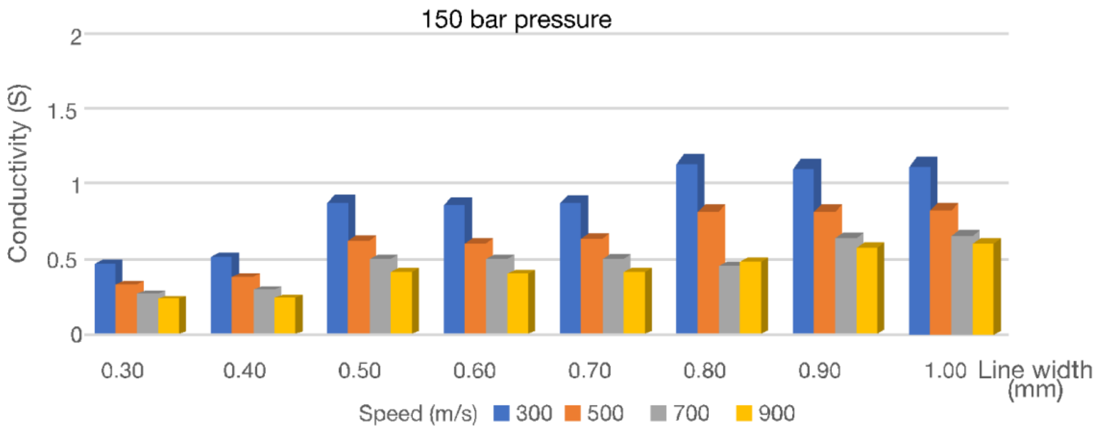

Figure 9: Conductivity values of lines printed at different speeds under 150 bar constant pressure

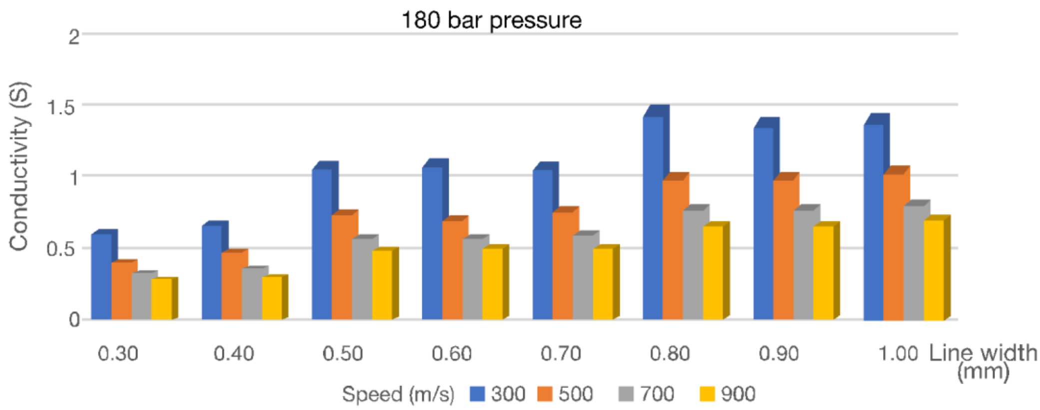

Figure 10: Conductivity values of lines printed at different speeds under 180 bar constant pressure

4. CONCLUSIONS

The increase in smart devices and their use in all areas of our lives, researches and studies on solar energy and other environmentally friendly energies increase the importance of printed electronics day by day. In addition to traditional printing methods, 3D printing systems are also preferred for printed electronics production. The printing system preference is mostly determined by the substrate material and the product to be produced, and the cost is also an important reason for preference. While the screen printing system is common in traditional printing systems, flexo or engraving methods are also used. In recent years, developments in digital printing systems, increasing diversity in printing materials, developments in ink and decreasing unit cost have made inkjet printing systems very popular. When we look at printed electronics in particular, the trend has evolved towards inkjet. Important R&D studies continue in inks, which is the most important issue for printed electronics.

In the light of the data obtained in the study, it has been determined that as the pressure increases and the line thickness increases, the conductivity value increases, while the conductivity decreases as the printing speed increases. The inkjet printing system will gain importance for the printed electronics whose market share is increasing by day. In addition, the development of organic inks instead of metal nanoparticle inks has made the subject even more important.

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3D PRINTED LITHOPHANE

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Abstract: *Lithophane is a transparent plate on which, with the help of the different thickness of this plate, an image is formed. Light that passes through the plate from the back side of the plate shows a clear gray image on the front side of this plate. The strength of the transparency is determined by the material of the plate and the light source coming from behind. Without backlighting, the subject on the lithophane cannot be seen.*

Lithophanes in the form of porcelain vases were discovered in China long before the technique made its way to Europe. In Europe the origins of lithophanes date back to the early 19th century in France. Europeans perfected the technique and also used it to reproduce famous portraits and paintings.

Today, the production of lithophanes is experiencing a renaissance with the advent of 3D printing technologies.

In the research paper, the process of making lithophane using 3D printing is presented. First, 3D printing technologies are presented, more specifically the technology of extrusion of materials or thermoplastics modelled by joining layers. Then, the materials used for 3D printing with the mentioned technology are presented. Next, the procedures for 3D acquisition and reproduction of reliefs are described, and at the end, the lithophane itself is presented. In the practical part, the whole process of making lithophane is presented. For the creation of the lithophane model, the 3D modelling program Blender was used, and the lithophanes in physical form were made with the Creality Ender 3 3D printer using PLA filament. Droplet and electrophotographic printers were also used to produce colour lithophanes. The influence of LED and halogen lamps on the final impression of lithophane reproduction was also compared. Lithophanes produced with different print settings and different colour reproductions were compared. The results showed that the best wall thickness is one millimetre, and the layer thickness is the smallest value allowed by the printer. The orientation of the lithophane during printing has a great influence on the final image of the design. The best orientation is upright. Color reproduction is best when using electrophotographic printing in combination with acrylic varnish. Lighting research showed that LED is better than halogen lamps. The finished lithophane was of satisfactory quality and could be used as a decoration for the home or to organize an art exhibition with a large number of coloured lithophanes reproducing various artworks and motifs.

Key words: lithophane, coloured lithophane, 3D printing, relief reproduction

1. INTRODUCTION

People are constantly creating and designing new works of art and objects. In the technological age, these creations can be transformed from the real world into the computer world and back into the real or material, physical world. We do all this to preserve art and cultural heritage, duplicate certain objects, render creations for easier presentation on computer screens and for many other reasons (Elkhuizen et al., 2019; Horne & Hausman, 2017; Koontz, 2003).

One of the ways to reproduce works of art is to convert them into a relief form and make a high-quality lithophane. Lithophane is a transparent plate on which an image is formed with the help of different thicknesses of this plate at certain points. Light traveling from the back of the panel through the panel displays a pure grayscale image on the front of that panel. The strength of the transparency is dictated by the material of the panel and the light source coming from behind, so called backlight. Without illumination from behind, the motif on the lithophane is unrecognizable (Lavelle, 2020).

The beginnings of lithophanes date back to the early 19th century in France, where Baron Paul de Bourguignon of Rubelles produced the first lithophane in Europe in 1827. They also discovered lithophanes in the form of porcelain vases in China and conclude that this technique was used in China long before it came to Europe. Europeans, however, later perfected this technique and used it more often, also for reproductions of famous portraits and paintings. They also used hand-cut porcelain and later developed a method of moulds combined with the use of wax, and these moulds were suitable for about 20 rapid reproductions (Yuan & Bourell, 2013).

The production of lithophanes experienced a revival in the 21st century with the entry of 3D printers into domestic households. To make lithophanes, we do not need much proficiency, however knowledge of 3D modelling and printing is required. 3D printing enables the production of lithophanes, as it can form a relief layer by layer. Also, current software allows the transfer of any 2D digital image into a 3D model which is suitable for printing. These software are based on the grayscale values of a coloured photograph. They change the coloured photo to grayscale, then invert it, and thereby obtain the values of the filament application. Imaging programs perceive this as values from 0 to 255, and a 3D printer perceives this as the height of a certain point on the lithophane. When looking at the lithophane with the eyes, the black colour is physically closer to the eyes and white is the opposite (Zukas & Zukas, 2015). Currently, the production of monochrome lithophanes dominates, but we have set ourselves the goal to also produce coloured lithophanes, as not much has been researched in this area.

2. METHODS

The structure of the process is shown in Figure 1 below. It shows how we started the work and how the steps follow one after the other. First, we devoted ourselves to the comparison of monochrome lithophanes with different parameters, and only then did we also analyse coloured lithophanes.

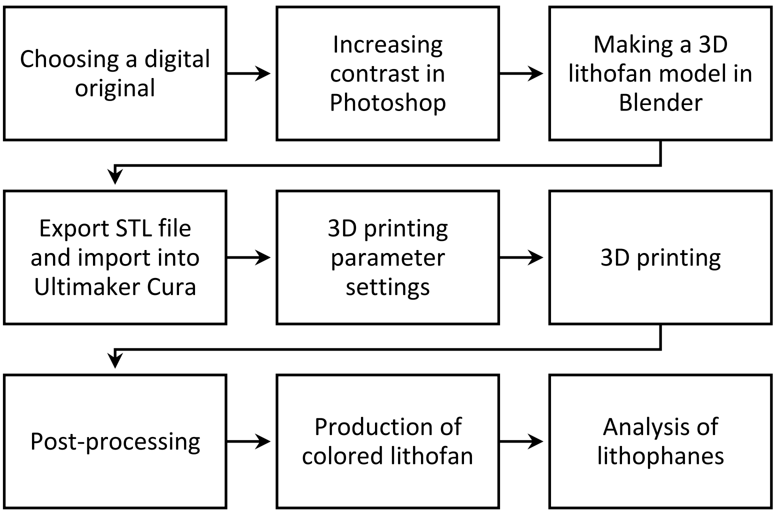

Figure 1: Procedure of experimental work

2.1 Lithophane motif and materials

We chose the painting The Starry Night by the painter Vincent van Gogh for reproduction, as it represents a well-known painting where contrasting colours, yellow and blue, are used. Due to the pronounced contrast, it was easier to analyse the colour reproduction on the lithophane. Also, the painting itself expresses a certain relief, which will be additionally expressed on the final lithophane. On the other hand, there are certain parts in the image that are quite detailed, which is a test for the quality of our 3D printer and for different print and design settings.

In the research we used: Creality Ender 3 3D printer, HP desktop Inkjet printer, HP desktop electrophotographic printer, desktop computer, Adobe Photoshop 2020, Blender 2.8, Ultimaker Cura, PLA filament, acetone, acrylic clear varnish, LED and halogen lighting.

2.2 Changing the contrast

We recommended to process the selected original digital image before further use for 3D printing. We can remove unwanted artifacts or change certain parameters to give us a higher quality final lithophane. It is typical for lithophanes that they work on the principle of contrast or the ratio between light and dark points in the image. Therefore, we also increased the contrast of the image. This way, the finished lithophane will be more embossed and the differences between the light and dark parts of the lithophane will be more visible. It should be emphasized that changing the settings depends on each motif separately. Figure 2 shows the original motif and Figure 3 shows the modified and edited version of the same motif.

Figure 2: Original motif

Figure 3: Edited motif

2.3 Making a 3D model of a lithophane

We decided to use the free program Blender version 2.8 to make the lithophane. This program allows the creation of 3D objects, which in our case, the lithophane is. The process of making a lithophane model is quite demanding. It is mainly based on mathematical transformations. In this way, the coloured image is converted to grayscale, and on this basis the program gets data on the value of each pixel separately, numbered between 0 and 255. Based on this, the height of a certain pixel on the motif is calculated. With the help of certain settings in Blender, we created a motif that is no longer in 2D form but is in relief. Light points are located lower than darker ones. Then we added thickness to the lithophane, as this is necessary for the final production with a 3D printer. At this point, we made a lithophane in the form of a square tile, which was ideal for our research. Finally, we just determined the axis directions, and then exported the 3D model file in .stl format.

2.4 3D printing settings

We set ourselves the goal of studying the influence of three different parameters on the printing process and quality, or usability of the finished lithophane. First, we devoted ourselves to monochrome lithophane, where we tried to find out the best settings for quality reproduction. We decided to use the Ultimaker Cura program to change the settings, as it offers all the functions we need and is also user-friendly.
The infill density was the same for all versions of lithophanes, i.e., 100%. We decided this way, since lithophane is dependent on the reflection and transmission of light, which a lower value of the infill density would change. We chose PLA filament because of its quality properties and ease of printing, and it is also a biodegradable polymer. The filament is white coloured, because lithophanes must transmit light and this works best with white polymers. Using transparent filament would not give adequate results because there would be no separation of the dark and light parts of the subject.

When printing, it is also important to mention the temperature settings. Our chosen printing temperature was 200 °C. Which is the recommended temperature of Azure Film, the manufacturer of our PLA filament. The temperature of the printing bed was set to 55 °C.
Table 1 below provides an overview of all the different settings we used when printing lithophanes.

Table 1: Print settings we used in the analysis

Sample	Orientation	Back thickness	Layer height
1	Lying down	0.5 mm	0.12 mm
2	Upright	0.5 mm	0.12 mm
2	Upright	0.5 mm	0.12 mm
3	Upright	1.0 mm	0.12 mm
4	Upright	2.0 mm	0.12 mm
3	Upright	1.0 mm	0.12 mm
5	Upright	1.0 mm	0.20 mm
6	Upright	1.0 mm	0.28 mm

2.5 Colour reproduction

We also wanted to colour the printed lithophanes. We did this using three different methods. The first method involved Inkjet printing on plain office paper. We chose it mainly because of its simplicity and accessibility. The second and third methods are quite similar, where we printed the image also on office paper, but this time with an electrophotographic printer. These two methods were based on the transfer of toner from paper to lithophane. While the first method is simpler and did not require the transfer of colour to the lithophane, however just gluing the paper to the back of a lithophane. The colour was transferred once with acetone and the second time with the help of acrylic varnish.

2.6 Lighting

The lighting of lithophanes is a key part of depicting a subject. Without lighting, the motifs on the lithophanes themselves are not recognizable, as we only see the relief of the white polymer, but the motif we want to show cannot be seen. That is why we compared the two most common types of lighting. LED lamps and halogen lamps. Regardless of the type of lamp, the most important thing is to illuminate the lithophane from behind and not from the front, as this is the only way to see the final motif on the lithophane. The environment in which we light is also important, because in an environment that is too bright, we will not see the effect of the backlight. Therefore, it is recommended to view the motifs in darker rooms.
The used LED lamp emitted a neutral white light with approximately 4500 K to 5000 K, while the halogen lamp emitted a much warmer light with approximately 2700 K. We also chose these lamps because of the significant difference in colour temperature, as we wanted to compare the effect of colour temperature on the final depiction of the motif on both colour and monochrome lithophanes.

3. RESULTS

This chapter presents the results and findings obtained during and after the experimental part of the thesis. First, we will examine monochrome lithophanes and then colour reproduction, followed by the influence of light. We showed the results in the form of photographs, which were captured under controlled conditions in a dark room. The lighting in the first and second part (monochrome and colour lithophanes) was backlit by LED lighting. In the third part, we compared LED and halogen light on monochromatic and coloured lithophanes.

3.1 3D printing settings

Three different parameters have been compared. The first of these was the orientation of the lithophane during printing. We compared this first, as it is the most basic and fundamental setting. Lithophane was printed in both horizontal and upright positions. The final conclusions of this comparison are that, for high-quality and accurate reproduction, we recommend choosing upright printing rather than horizontal printing, as the differences are significant and should not be ignored. Personally, we find the horizontal position interesting especially in terms of art, as it gives off its charm of a mosaic puzzle, which is interesting in its own way. We can find both lithophanes printed in different orientations in Figure 4 and Figure 5 down below.

Figure 4: Horizontal print

Figure 5: Upright print

We continued by changing the thickness of the thinnest part of the lithophane or simply put, the thickness of the back. With this, we wanted to find out which thickness of the lithophane backing (0.5; 1.0; 2.0 mm) produces the best reproduction, quality and transparency of the lithophane. The back thickness is important, as the tile can quickly be too thin or too thick. The most obvious, immediately visible difference is the difference in the colour of the motif. The white polymer moved towards a yellowish or orange colour tone as the back thickness increased. This is due to the opacity of the white PLA filament, which, as the thickness increases, quickly begins to stop the light traveling through the polymer. The thinnest lithophane (Figure 6) did indeed transmit light the best and printed the fastest, but the tile was simply too thin for our 3D printer, as artifacts showed up because of the wall was too thin. The thickest lithophane (Figure 8) let in too little light and yellowed too much when exposed to light. Thus, the winner was the middle one (Figure 7) with a thickness of 1mm.

Figure 6: Back thickness 0.5 mm

Figure 7: Back thickness 1.0 mm

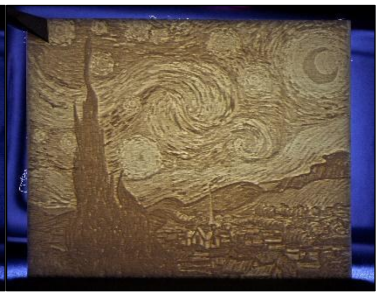

Figure 8: Back thickness 2.0 mm

The last comparison in this set was the comparison of different layer height settings and the quality of printing. We wanted to compare the layer height, as it is known that they can affect the quality of the prints, and we wanted to test at what level visible changes occur, or whether there are any changes in the motif at all. We were also interested in whether, at higher values of layer height, the printer would have any problems printing such thin structures. We compared layer heights of 0.12 mm (Figure 9); 0.20 mm (Figure 10) and 0.28 mm (Figure 11). The results showed that the best setting was the smallest setting i.e., 0.12 mm, as the larger two settings produced visible layers in the motif. Visible layers not only disturb the eye, but also degrade the accuracy of the subject. Not only the layers, but also the artifact in the form of a vertical line on the right side of the lithophane are disturbing. This is not noticeable on the smallest setting. The conclusion is that in our case 0.12 mm layer thickness gives the best results and it is not worth using the other two settings if we want a quality and accurate reproduction of the original image, especially in the details of the motif.



Figure 9: Layer height 0.12 mm *Figure 10: Layer height 0.20 mm* *Figure 11: Layer height 0.28 mm*

3.2 Colour reproduction

The results were somewhat in line with our expectations when we saw how poorly the paint transferred from paper to lithophane using the second method, using acetone. This is shown in Figure 13. Too little colour on the lithophane itself is manifested in the fact that the colour on the illuminated lithophane is not noticeable at all. Only a dark spot is visible on the left side of the lithophane, where most of the black colour has been transferred and makes it difficult for light to penetrate to the other side. The lithophane also deformed, as the reaction between acetone and polymer took place, which is why we do not recommend this method.
The simple first method showed a good result, considering the effort involved, compared to the other methods. Mainly in colour saturation. The stars and blue sky are very beautiful, but in the darker parts, the details are completely lost and the subject becomes completely unclear, as shown in Figure 12. Also, compared to the last method, the blue areas of the image are blended together and the white lines in the image do not come out in the final reproduction.
The best of all is the last method using acrylic varnish. The paint on the back side of the lithophane lets in just enough light so that the details are not lost. That is due to the paper being removed from the back in the last step pf the process. Although the colours are paler than with the first method, they are reproduced more accurately because they do not blend into each other as shown in Figure 14. Also, the third method allows viewing the image from the other side in daylight, which the other two methods do not allow, but it is true that this image is mirrored.



Figure 12: Inkjet LED *Figure 13: Acetone LED* *Figure 14: Acrylic varnish LED*

3.3 Lighting

From this experiment, we learned that LED lighting is much more suitable for lighting lithophanes than a halogen lamp and, consequently, an ordinary tungsten lamp. In principle, this applies to all lights, including LED lights, which have a colour temperature of around 3000 K. We have found that neutral white light is the most suitable, as it gives good results for both monochrome and coloured lithophanes and does not change the colour tone of the polymer or the applied colours. Also, LED lights do not heat up excessively, as halogen lamps do, and there are no problems with possible deformation of the lithophane during long exposure to LED lamps. Figure 15 shows a monochromatic lithophane being lit up from the front and not the back. This shows there is a big difference in being lit up from the front or the back of the lithophane. Figures 16 and 17 compare the monochrome lithophane being backlit by LED light or whit a halogen lamp. We can observe that there is a great difference in the colour tone of the motif. Figures 18 and 19 show the same comparison as the later one, but this time using coloured lithophane with the third method i.e., using acrylic varnish. Again the difference can be seen immediately.



Figure 15: Monochrome- no backlight

Figure 16: Monochrome – LED

Figure 17: Monochrome - halogen


Figure 18: Coloured lithophane - LED

Figure 19: Coloured lithophane - halogen

4. DISCUSSION

It turned out that the final image of the motif was most affected by the orientation of the lithophane during printing, where the upright orientation proved to be better. The back thickness and layer height also significantly affect the final quality. Where the 0.5 millimetre back thickness presented minor problems when printing, the 2.0 millimetre thickness stopped too much light when exposed. At higher values of layer height, longitudinal lines started to appear, which negatively affect the image of the motif. The results show that the best parameters are the upright orientation, the back thickness of 1.0 millimetre and layer height of 0.12 millimetres. These parameters ensure stability during printing and the cleanest image where even the smallest details can be discerned.

Findings in colour reproduction show that the easiest method is the technique of printing on paper with a Inkjet printer and attaching the cut-out to the back of the lithophane. This gives satisfactory results, especially if the original image is lighter and brighter. The use of chemicals, on the other hand, is more complicated. The technique using acetone did not transfer a sufficient amount of colour to the polymer, which is reflected in the final result, which is not satisfactory and the coloration of the lithophane does not occur when illuminated. There was also deformation of the polymer at the edges where the lithophane curled. If we are not limited by time, electrophotographic printing in combination with acrylic varnish gives the best results. Here, the colour is well transferred from the sheet to the polymer, and thus the influence of the paper when light penetrates through the lithophane is eliminated. In this case, the image is the brightest, where all the details are visible, and sufficiently colourful.

The last experiment dealt with the influence of the colour temperature of the lights. We compared the LED light and the halogen lamp. It turned out that the halogen light emits too warm a light, thus causing the final motif to acquire an orange tone over the entire surface of the lithophane being observed. This can be used as an artistic approach, as you might do with a horizontal orientation when printing a lithophane, but especially for coloured lithophanes we do not recommend the use of a halogen lamp. Also, the halogen lamp emits a lot of heat, which can have negative consequences on the PLA polymer if the lithophane would be illuminated for too long. This could otherwise be prevented by using more temperature-resistant thermoplastics. Despite everything, the results show that the best reproduction of both monochrome and coloured lithophanes is achieved using neutral white LED lights. In both cases, we recommend lighting the lithophane in darker rooms if we want the motif to be seen as best as possible.

5. CONCLUSIONS

With the production of our lithophanes, we have shown that the 3D printer is a suitable tool for reproducing works of art in the relief form that is typical of lithophanes. With appropriate parameter settings (infill density, layer height, back thickness) in the printing process and upright printing orientation, we can produce high-quality lithophanes. As long as, after the 3D printing is finished, the lithophane is processed appropriately, e.g., with acrylic varnish, satisfactory colour reproduction can also be achieved when using a neutral white LED light.

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DESIGNING MOVABLE CHAIN LIKE STRUCTURE WITH 3D MODELED ELEMENTS

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Abstract: *The field of 3D printing has developed greatly to date, and it is expected that this development will continue. 3D printing is already being used in the fashion industry, where it was first used for rigid, architectural shapes and later for a variety of movable structures. However, the area of mobility, comfort and softness is still under development in this field. The exploration of the above properties was also the reason for the present research work, the aim of which was to study the process of creating a textile-like 3D structure by assembling individual elements into a mesh. Various factors in both the design and technical areas had to be investigated and considered. The design process included the technical and visual part, i.e., the design of the individual elements, as well as the creation of different repeating patterns, as the shape and colour of the elements influence the final appearance. Different approaches were tested when modelling the individual elements. Through the research, other design approaches were also used, such as the use of geometry nodes or animation nodes, which are available as plug-ins in the Blender software. We combined different elements to create meshes or textile-like structures that were simple at first, but later resulted in more interesting designs by varying the size and shape of the elements, their arrangement, and colours. There are still many possibilities to develop the patterns further, for example, the elements could be arranged in different ways, or more emphasis could be placed on the shape and colour of the elements.*
Finally, we experimentally printed part of the chain-like structure and compared it with other structures designed in a 3D program and checked the size and density of the mesh by virtually simulating the fall of the mesh onto the body.

Key words: 3D printing, 3D textile-like structure, fashion, SLA technology

1. INTRODUCTION

3D printing is still considered a futuristic technology, although the first concepts of 3D printing appeared in a science fiction story "Things Pass By" by Murray Leinster in 1945. However, it was put into practice in the early 1980s when Chuck Hull invented the process of stereolithography (SLA) (Turney, 2021). Nowadays, 3D printing is used in various industries such as medicine, aerospace, culinary, fashion and others. In the textile field, 3D printing is used in three forms: 3D printing directly on textiles, 3D printing of flexible structures, and 3D printing with elastic materials. Different printing technologies are used for all three forms. For direct printing on textiles, the most commonly used technology is FDM (Fused Deposition Modelling), in which the extruded polymer is deposited layer by layer through the nozzle of the 3D printer onto the surface of the textile. SLS (Selective Laser Sintering) technology is the most used for printing solid but flexible structures, and SLA technology is usually used for printing with elastic materials. Due to the high precision of both SLS and SLA technologies, SLA technology can also be used to fabricate flexible structures, but printing would require supporting structures (Sitotaw et al., 2020).
The goal of our research and design process was to create various chain-like structures that mimic a textile structure. They should be movable and able to adapt to the object of collision for different purposes, such as making a dress, a fashion piece, or an accessory for interior decoration. During the design process, we used the 3D program Blender to model various chain elements derived from Celtic knots, which were virtually assembled into a chain-like structure to create interesting mesh patterns. We also simulated the fall and collision of the material with various collision objects, such as cylinders, cubes, and also with a 3D human avatar. The simplest structure, consisting of a torus, was also 3D printed using SLA technology so that we could test the mobility of the textile-like structure.

1.1 3D printing of flexible structures

Flexible 3D-printed structures that simulate textiles can be produced using three different methods (Sitotaw et al., 2020). In the first method, called "mesostructure," the individual elements of thin layers or sheets are aligned perpendicular to the base surface, which allows them flexibility in different directions. In this way, materials such as metal can be made flexible without changing their physical properties (3DPrint, 2014). This discovery was made by Andreas Bastian, who developed his new material, which can be seen in Figure 1.

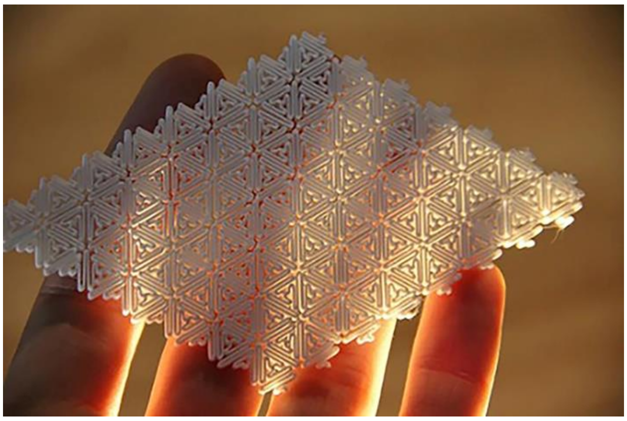

Figure 1: Andreas Bastian - "mesostructure" (3DPrint, 2014)

The second method is based on a patterned structure of many precisely designed and modelled triangular panels connected by hinges. They are all 3D printed as a single piece. While each element is rigid, when they form an entire dress, they behave like a continuous fabric that conforms well to the body. Unlike traditional fabrics, this fabric-like structure is not uniform, but varies in drape, flexibility, and pattern in space. No cutting is required to make such a structure, and much less material is needed. An example of the mentioned method is the Kinematic dress developed by the Nervous System company (Nervous System, 2014), shown in Figure 2.

Figure 2: a) Kinematic dress, b) Detail (Nervous System, 2014)

Finally, the third method is based on connecting rings (Bingham and Hague, 2013) or other closed elements (of different shapes and sizes) and mimics the structure of medieval protective clothing, which consists of tightly connected metal rings. Each ring has enough space to move freely, which allows good draping around the body. When printing such a material, for example, with FDM or SLA technology, we need to use support structures, because the empty spaces between the rings do not provide a stable surface for printing.

Jiri Evenhuis and Janne Kytanen were the first to start designing material using the third method mentioned above (Janne Kyttanen, 2000). The first project using 3D printing of textiles was carried out in 2000. The project included a fully 3D printed dress ("Black drape dress"), which can be seen in Figure 3.

Figure 3: Jiri Evenhuis and Janne Kyttanen drape dress (Janne Kyttanen, 2000)

2. METHODS

The research began with the design of the individual elements in the 3D computer program Blender. In the further course, the individual elements were connected to form a mesh. First, we modelled the simplest torus shape and started with the determination of the design method, where we learned the process and method of modelling and assembling the elements into a mesh. The elements assembled into a mesh represented a textile-like structure, part of which was also 3D printed using SLA technology with the FormLabs Form 2 printer.

After the testing part of the design process was completed, the design of the individual elements inspired by Celtic knots began. The design process was the same as for the torus, where the individual elements were first modelled and then assembled into a mesh.

As mentioned above, the 3D computer program Blender was used for the design process, and all the elements were modelled based on Bezier curves (Bezier Curve, Bezier Circle) or using the Curve plug-in: Curve - Knots - Torus Knot Plus and Braid Knot.

2.1 Determination of the design method

The first step was to become familiar with the process and methods of modelling a single element and assembling it into a mesh that would mimic textiles. Therefore, the first element was a simple torus shape as shown in Figure 4.

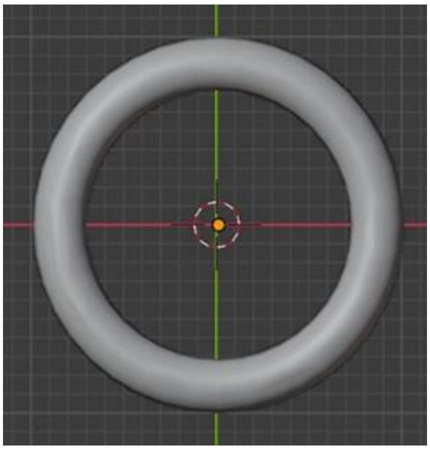

Figure 4: Initial torus shape

Once the single element was modelled, it was assembled into a grid, considering the slope of the elements and the distance between them. The slope ensures that the elements fit together, and the distance between them allows the structure to move. Initially, the tori were assembled into a single chain and then duplicated until a larger surface was created (Figure 5).

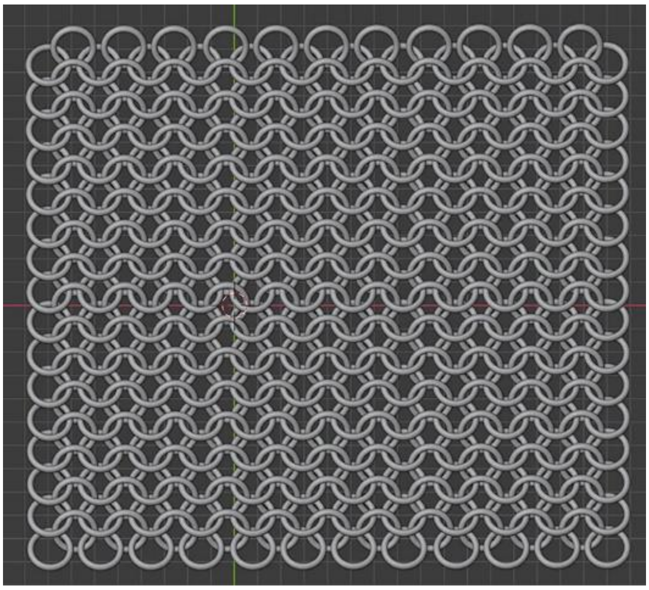

Figure 5: Textile-like structure from torus shape

Further on, the mesh imitating textiles was simulated on the collision object, observing the movement of the structure and its visual appearance. The Rigid Body command was used to calculate the physical forces involved. The physics of Rigid Body is discussed in Section 2.3. and the resulting simulation is shown in Figure 6.

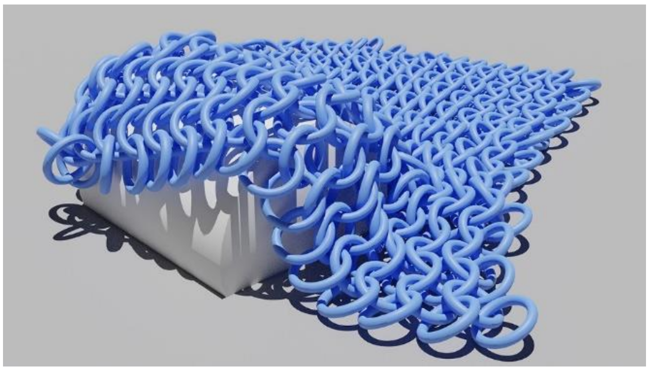

Figure 6: Simulation of textile-like structure on the collision object

2.2 Method verification process

In the test part, we established the method, which was verified during further development and design. This was followed by the design of individual elements inspired by Celtic knots, although the starting point for each design of the element was different. The initial geometry of the chain link was obtained from the Curve plug-in, such as the Torus knot, the Braid knot, and the Bezier Circle template.

The shape of the Dara knot was based on a curve - Braid knot (Figure 7a), with the number of sides reduced and the thickness of the basic shape increased (Figure 7b). Figure 7c shows the solid model of the individual chain link. For the process of 3D printing and simulation, the final shape of the knot had to be changed from a curve to a mesh.

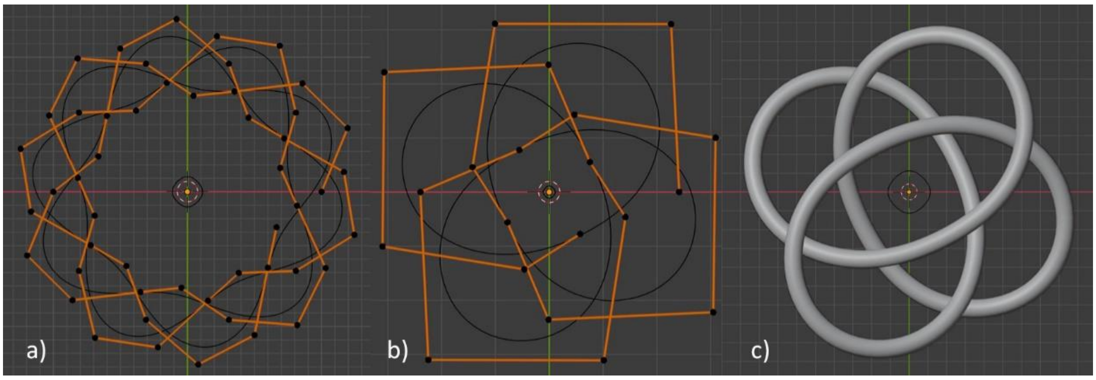

Figure 7: a) Initial geometry of Dara knot, b) Remodelled geometry, c) 3D model of the knot

The shape of the Endless Knot looks like interconnected squares; therefore, the individual element was square-shaped. The starting point of the element was the Bezier Circle template (Figure 8a), for which the number of points on the curve was increased with the Subdivide command, which then facilitated the transformation of the circular shape into a square, as shown in Figures 8b and 8c.

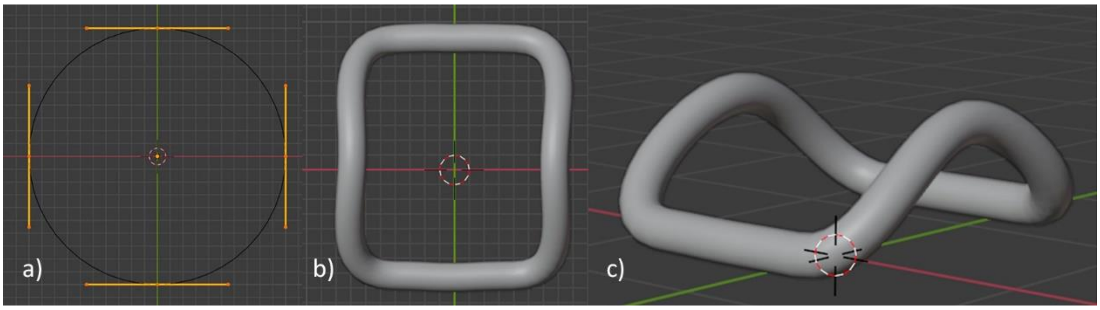

Figure 8: a) Initial geometry, b) Final shape of the element, c) Side view of the final shape

The element inspired by Solomon's knot was modelled using a curve - Torus Knot Plus (Figure 9a), increasing the number of spins (Figure 9b) and reducing the inner circumference, and therefore the shape of the curves shifted towards the centre, which can be seen in Figure 9c.

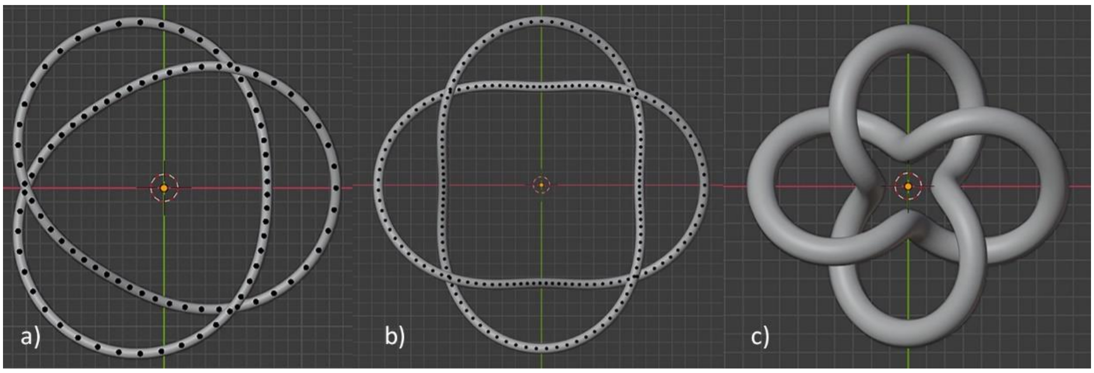

Figure 9: a) Initial geometry, b) Remodelled initial geometry, c) Final shape of the element

2.3 Assembly of elements and simulations of textile-like structures

All the resulting textile-like structures were assembled in the manner already described in the test section. First, the elements were assembled into one chain, which was then multiplied to the desired size. Figure 10 shows meshes made of identical elements.

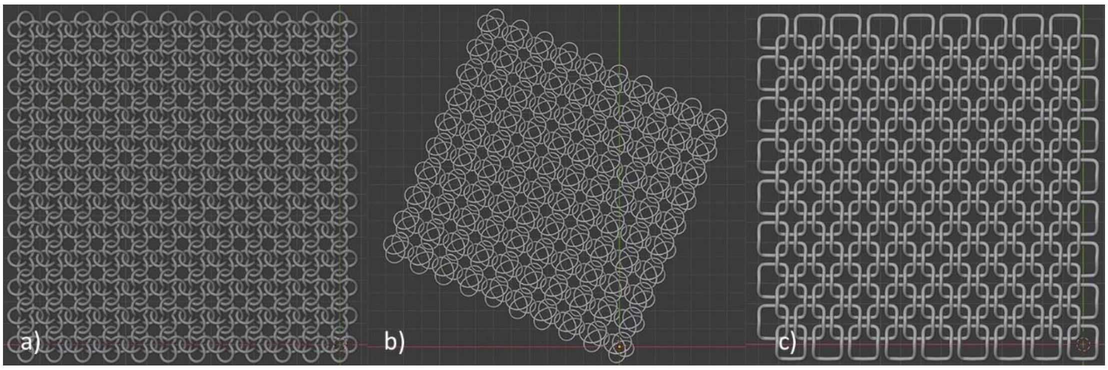

Figure 10: Textile-like structures of a) Dara knot, b) Salomon's knot, c) Endless knot

By simulating the fall of a rigid object onto a collision object, we learned about the use of physics in Blender on the Physics Properties - Rigid Body tab. The Rigid Body command is used to simulate the motion of solid objects, defining active and passive bodies. Active bodies are simulated dynamically, while passive bodies remain static (*Blender*, n.d.). The purpose of creating simulations was to observe the behaviour and movement of the designed textile-like structures on various collision objects, including the body. An example of a rendered simulation is shown in Figure 11.

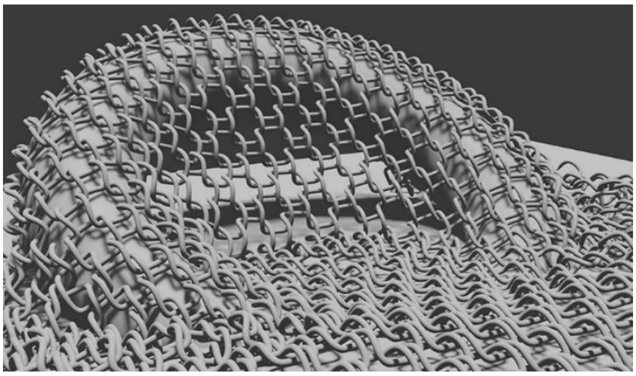

Figure 11: Simulation of textile-like structure designed from Endless knot elements

2.4 Designing patterns

Different shapes, colours and sizes of the elements were used to achieve different patterns in textile-like structures. Two different forms of elements were created from one knot, one of which was a Celtic knot, the other a variation of it. After designing an interesting pattern of similar elements, a contrasting colour was added to some of them. A colour combination of white and blue was used, and a monochrome pattern was created for comparison. Figure 12 shows an example of patterns in textile-like structures using colours and the Solomon knot in two variations.

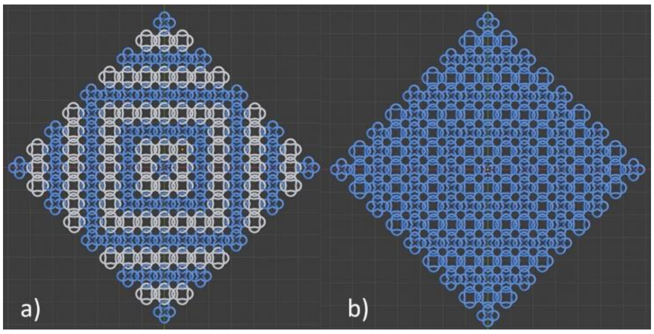

Figure 12: a) Blue-white pattern, b) Monochromatic pattern

2.5 3D printing of textile-like structure

The 3D printing attempt refers to the test part, where a part of the torus mesh was printed with printer FormLabs Form 2. Printer supports SLA technology and allows high precision and quality print as well as easy preparation and maintenance. The purpose of 3D printing was to check the flexibility and the strength of the textile-like structure and to find out the appropriate size of each element.

Firstly, the 3D model was checked for possible errors in computer program Blender using the 3D print suitability checker plug-in, and then imported into the PreForm application, where it was prepared for printing (determining the layout and slope, creating support structures). The printer took 7 hours and 5 minutes to print a part of the textile simulation with dimensions of 6.5 × 6.5 cm, producing 1331 layers of 0.05 mm thickness.

After 3D printing, further processing was required. The object was washed with isopropyl alcohol (IPA), moving, and soaking the individual parts in the solvent for optimal cleaning. After printing with SLA, the polymerization reaction may not be fully complete, which means that the printed object has not yet reached its final material properties and may not have the expected properties, especially for heavily stressed parts. Exposing the object to UV light helps to solidify the material properties (Formlabs, n. d). The support structure was then removed. Figures 13 and 14 show the printed test part with the support structures still visible and the printed part after removal of the support structures.

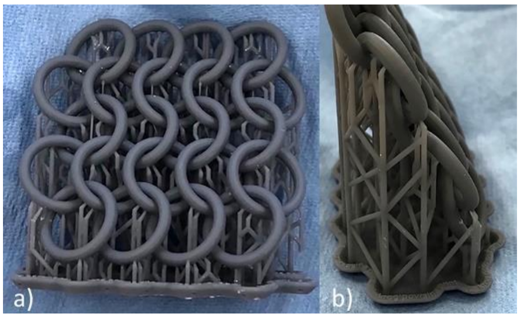

Figure 13: a) 3D printed part with visible support structures b) Side view

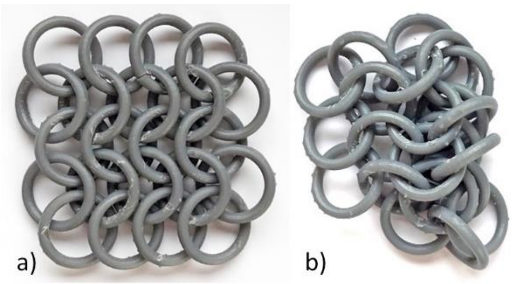

Figure 14: Printed part after removing support structures

3. RESULTS AND DISCUSSION

The 3D printing process has shown that the textile-like structure can be movable, even if it consists of rigid elements. The spacing between the elements is very important because it allows the chain-like object to be flexible. In our 3D-printed piece, the distance or slope was a bit too small, so the elements stuck together in some places. Nevertheless, the elements could be separated, but the surface was damaged, which can also be seen in Figure 14.

In our case, the diameter of each element was 21 mm, but they could be larger or even slightly smaller, depending on the purpose for which the structure is used. For making lampshades, bags or decorative curtains, the elements could be even larger, but for making clothes, the elements should be closer together and smaller.

3.1 Final textile-like structures

When designing patterns in textile-like structures, it was also necessary to pay attention to the spacing between elements, as mentioned earlier, because spacing allows for movement. Visually interesting patterns were created when we put together different shapes and sizes of elements. In addition, even more interesting patterns were created when colour was added.

Colour emphasizes the difference between elements and highlights the pattern on the surface. In monochromatic patterns, the different shapes of the elements are somewhat lost, although they still form an interesting structure because of the empty areas of the elements that make up the patterns. Looking at the multi-coloured patterns from a distance, one colour would most likely dominate the other and the overall structure would look the same, however every step closer to the textile-like structure, the pattern becomes more visible. Patterns also appear when light shines through the structure because the empty spaces between the individual elements create shadows, as seen in Figure 22. This paper presents some approaches, but the possibilities for pattern design are endless.

Example 1:

Figures 15 and 16 show examples of the Dara knot pattern. The pattern was created by combining original elements into squares, separating the squares with lines of Dara knot variations. Figure 15b also shows a monochrome pattern that focuses on the empty spaces between the elements and their shapes.

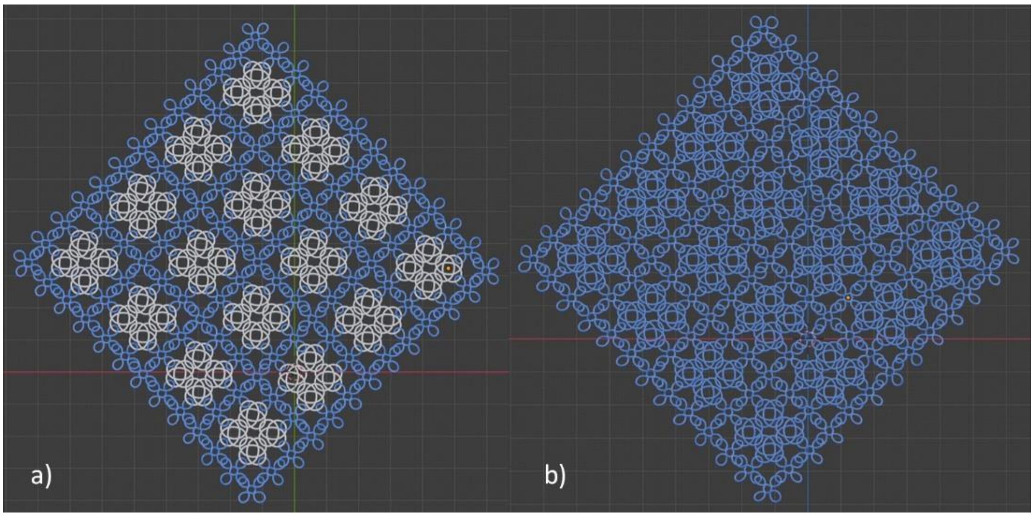

Figure 15: a) Blue-white pattern, b) Monochromatic pattern

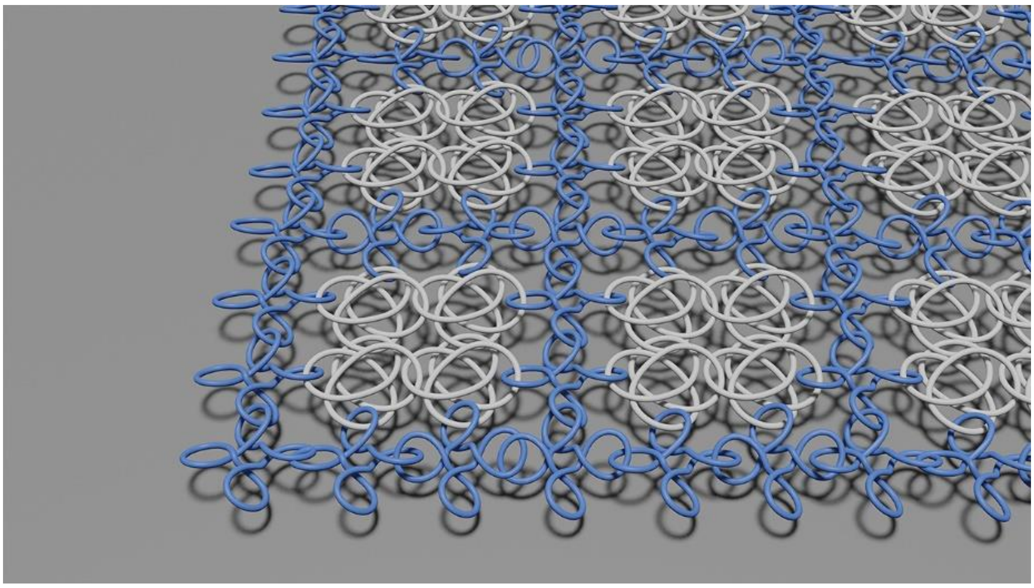

Figure 16: Blue-white pattern render

Example 2:

Figures 17 and 18 show a Dara knot pattern in different sizes, in the combination of blue and white, monochrome and in a combination of light and dark blue tones. We can see that all colour combinations offer new patterns, although the base is the same in all of them. To create interesting patterns, we must not forget about the colour in addition to the shape, size and arrangement of the elements.

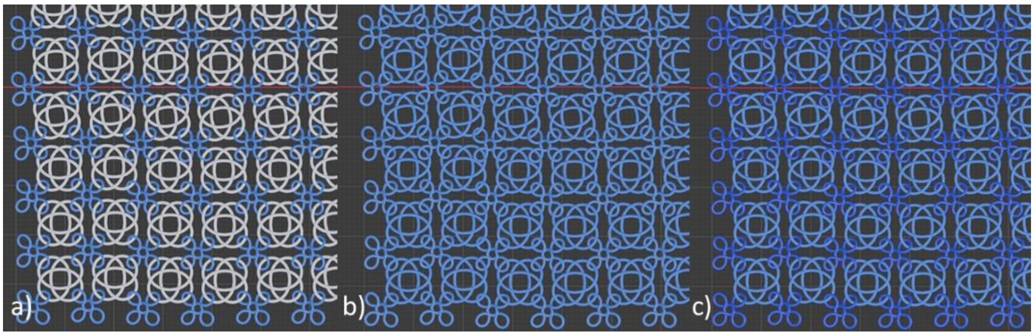

Figure 17: a) Blue-white pattern, b) Monochromatic pattern, c) Light-dark pattern

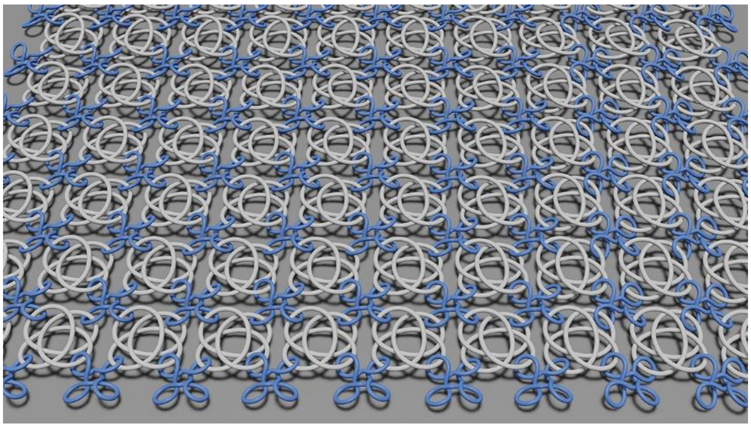

Figure 18: Blue-white colour pattern render

Example 3:

A pattern in combination with the Endless Knot and the Torus shape element, where the torus connects the Endless Knot elements in vertical and horizontal lines, is shown in Figures 19 and 20.

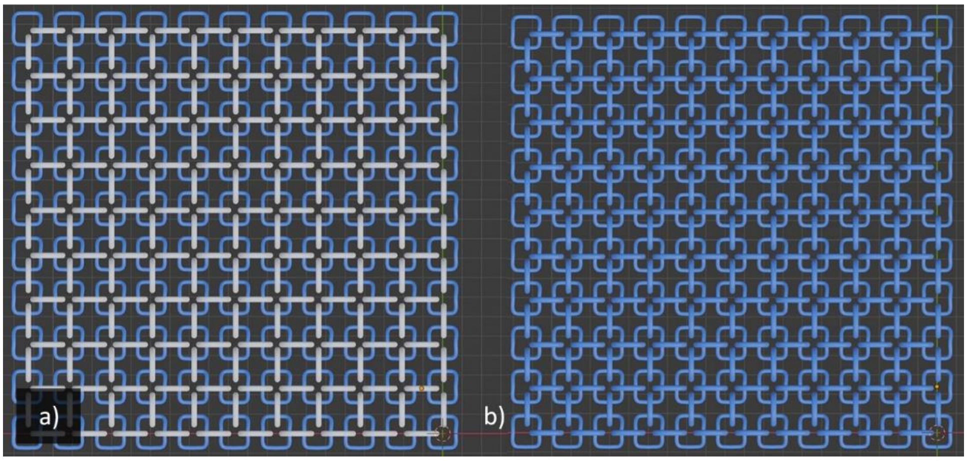

Figure 19: a) Blue-white pattern, b) Monochromatic pattern

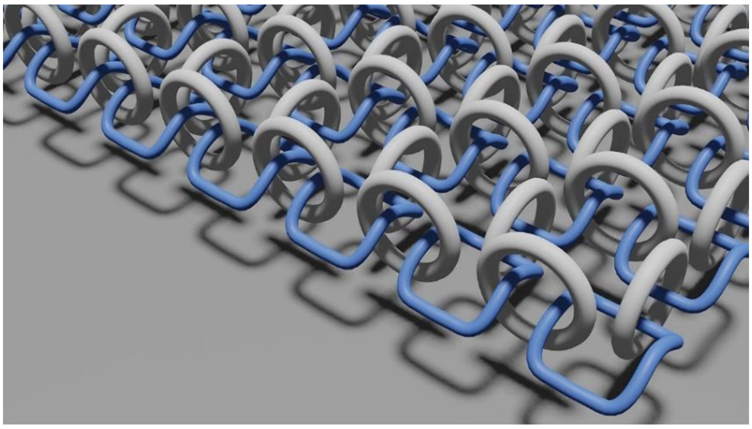

Figure 20: Blue-white colour pattern render

Example 4:

Example 4 shows the Solomon's Knot pattern and its variation in a different size, with the elements arranged in lines, as shown in Figure 21. The monochromatic pattern shows the pattern generated by the elements themselves with their unique shape. The present example also shows the pattern of the shadow created by the light shining through the structure (see Figure 22).

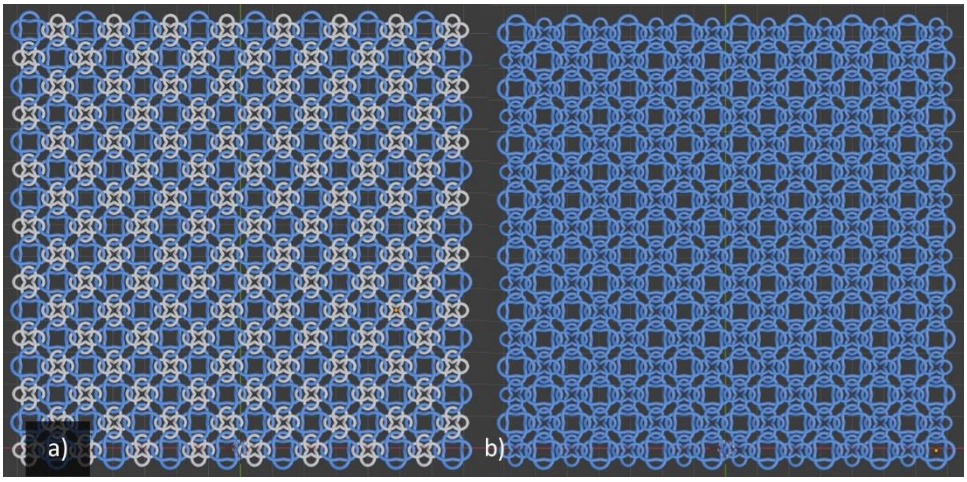

Figure 21: a) Blue-white pattern, b) Monochromatic pattern

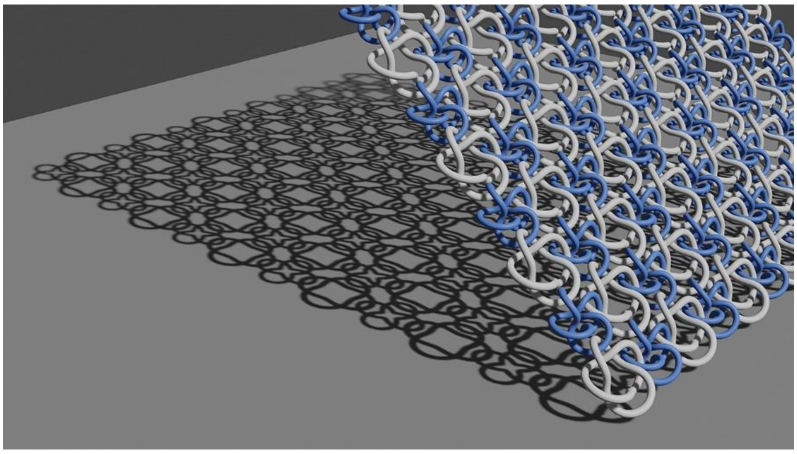

Figure 22: Interesting shadow of the pattern

3.2 Final simulations of textile-like structures

The simulations of textile-like structures have shown us that the size of the elements also affects the wrinkling - smaller elements provide a better fit. Therefore, a larger number of smaller elements allows for a better fit of the mesh to the object and consequently a better mobility of the structure. Figures 23 and 24 are examples of rendered simulations on different objects, showing the behaviour of each mesh-textile simulation.

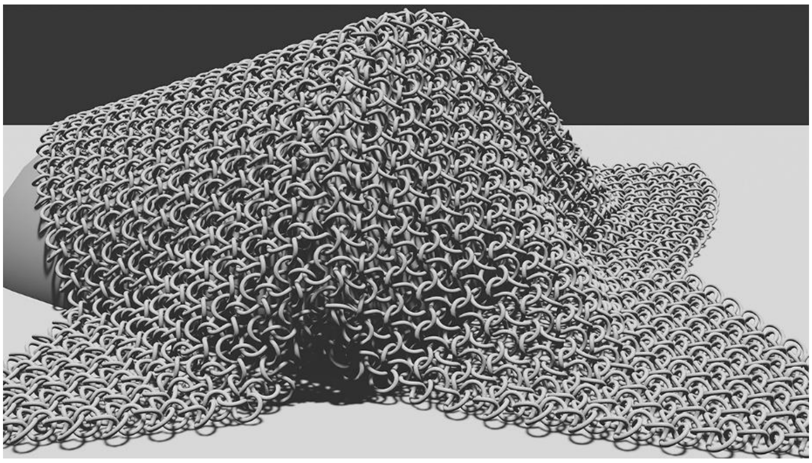

Figure 23: Simulation of Salomon's knot textile-like structure on an object

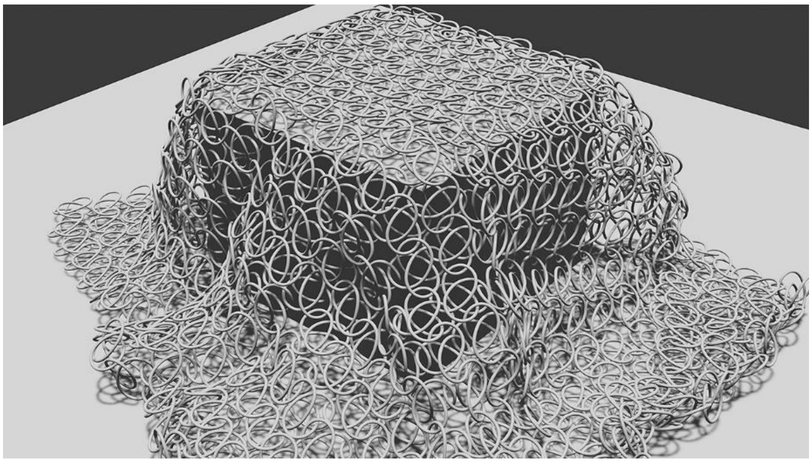

Figure 24: Simulation of Dara knot textile-like structure on a cube

The use of 3D textile-like structure simulations on a human body as a garment is shown in Figure 25. However, the use of "plastic" materials in direct contact with the skin as everyday clothing is still an open area of research, as the materials do not yet allow such comfortable and breathable clothing to be produced. Alternatively, the textile-like structure created could be used to make handbags, lampshades, and perhaps decorative curtains. With further research, 3D textile simulations could also be used to make the back and seat of chairs and deckchairs.

4. CONCLUSION

3D printing is becoming a widespread technology that already allows us to print many different objects, so in the future it may become one of the leading technologies for mass production.
This paper presents the process of designing a textile-like structure from modelling the 3D elements to assembling them into a mesh. During the modelling process, different approaches were used to create a single 3D element, which are presented in this paper. However, other methods can also be used, for example Geometry Nodes or Animation Nodes, both of which are used as add-ons in the 3D computer program Blender.

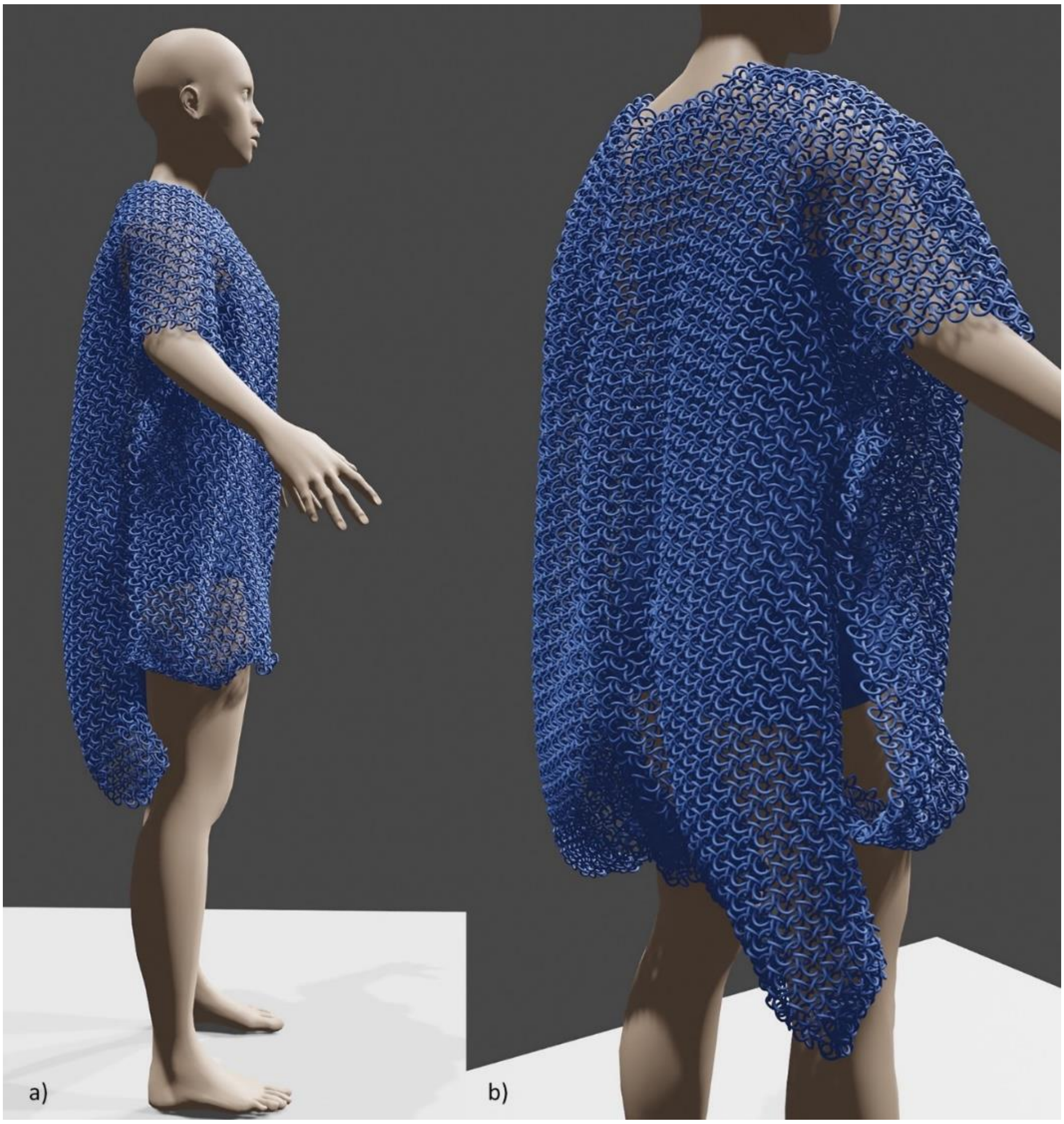

Figure 25: Final render of textile-like structure on human body a) Side profile, b) Back

Throughout the process of modelling, animating, and realistically rendering the textile-like structures, we learned that the individual elements of the textile-like structures must be considerably small and dense to create the chain-like material that is movable and drapes similarly to a textile. More interesting structures were also created by putting elements of different shapes and sizes together and then adding them colours to create patterns. However, there are many other ways to design patterns, and this can be whole other research. Further research related to colour can also be done in the field of 3D colour printing, where, for example, colour patterns can be printed using the HP Multi Jet Fusion colour 3D printer. Finally, further experiments can be conducted on the materials and physical properties of the elements, such as what happens when an elastic material or a different printing technique is used. Nevertheless, developments in various areas of creating textile-like 3D structures are possible, whether in terms of structure, materials, or colour.

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REVIEW OF PHOTOPOLYMER MATERIALS IN MASKED STEREOLITHOGRAPHIC ADDITIVE MANUFACTURING

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Abstract: *Among the many types of additive manufacturing, stereolithography (SLA) stands out as one of the most versatile technologies, especially in the production of large prototypes of extremely high surface quality. The basic working principle of this technology has not changed for almost thirty years, but the recent rapid development of the mask-based variant of stereolithographic 3D printing technology (MSLA) has significantly increased its popularity and made it available to a wider range of users. This is especially true for MSLA 3D printers that use liquid crystal displays (LCD) for mask forming. These 3D printers are characterized by large build volume, high resolution and speed of model production, and low price. These factors make them extremely attractive for rapid prototyping or small-scale serial production. However, although they are superior to classical laser-based stereolithography in many technical aspects, their current main drawback is the smaller range of available materials. The development of modern stereolithographic technology has clearly shown that the capabilities of 3D printers themselves are just as important as the materials from which the models are made, the diversity of their mechanical characteristics, available colours, and optical properties. The materials used in all variants of SLA technology are liquid thermoset polymers that are sensitive to UV light (photopolymers). A wide range of areas of application requires a wide range of materials that meet the specific needs of each application. MSLA, as a newer technology, still does not have the same range of materials as 3D printers based on the laser variant of stereolithography. The situation is significantly improving with the increase in the number of available MSLA 3D printers, their popularity, and improved technical characteristics, and it can be said that this is the last step in legitimizing MSLA technology as a competitor to laser stereolithography. The aim of this paper is to analyse the material market for MSLA technology, categorize the supply of materials and objectively compare the available materials with those offered by reputable manufacturers of materials for classic SLA 3D laser printers. Special emphasis is placed on the quality and scope of technical specifications of MSLA materials, which is crucial for their professional use. In addition, the impact of thermoset polymers on user health and the environment is an especially important topic, so an overview of plant-based materials was also made.*

Key words: additive manufacturing, stereolithography, materials, photopolymers

1. INTRODUCTION

There are currently only two additive manufacturing (AM) technologies available to broader range of desktop and professional users that are not willing to pay exorbitant amounts of money to produce their parts. These are Fused Deposition Modeling (FDM) (Chennakesava & Narayan, 2014) and Stereolithography (SLA) (Kafle et al., 2021).

It should be noted that FDM is a trademarked name of Stratasys corporation, one of the leading manufacturers of 3D printers. FDM is also commonly known as Fused Filament Fabrication (FFF) (Singh et al., 2020), which is just a different name for FDM that was coined by the open-source RepRap project. RepRap is credited for popularizing FFF technology and AM in general, since their open-source printers inspired by the expired Stratasys FDM patent was the first AM machine that was available and financially accessible to broader set of users. FFF went down in history as the first consumer desktop AM technology available.

FFF 3D printers are known for their low cost, ease of use, extensive selection of different models, large build volume and a wide range of available materials. Success of any AM technology is based upon cost and performance of 3D printers and the range of available materials. FFF scores high in both categories, but the latter is especially important and goes in favour of FFF. There are many thermoplastics that can be fed into an FFF 3D printer, from low-cost PLA to flexible and elastic ones, to high performance carbon fibre reinforced PEEK composites. Most importantly, almost all these materials can be printed on sub-

1000€ 3D printers, out of the box or with small modifications. This fact alone means that there is a vast array of applications where these low-cost 3D printers can be used.

However, like any AM technology, FFF has certain drawbacks that limits it's usability. Low build speed and low resolution are most prominent. All FFF 3D printers feature a nozzle that extrudes melted plastic. Diameter of nozzle strongly determinates resolution and build speed. Larger nozzles can extrude material faster, but resolution drops significantly, and smaller nozzles increase resolution with drastic decrease in build speed. However, one competing AM technology can offer both high resolution and build speed along with most benefits of FFF technology.

Stereolithography was the first, original AM technology that was introduced in 1980s. Original SLA concept, still used today, uses UV lasers (Stampfl et al., 2008) to spatially solidify a thin layer of liquid photopolymer. This approach to SLA has exceedingly slow build times since laser beam has very small diameter and is mechanically steered. More modern approach is masked stereolithography (MSLA) which uses various techniques to project an entire object cross-section into the photopolymer layer (Potgieter et al., 2008). This results in extremely fast build speed that can exceed 100 mm/h in desktop 3D printers and over 600 mm/h in some professional 3D printers. Resolution of these 3D printers is determined by spatial resolution of light modulator being used and layer thickness. This type of SLA technology drastically mitigates drawbacks of FFF technology as the second AM technology available to desktop consumers

First instance of MSLA was DLP (Digital Light Processing) SLA, where masking was provided by digital micromirror device, based on micro electro-mechanical design (Sampsell, 1994). This variation of SLA has certain advantages, primarily that DLP device can handle high energy light sources in UV band, given that it's micromirrors are made from polished aluminium. This ensured high build speed and device longevity. However, DLP technology is patented and manufactured exclusively by Texas Instruments and as a result DLP device prices are high. Other drawback is limited resolution. Largest DLP device has a resolution od 2560x1600 physical pixels, where every pixel corresponds to a single micromirror. There is a 4K DLP device, but that resolution is achieved through frame blending of images produced by lower resolution DLP array and cannot be considered a true 4K image.

Second instance of MSLA is LCD (Liquid Crystal Display) SLA, and this technology is the topic of this paper. This type of MSLA uses ordinary LCD panel without any back illumination as spatial modulator for layer projection (Wu, Xu & Zhang, 2021). LCD pixels are normally opaque when turned off, but turn transparent when fully switched on. These 3D printers use UV LED arrays to uniformly shine directional light through the LCD panel. Image of a current layer that is to be formed is displayed on the panel. This creates a transparent mask through which UV light passes and spatially solidifies light sensitive resin. This approach to SLA has numerous advantages. LCDs can easily be made large and high resolution. There are already 13-inch panels with 8K resolution available in some high-end desktop LCD SLA 3D printers, and there is no technological reason why size and resolution couldn't increase further. LCD panels are low-cost devices available from many manufacturers, therefore LCD SLA 3D printers are also mostly low-cost devices, even those considered high-end in LCD SLA user community. Only real drawback is that LCD panels are not very transparent at 405 nm wavelength that is predominantly used to solidify resin. Only 2-6% of light passes through the panel, rest in converted to heat (Penczek, Kelley & Boynton, 2015). There is also the problem of LCD panel degradation since strong UV light must be used on account of panel's low transparency in UV band. This causes loss of contrast and light bleeding through opaque pixels. There is no actual data on degree of degradation over time, but manufacturer's estimates vary from 500 to 2,000 hours depending on UV array light intensity and type of LCD panel- This means that LCD panels can be a perishable part of 3D printer that must regularly be replaced if 3D printer is used often.

LCD SLA is the dominant variant of MSLA technology. There are many contributing factors to this. Low 3D printer cost, large number of manufacturers and models, simple use, high-detail and high-speed 3D printing, low maintenance, simple machine design and a large community of users. However, any AM technology is only good as the materials that can be used to build parts and products. It can be said that today most AM technologies are at a point where they are more than capable to producing high quality parts in volume. However, precision, surface quality, build speed and tolerances that a machine can achieve are meaningless if there are no materials suitable for a particular product that needs to be produced. It is therefore of paramount importance that AM technologies can build parts with a very wide range of materials. This presents a problem since products are made from a vast range of materials.

SLA works exclusively with thermosetting polymers (Zhang & Xiao, 2018). User either directly pours resin into the build tank or inserts a resin cartridge into the 3D printer, depending on manufacturer and model. Parts are then produced from that resin. It is immediately obvious that due to working principle SLA

technology can produce only single-material parts. Only exception to this is BCN3D's VLM technology that can use two resins in the same part, but as of now has only been announced as an expensive, professional technology.
Purpose of this paper is to investigate current situation on low-cost resin market (consumer market), as these materials are the ones that are used in consumer LCD SLA 3D printers. LCD SLA 3D printers are a relatively new occurrence and therefore availability of related low-cost resins has generally trailed behind the wide range of professional materials made available for professional SLA printers from industry leading manufacturers. Situation has significantly approved over the last few years, but although there is now a wider range of available materials, they are mostly sold "as-is", meaning there is usually no mechanical data provided. Instead, users must rely on vague manufacturers' descriptions and anecdotal advice from user community when choosing appropriate material for a certain application. This is one of the most important reasons why LCD SLA 3D printers can hardly be used in more serious prototyping and manufacturing role where mechanical properties of produced part are important. It also explains why these 3D printers are still mostly used for miniatures printing and similar high-detail applications and not production of functional parts. Of course, users can still print using professional resins, but that defeats the purpose of using low-cost machines, since professional resins can cost anywhere between 150 and 300 €/kg, whereas low-cost resins are usually in 25-50 €/kg range. This means that just three kilograms of professional resin are more expensive that a large majority of LCD SLA 3D printers and that amount of resin can be used in under a week of consistent printing.

2. METHODS

It must be understood that there is almost no concrete available data on sales volume of individual consumer resin manufacturers, nor is there a clear consensus on where the distinction between manufacturers of professional and consumer resins is. For now, LCD SLA 3D printing can be considered entirely centred on non-professional users that employ these machines for personal projects. It is therefore of little surprise that there is no serious research about this topic.
Given that there are no clear data on popularity or size of consumer resin manufacturers, it was decided to select a representable sample of manufacturers based on their popularity and reputation in user community and websites dedicated to 3D printing. Selection was further narrowed based on Google Trends search popularity over the last 12 month. In the end six manufacturers were selected. Three of those produce 3D printers and resins, while three only produce resins.
Formlabs was selected as a representative for professional side of resin manufacturers and was used as a comparison to manufacturers of consumer 3D printers and resins. Formlabs is a very popular and established company that produces laser-based SLA 3D printera, along with a very wide range of resins. It is considered as an affordable professional SLA solution and is therefore extremely popular with high-end desktop users, smaller companies, research facilities and educational institutions. As was mentioned earlier, it is their wide selection of available resins that make them so appealing. We surmise that Formlabs is an ideal company with which to compare consumer resin manufacturers, as it offers a wide selection of materials with available mechanical datasheets, but is still not considered a highly professional manufacturer like 3D Systems or Stratasys that also offer SLA 3D printers. Importantly, in contrast to those major manufacturers, Formlabs makes prices of their resins available.
Resins of every manufacturer are usually separated in three categories: basic, engineering and specialty. This is how most professional resin manufactures divide their range. Basic resins are designed for purely visual aspect of prototyping. They have high surface quality, print fast and achieve fine details. Engineering resins are used to produce functional parts and therefore have high mechanical properties. They are often meant to simulate other commonly used plastics, such as ABS plastic and therefore have similar mechanical properties to them. Specialty resins are considered those that have some property that is novel or highly specific, such as dental resins that aim to simulate specific type of tissue or plant-based resins that aim to offer low-odour printing that is ecologically more acceptable. Again, there is no clear distinction between these categories and in context in this paper it is based on how professional manufacturers categorize their products.

3. RESULTS

Based on initial research of user communities (Reddit/3dprinting, Quora/3D printing, 3D Hubs) and dedicated websites (All3DP, 3DPrinting, Clever Creations, TCT Magazine, 3D Insider) we identified seven

most prominent companies that produce both 3D printers and resins. These are Elegoo, Prusa, Peopoly, Flashforge, Creality, Anycubic and Phrozen. Further five prominent companies were identified that only produce resins. These are eSun, Nova3D, Monocure3D, Liqcreate and Sunlu.
Google trends gives further insight into popularity of these companies. The term that was used was *"name_of_the_company resin"*, i.e. *"creality resin"*. Term *"resin"* was included as to discount results advantage that companies offering both 3D printers and resins would have. Results are shown in Table 1.

Table 1: Relative search result share of considered companies

Company name	Offer	Rank	Relative search result share
Anycubic	3D printers and resins	1.	100%
Elegoo	3D printers and resins	2.	90%
Phrozen	3D printers and resins	3.	31.6%
Creality	3D printers and resins	4.	28.4%
eSun	Resins	6.	20%
Prusa	3D printers and resins	5.	14.2%
Liqcreate	Resins	7.	14.2%
Monocure3D	Resins	8.	12.6%
Sunlu	Resins	9.	11%
Nova3D	Resins	10.	7.9%
Flashforge	3D printers and resins	11.	4.7%
Peopoly	3D printers and resins	12.	3.1%

Based on the results Anycubic, Elegoo and Phrozen were selected as representatives of companies offering both 3D printers and resins, while eSun, Liqcreate and Monocure3D were selected as representatives of companies that offer only resins. While these six companies do not represent the whole market, they do hold a significant stake in it and can therefore give a good overview of the general trends.
Material range, pricing and mechanical datasheets were collected for every company. Amount of available data in mechanical datasheets was divided into three categories: *"none"*, *"basic"* and *"extensive"*. *"None"* means that no mechanical data was provided. Purely descriptive or relative terms provided by manufacturers were not taken into consideration since they do not represent any useful information. Resins with only one or two mechanical parameters were also bundled into this category, since this limited set of information is insufficient to derive any serious conclusion on the mechanical behaviour of parts produced from those resins. *"Basic"* category contains resins for which some data was provided and this was limited to 3-6 mechanical parameters since this amount of data is sufficient to predict reasonably well behaviour of parts produced using these resins. Finally, *"extensive"* category was reserved for resins that have 7 or more mechanical parameters provided, meaning that it is possible to accurately predict behaviour of parts produced using those resins. Resin offerings of all manufactures are shown in Tables 2-7.

Table 2: Anycubic's resin range

Resin name	Price (USD/kg)	Mechanical data
Colored	38	none
Plant based	41	basic
Flexible tough	60	basic
DLP Craftsman	45	basic
Water-wash	36	basic
Standard	35	basic
ABS-like	38	basic
Dental	60	none
Average price:	**44.1**	

Table 3: Elegoo's resin range

Resin name	Price (USD/kg)	Mechanical data
Plant based	35	basic
ABS-like	34	extensive
Standard	29	basic
8K standard	30	none
Water-washable	34	basic
8K water-washable	40	none
Thermochromic	40	none
Average price:	**34.6**	

Table 4: Phrozen's resin range

Resin name	Price (USD/kg)	Mechanical data
Aqua 4K	40	extensive
Aqua 8K	50	extensive
Speed	38	extensive
Aqua	38	extensive
Water-washable	38	extensive
Mud-like	140	extensive
Flex	69	extensive
ABS-like	33	extensive
Castable W40	240	none
Castable W20	220	none
TR300	50	extensive
Castable Dental	200	extensive
Protowhite Rigid	80	extensive
Rigid Pro410	70	extensive
Functional TR250LV	38	extensive
Stiff	80	extensive
Tough	78	extensive
Average price:	**91.5**	

Table 5: eSun's resin range

Resin name	Price (USD/kg)	Mechanical data
eResin PLA	60	extensive
eResin PLA Pro	60	extensive
Standard	70	extensive
Water-washable	60	extensive
PM200 PMMA-like	56	extensive
Hard Tough	80	extensive
eResin Flex	120	extensive
Average price:	**72.3**	

Table 6: Liqcreate's resin range

Resin name	Price (Euro/kg)	Mechanical data
General purpose	90	extensive
Premium Flex	75	extensive
Premium Model	75	extensive
Premium Black	66	extensive
Premium Tough	75	extensive
Hazard Glow	150	extensive
Tough X	140	extensive
Strong X	160	extensive
Flexible X	130	extensive
Composite X	113	extensive
Clear Impact	130	extensive
Wax Castable	90	extensive
Gingiva mask	140	extensive
Dental model	140	extensive
Average price:	**113.8**	

Table 7: Monocure3D's resin range

Resin name	Price (USD/kg)	Mechanical data
3D Pro Bigvat	119	none
3D Pro Crystal Clear	119	none
3D Pro Deep Black	119	none
3D Pro Glow	141	none
Study	137	none
Precise	160	none
Gingiva	160	none
Tuff	121	basic
3D Rapid	55	none
Flex100	121	none
Average price:	**125.2**	

It should be noted that eSun offers much broader range of resins, 18 in all, but for 11 of those resins pricing was not provided and therefore these were excluded from Table 5.
Formlabs' resin library is considerably larger than any previously mentioned manufactured, containing 36 different resins. Average price of one liter of resin is 263.3 USD. Formlabs provides extensive mechanical datasheets for all resins, with most high-performance resins featuring highly detailed testing data.

4. DISCUSSION

Anycubic, Elegoo and Phrozen are clearly most prominent manufacturers of SLA resins in consumer market. Almost all 3D printers come bundled with some amount of standard resin that is meant to get users going fast. If users get good result with these resins, it is reasonable to expect that they will continue to use the same one. Hence, they purchase the same resin from the same manufacturer. It is therefore not surprising that the most prominent 3D printer manufacturers are also the largest suppliers of SLA resins.
However, resin range of these manufacturers is usually very basic, as shown by the data. Their range mostly consists of standard, water washable, ABS-like and plant-based resins. This is more than enough for casual users that are mainly interested in producing art-based models, such as miniatures, but it is not usable for functional part manufacturing or serious prototyping. ABS-like materials do offer better mechanical properties than standard resins, but availability of detailed mechanical specifications makes it difficult choice to make. In general 3D printer manufacturers offer very scarce mechanical data. Anycubic offers 8 materials, 6 of which have only basic mechanical data available. Elegoo offers 7 materials, 3 of which have basic mechanical data and only one with full data available. Only exception in this category is Phrozen. They offer much broader range of resins, 17 in total. 15 of them have detailed mechanical

specifications available. This is somewhat reflected on pricing – average price per kilogram is 91.5 USD, but this is mostly contributed by expensive castable and dental resins. Price of standard resins is on par with Anycubic and Elegoo. Another difference in their resin range is absence of any kind of plant-based resin.

In contrast, companies offering only SLA resins have a broader range of materials with usually better mechanical specifications provided. They also have higher prices. eSun and Liqcreate offer several high-performance materials that can be easily used to produce functional parts or prototypes. Monocure3D is an outlier in this case, they offer smaller range of resins and provide mechanical data for only one resin. Only two other resins have any mention of mechanical data and they are limited to two parameters. This is disappointing since Monocure3D's prices are comparatively high. I general, it is worth noting that none of these companies offer plant-based resins, which is an interesting situation given their broader range of resins than Anycubic and Elegoo, both of which offer plant-based materials.

Exploring Formlabs range of materials reveals that they have by far the broadest offering of materials and most detailed mechanical datasheets. This is to be expected from a closed, professional systems and highlights how far behind are consumer SLA resin manufacturers. Resin price matches this level of refinement, as Formlabs's materials of similar categories are more expansive than eSun's and Liqcreate's. Of course, this difference makes more sense in high performance materials, but difference between standard materials is vast – Formlabs standard materials (149 USD) are vastly more expansive than Anycubic (38 USD) and Elegoo (29 USD).

5. CONCLUSION

It is difficult to gauge entire resin market for consumer MSLA 3D printers. There are many 3D printer manufacturers offering their own resins and there are many manufacturers specialized only in resins. This paper aims to cover most notable companies in both segments and data suggests that the market situation is rapidly becoming more favourable for desktop MSLA users seeking to utilize more advanced resins at a reasonable price. Prime examples of this are Phrozen Liqcreate. Phrozen has a diverse offering of resins at a reasonable price, while Liqcreate offers rather advanced resins like Composite X, albeit at a higher price. However, it is still substantially less expensive than Formlabs's offering of high-performance materials.

Somewhat surprising is the fact that there are very few eco-friendly resins available. Apart from Anycubic and Elegoo, there are no plant-based resins from any other manufacturers considered in this paper. Desktop resin 3D printing is becoming more popular and one of the most negative aspects of this technology is the fact that resins are difficult to work with and hazardous to health. Up until recently, all resins had to be washed in isopropyl alcohol. Today, all resin manufacturers offer water-washable resins that can be cleaned in tap water. While this is much more convenient for users, these resins still present health hazard. As MSLA technology grows in popularity, development of less toxic, eco-friendly resins is of paramount importance for the users and the environment.

It can be concluded that the range of affordable priced resins is substantial, if not yet diverse like in professional SLA 3D printing. Given that MSLA 3D printing is a still a rather new technology, the outlook for further expansion of material range is good. Many of the companies offering MSLA 3D printers and affordable resins are of Chinese origin, and that has historically been viewed as a negative. However, more and more of these companies are achieving recognition in Western markets and this leads to increased sales, which in turn leads to more research and development of new resins. Therefore, the market in rapidly expanding and it will be interesting to see further developments in years to come.

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EDIBLE FILM PRODUCTION WITH ALOE VERA EXTRACT AND ITS PRINTABILITY

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Abstract: *The main concern with protecting fruits and vegetables from bacterial infection and growth is ensuring product quality and safety. Hydroxyethyl cellulose, with –OH in the natural cellulose molecule substituted by a hydroxyethyl group, has been widely used in oil exploitation, coating, medicine, food and polymerization process. It is nontoxic and low-cost. Aloe vera is a well-known herbal plant that is used for its therapeutic properties. The gel extracted from Aloe vera plants contains a variety of biologically active compounds, phenolic contents, and minerals. In this study, the edible films containing different proportions of aloe vera and hydroxyl ethyl cellulose were prepared. The structural and antibacterial properties of the obtained edible films were examined. The obtained films were printed with inkjet. Color and adhesion properties of printed samples were determined and it was observed that the edible films showed antibacterial properties.*

Key words: Edible film, hydroxyethyl cellulose, aloe vera, printability

1. INTRODUCTION

The main concern with protecting fruits and vegetables from bacterial infection and growth is ensuring product quality and safety. Edible films and coatings, such as wax on various fruits, have been used for centuries in order to ensure product quality and safety. Edible films are generally prepared from proteins, polysaccharides, lipids and their combinations with some additional food grade additives (Maan et al., 2021; Cheng et al., 2022). Various natural polysaccharides such as cellulose, chitosan, starch, pectin, alginate, gums, agar, dextran are widely used as edible films due to their performance in extending the shelf life of different food products. Edible film, when applied to a solid food surface, represents an edible primary packaging due to its direct contact with the food surface (Han, 2014; Galus & Kadzińska, 2015; Lin et al., 2022). Although this is not a new concept; however, current research focuses on developing active food packaging using new compounds derived from various herbal plants that can offer more functionality than just providing barrier and mechanical strength. Today, herbal plants in edible film use have become even more common. The aloe vera has been used for healthy applications and other fields for example; beauty, medicinal and skin care properties (Mary et al., 2022; Mahajan et al., 2022). Numerous substances, including minerals, enzymes, hormones, and carbohydrates, can be found in aloe vera gel extract. Aloe vera and its bioactive components have so been researched to learn more about its exciting prospective applications in the field of medicine (Hadi et al., 2022; Hou et al., 2021; Farid et al., 2022). Aloe vera is a botanical with great medicinal value that has been well researched for use in food, medicine, and cosmetics (Passafiume et al., 2020). It is the most well-known species of aloe and a member of the Aloaceae family (Vieira et al., 2016). It is a xerophytic plant that is succulent and well adapted to growing in dry climates. Soft, slick tissues including parenchyma cells make up aloe vera gel. It is a clear object and has a complex composition; In addition to carbohydrates, proteins, fiber, soluble sugars, vitamins, minerals, amino acids, organic acids, and phenolic compounds, it also contains a variety of bioactive substances. Due to its success in prolonging the shelf life of numerous perishable food goods during the past 10 years, it has attracted a lot of attention as an edible film. Aloe vera gel films are a great example of natural and active packaging because of their barrier qualities as well as their antioxidant and antibacterial potential.
In this study, aloe vera containing edible films was prepared and then we investigate the antimicrobial activity of the prepared films and its printability.

2. METHODS

2.1 The preparation of aloe vera gel from aloe vera plant

Leaves of aloe vera were cleaned by distilled water. The gel was collected from the leaves and then was stirred vigorously and aloe vera gel was prepared to use at edible film preparation (Figure 1).

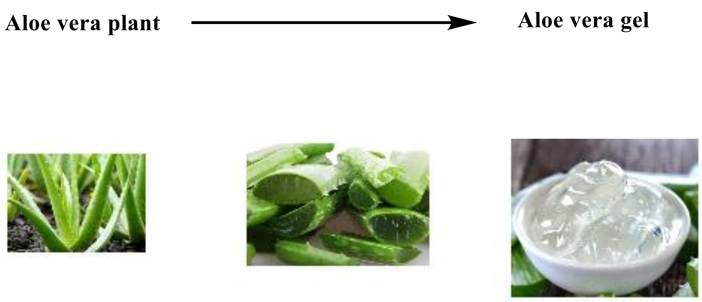


Figure 1: Preparation of aloe vera gel

2.2 The preparation of the edible films

%1 wt hydroxyl ethylcellulose (HEC) solution in distilled water is prepared. F0 formulation is edible film without aloe vera. F0 is prepared with hydroxyl ethylcellulose. For F1 formulation, 1 g HEC and 0,01 g aloe vera are mixed and then the mixture was poured into Teflon molds and dried in a vacuum oven at 60°C. The formulation table of the prepared edible films was given in Table 1.

Table 1: Formulation Table

	HEC (g)	Aloe vera (g)
F0	1	-
F1	1	0,01
F3	1	0,03
F5	1	0,05

ATR–FTIR spectrum was recorded on Perkin Elmer Spectrum100 ATR–FTIR spectrophotometer. Shimadzu 310 UV–Vis–NIR spectrometer was used to assess the transmission percentage of the edible films. The wettability of edible films was determined using the contact angle with the sessile water droplet method. The characteristics of printed surfaces were determined with contact angle (TAPPI T458). Distilled water was used as standard wetting fluid in a Pocket Goniometer Model PG-X, (FIBRO Systems AB, Sweden), which was measured as a function of time. The program is of version 3.4. Images of water droplets were then recorded by using a CCD video camera. Surface energies were calculated on the contact angle by ASTM D5946-17 standard test method.

The obtained films printed as a background with the BENTSAI BTHH 6105 handheld thermal inkjet printing machine. The colors of unprinted and the printed films were measured by X-Rite eXact portable spectrophotometer, gloss measurements were measured with BYK Gardner gloss measuring device at an angle of 60° and 75°. Color differences were calculated according to the CIELab (2000) technique.

3. RESULTS

3.1 ATR-FTIR

The produced edible films ATL- FTIR spectra is shown in Figure 2. The prepared edible films' ATR-FTIR spectra in comparison to HEC is shown in Figure 2. The spectra of the edible films' absorption bands resembled those of the F0 formulation. In the literature, stress vibrations of C-H have been linked to the peaks at 2924 and 2874 cm^{-1} in the spectra of HEC (Şen et al., 2018). Additionally, at 3400 and 1061 $cm^{-1,}$

respectively, the vibration bands associated with hydroxyl groups and -C-OH bonds could be detected. This peak, which was observed at 1061 cm^{-1}, was observed to have significantly lowered when compared to the edible films. (Beyler Çiğil et al., 2022).
Accordingly, it can be argued that the edible films were successfully prepared. The ATR-FTIR spectra of the prepared antibacterial coatings with nanosilver/hydroxyethyl cellulose/polyacrylic acid/sorbitol in another our study were similar to those in the present study (Beyler Çiğil et al., 2022).

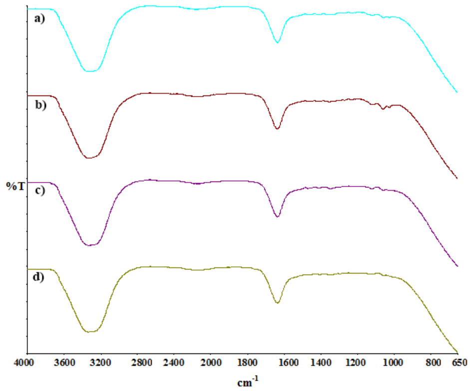
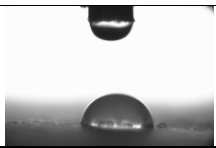
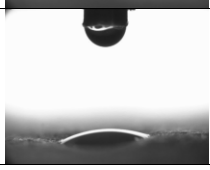


Figure 2: ATR-FTIR spectra of a) F0, b) F1, c) F2 and d) F3 formulations

3.2 Contact Angle

The contact angle is measured in the liquid where the liquid vapor interface meets a solid surface. Surface roughness has a strong influence on the contact angle and wettability of a surface (Birtane et al., 2019). The contact angle of edible films containing aloe vera decreases with increasing aloe vera content. Contact angle images of edible films are given in Table 2. The contact angle values were slightly decreased with the presence of aloe vera in edible films. This may be related to the hydrophilic structures in aloe vera. Similar results have been reported in the literature (Pereira et al., 2013).

Table 2: Total surface energy and contact angle values of all papers according to ASTM D5946 method

Paper samples	Total surface energy (mJ/m^2)	Contact Angle with water	Images
Base paper	42.3	62.8	
F0	54.9	38.4	
F1	51.2	28.1	
F3	55.7	26.0	
F5	58.0	19.6	

3.3 Printability Properties

Table 3: Color characteristics and glosses of coated papers

	L	A	b	Delta E	Gloss
Base paper	91.76	2.43	-10.71		5.8
F0 film's	89.13	2.02	-9.54	1.87	13.0
F1 Film's	90.03	2.03	-9.52	1.41	13.4
F3 Film's	90.55	2.13	-9.85	1.00	13.6
F5 Film's	91.92	2.36	-10.08	0.45	14.2

In order to determine the color and gloss of the prepared film, the measurements were made on white paper and the results are given in Table 4. When Table 4 is examined, it is seen that the change in L and b values, in which the color of the film without aloe vera, changes the most. The change in b value indicates that the color has shifted slightly towards yellow. With the addition of aloe vera, the color shift to yellow with a slight blue/green glow, which is the color of aloe vera itself, is reduced. And accordingly, a decrease in delta e, which is the color change value, was observed. When all coatings are examined, the delta e difference is below 2 and it is not possible to distinguish this difference with the human eye. When the gloss values were examined, it was determined that the gloss of the white paper used as the background was 2 times lower than the films. The fact that the surface of the white office paper is rough and the surface of the produced film is smooth revealed this result. In addition, an increase in gloss was observed as the amount of aloe vera added to the formulation increased.

Table 4: Color characteristics and glosses of printed papers

	L	a	B	Delta E	Gloss
Base paper print	53.97	-26.71	-48.63		6.7
F0 Film's Print	52.99	-26.08	-48.30	0.85	21.6
F1 Film's Print	53.90	-26.65	-47.49	0.78	22.1
F3 Film's Print	53.90	-26.11	-47.14	0.70	22.7
F5 Film's Print	54.22	-26.61	-46.16	1.01	23.3

Cyan ink was applied on the films produced with a thermal inkjet printer and the color and gloss values of the prints were measured on white office paper. Obtained results are given in Table 4. When the results are examined, it is seen that the color changes are lower than the unprinted films compared to the base paper (Only the F5 formation delta E difference is higher). This is because the cyan ink tolerates yellowing. Thus, yellow glows by the pigment were reduced and the color became closer to the base paper. The color differences of all prints are below the detection limit of the human eye, that is, all prints are seen in the same color as the main paper. Gloss values, on the other hand, increased approximately 2 times compared to the base films. This is due to the gloss of the resin in the printed ink. Parallel to the unprinted films, an increase in the gloss value was observed as the amount of aloe vera increased.

3.4 Optical properties

The transmission percentage of the prepared edible films was characterized by UV–Vis spectroscopy. The UV–Vis transmission spectra of the edible films are given in Figure 3. It was found that between 750 and 300 nm, The optical transmittance of edible films decreased slightly with increasing aloe vera content. But it can be seen that the decrease in the optical transmittance in the visible region is very low. This situation can be attributed to the homogeneous dispersion of aloe vera in hydroxylethyl cellulose.

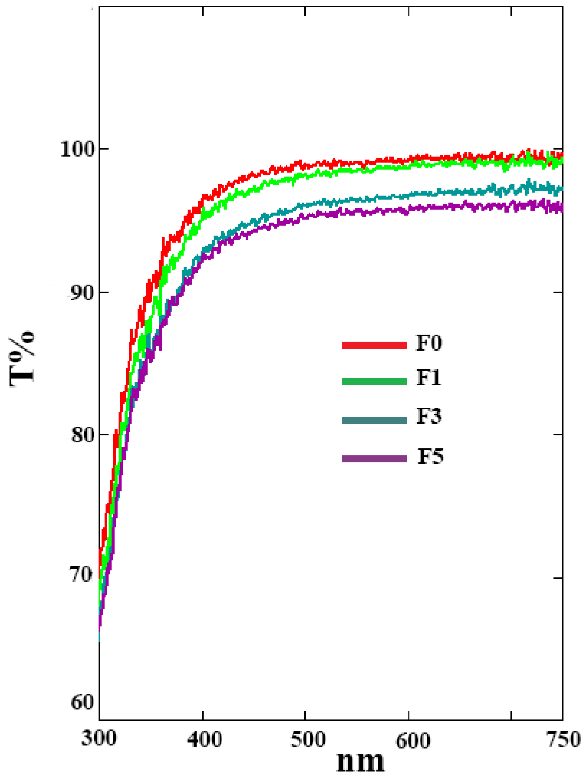


Figure 3: UV–Vis transmittance of edible films

3.5 Antimicrobial activity of Aloe vera containing coatings

Antimicrobial films made with aloe vera were tested against Gram-positive pathogenic bacteria like *S. aureus* and Gram-negative pathogenic bacteria like *E. coli*. Table 5 displays the widths of the samples' inhibition zones. It was noted that *S. aureus* and *E. coli* grew uniformly in every area of the petri plates used for the control samples. It was discovered that all edible films that had been made had inhibitory effects on *S. aureus* and *E. coli*. Aloe vera's inherent structure is what gives edible films containing the plant its antibacterial properties. Both bacterial species' antibacterial qualities improved as aloe vera concentration increased.

Table 5: Antimicrobial activity of the edible films against E. coli and S. aureus (inhibition zone diameter in centimeter)

Sample	*E. Coli*	*S. Aerus*
F0	1.4	1.1
F1	1.5	1.2
F3	1.8	1.5
F5	1.8	1.5

4. CONCLUSIONS

In the present study, the edible and environmentally friendly antibacterial edible films were prepared with HEC and aloe vera. The ATR-FTIR results showed that the coatings were successfully prepared. Also, it was observed that aloe vera is covalently bound to the surface of hydroxylethyl cellulose. Moreover, it was observed that aloe vera significantly increased the antibacterial behavior of the edible films. The zone of inhibition was measured for both *E. coli* and *S. aureus* as 14 and 11 mm respectively. In a general evaluation, it was seen that the edible antimicrobial films were successfully obtained and can be used in the printing industry.

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THE INVESTIGATION OF EDIBLE PACKAGING FILMS BASED ON PULLULAN AND ALGINATE

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Abstract: *The packaging industry is highly dependent on fossil resources and have serious environmental drawbacks. The largest part of the total volume of plastic waste is generated from food packaging, so new packaging strategies with green materials are required. Using the edible packaging films which are renewable, biodegradable and versatile, can reduce the amount of plastic waste. Also, there is an increasing demand of higher quality foods and a growing interest from consumers for minimally processed fresh-like foods with an extended shelf life. Edible films can be effective barriers which prevent unwanted mass transfers in foods. They can be green alternative to synthetic petroleum-based polymer packaging materials and nowadays this topic is a fast-growing area. Sodium alginate as a natural polysaccharide can be used for edible films with excellent properties such as transparency. But, sodium alginate practical applications in food packaging are limited as single-component because of poor mechanical and barrier properties. At the same time, pullulan is an extracellular and water-soluble microbial polysaccharide with good film-formation properties. The packaging materials made from pullulan and alginate may be better candidates for edible packaging films. The objective of this study was to formulate pullulan and sodium alginate based edible films for food packaging. For that purpose a series of pullulan/alginate films with different ratios were prepared. To improve film flexibility and processability, glycerol was added as plasticizers in the film formulation. Designed films were solvent cast from aqueous polymer solution. Understanding the film-forming mechanism during the drying process is crucial to predict properties of the obtained films, so rheological properties of prepared solutions were investigated. Formulated films have the potential to be used as inner primary packaging and can be manufactured by preparing a film-forming composition and enclosing a food product with the film. Using this kind of packaging material, no waste is generated contributing to the circular economy.*

Key words: packaging, edible film, rheology, alginate, pullulan

1. INTRODUCTION

The biodegradable and eco-friendliness of packaging materials are desirable benefits associated with their use, primarily in the food industry. Also, there is constantly need to extend shelf life of food products, which is these days specially enlarged. This can be achieved by enriching of packaging food materials with active agents, which decrease the growth of pathogens in food. Wrapping of food by film with antimicrobials which slowly release from the packaging material and dissolve onto the surface of the food through direct contact, results in significantly greater shelf life of packaged food (Erceg et al., 2022). Another possibility of achieving the mentioned requirements is the application of edible films as food packaging materials. Edible films and coatings are promising for delaying quality deterioration of food products and they function as natural preservation and a safe protection for food (Giancone et al., 2008; Apriliyani, Rahayu & Thohari, 2022). They also improve the gas and moisture barriers, mechanical properties, sensory perceptions, and microbial protection and prolong the shelf life of various products, such as foods (Janjarasskul & Krochta, 2010).
Edible films and coatings are made from edible biopolymers and food-grade additives (Jung, 2014). Pullulan films have properties which make them an ideal material for edible films and coatings. Despite the many potential applications of pullulan, extensive use of this polymer is hampered by its high cost (Tong, Xiao & Lim, 2008). One of the possibilities to reduce the cost of pullulan-based films is to blend them with other compatible biopolymers, such as sodium alginate, which films have excellent properties such as transparency, but poor mechanical and barrier properties.
Thin layers on edible products are usually applied as a liquid with varying viscosity on the surface of fresh and processed foods by spraying, spreading and dipping technique (Apriliyani, Rahayu & Thohari, 2022). The properties of the produced edible films and coatings are in correlation with a rheological properties

of film-forming solution. The rheological properties describe the flow behavior of film-forming solution, hence becomes a crucial property because it influences the spreading ability, thickness, uniformity of casting layer and consequently affect the performance of the film (Silva-Weiss et al., 2013; Chen, Kuo & Lai, 2009).
The aim of this research was to investigate rheological properties of film-forming pullulan/sodium alginate solutions. For that reason, solutions with different ratios of pullulan and alginate were prepared by a casting method and dried, yielded uniform coherent films. Flow properties of film-forming solutions are important to identify the most appropriate coating system and optimize operating conditions (Ma et al., 2017). Therefore, it was necessary to study the rheological properties of the prepared pullulan/alginate solutions, specially because the flow behavior of film-forming solutions could affect the mechanical properties, and the application and processing design.

2. EXPERIMENTAL SECTION

2.1 Materials

Pullulan with a molecular weight of 574.570 g/mol was supplied from Avena Lab (Serbia). Alginic acid sodium salt was obtained from Alfa Aesar (USA). Structural formulas of pullulan and alginic acid are shown in Figure 1a and Figure 1b, respectively. Glycerol, which was used as a plastificator was purchased from ZORKA Pharma (Serbia).

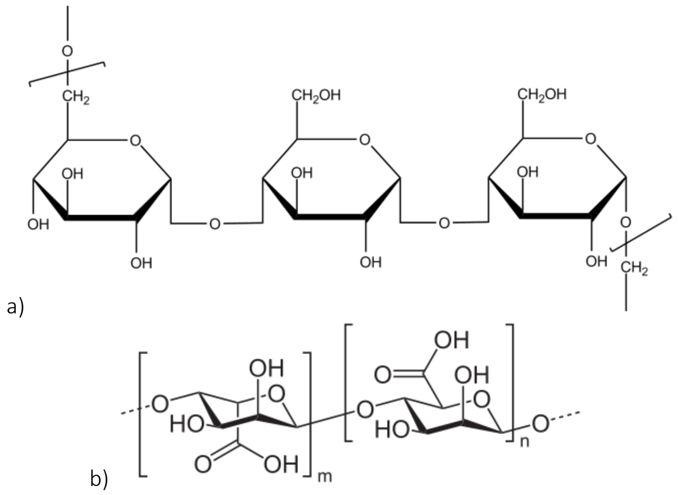


Figure 1: Structural formula of pullulan (a), and alginic acid (b)

2.2 Preparation of pullulan/alginate blends

Blends were prepared by solution blending of pullulan and alginate in different weight ratios. The pullulan and alginate solutions were prepared by dissolving pullulan and alginate (5 wt%) in distilled water at 50 °C, under stirring (1200 rpm) for 2 h. Composite pullulan/alginate films were prepared by mixing of solutions in different weight ratios (1:1, 1.5:1, and 2:1). Glycerol was used as a plasticizer in the amount of 30 wt% per total biopolymers mass. The films were obtained by casting of solutions on Petri dishes and drying at 50 °C in a vacuum drying oven. The applied combinations of the pullulan and alginate produced a good blend uniform films and the photograph of the dried sample of edible film Pul/Alg 2:1 is shown in Figure 2.
Different weight ratios of pullulan and alginate were prepared to investigate their influence on the rheological properties of prepared blends. The pullulan/alginate blends were denoted as Pul/Alg 1:1, Pul/Alg 2:1 and Pul/Alg 1.5:1 according to different mass ratios of pullulan to alginate as shown in Table 1.

Table 1: Composition of pullulan/alginate blends

Sample	Pullulan (g)	Alginate (g)	Amount of plasticizer (wt%)
Pul/Alg 1:1	1.00	1.00	30
Pul/Alg 2:1	1.33	0.67	30
Pul/Alg 1.5:1	1.20	0.80	30

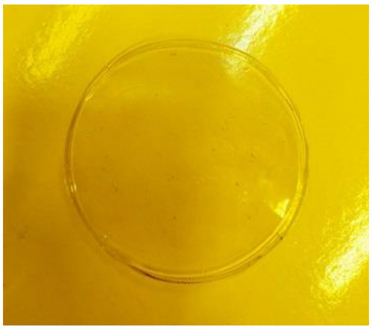


Figure 2: Photograph of the pullulan/alginate film (sample Pul/Alg 2:1)

2.3 Rheological measurements

The rheological properties of film-forming pullulan-alginate solutions were carried out by Haake Mars rheometer (Thermo Scientific, Karlsruhe, Germany) equipped with a cone-plate geometry at 25°. Steady–state measurements were performed at a shear rate from 1 to 100 s^{-1}. Two dynamic studies were performed:

a) frequency sweep test, over a range of 0.1 to 10 Hz
b) amplitude sweep test at a constant frequency of 0.1 Hz, over a range of 0.05 to 400 Pa.

Storage or elastic modulus (G', Pa) and viscous or loss modulus (G", Pa) were monitored in the function of linear frequency and stress in order to obtain mechanical spectra.

3. RESULTS AND DISCUSSION

The rheological measurements have shown that obtained solutions display thixotropic behavior (Figure 3), and the viscosity of solutions decreases with increasing in pullulan amount.

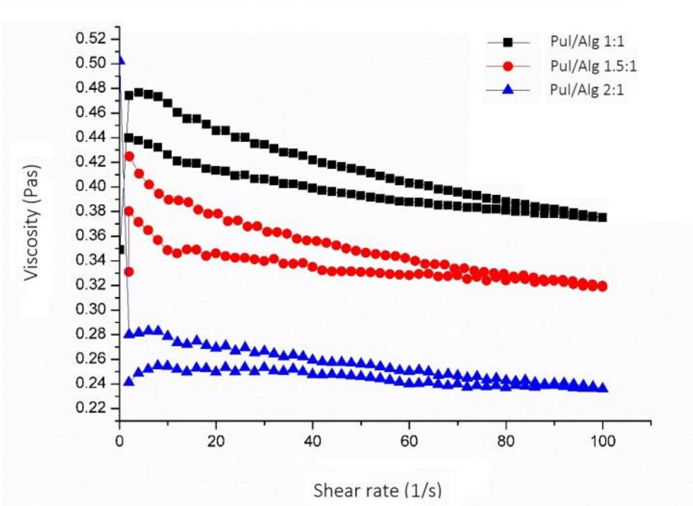
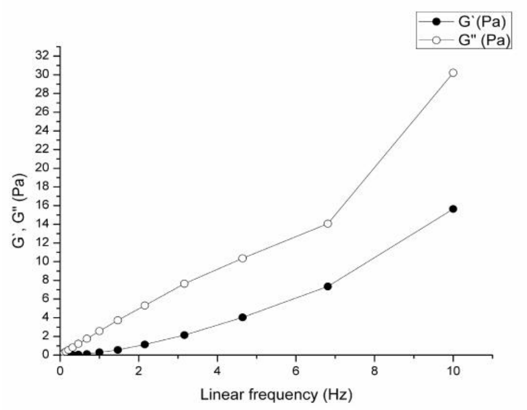


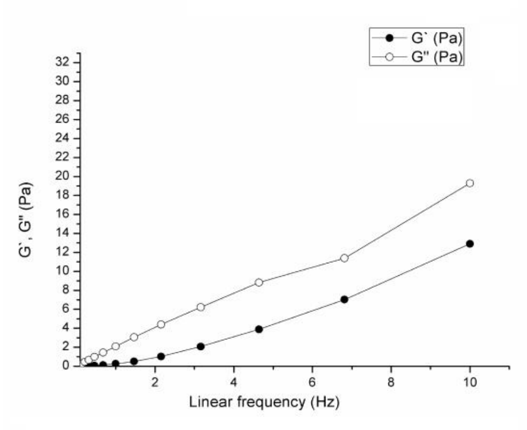
Figure 3: Steady rheological behavior of composite solutions at different Pull/Alg weight ratios

The values of elastic (G`) and viscous modulus (G”) increase with increasing in linear frequency. The greatest values of moduli are recorded for the sample with the lowest value of pullulan (1:1) (Figure 4 a). Results of the amplitude sweep test are shown in Figure 5. Elastic modulus values decrease with an increase in shear stress, while the viscous modulus is practically independent of stress over the whole investigated range (Figure 5). Considering the higher values of viscous moduli over the whole frequency and shear stress range, low and constant elastic modulus values, prepared solutions show typical viscous behaviour.



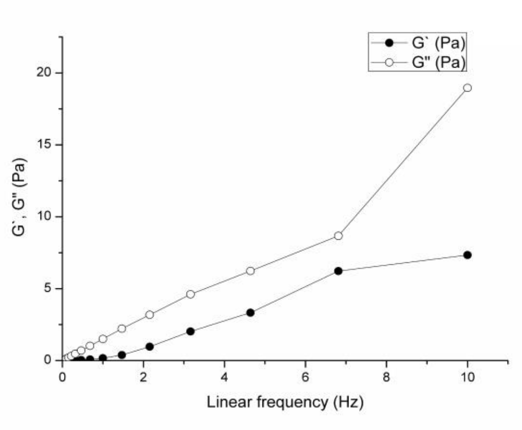
Pul/Alg 1:1

a)



Pul/Alg 1.5:1

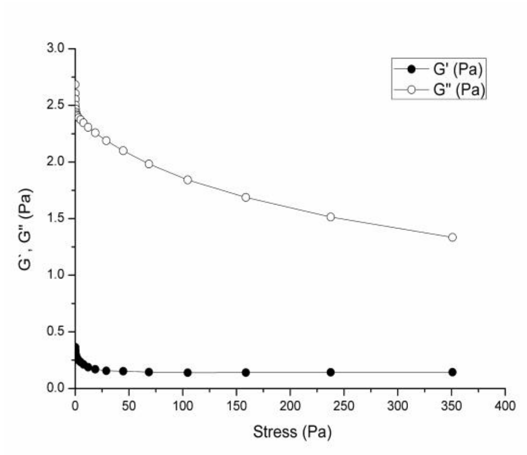
b)



Pul/Alg 2:1

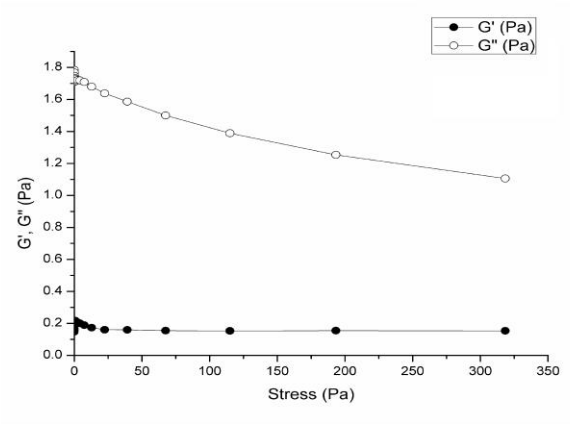
c)

Figure 4: Variation of shear elastic and viscous moduli versus frequency for pullulan/alginate film-forming solutions (a - sample Pul/Alg 1:1, b - sample Pul/Alg 1.5:1, and c - sample Pul/Alg 2:1)



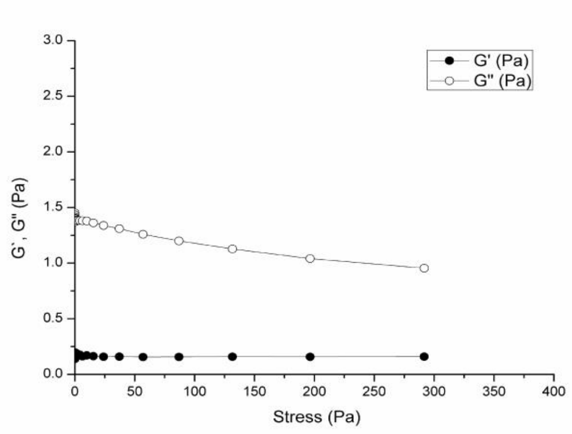
Pul/Alg 1:1

a)



Pul/Alg 1.5:1

b)



Pul/Alg 2:1

c)

Figure 5: Variation of shear elastic and viscous moduli versus shear stress for pullulan/alginate film-forming solutions (a - sample Pul/Alg 1:1, b - sample Pul/Alg 1.5:1, and c - sample Pul/Alg 2:1)

4. CONCLUSION

The main objective of this paper was to investigate the properties of different blending ratios of pullulan/alginate edible packaging films. The rheological behavior of the prepared film-forming solutions was evaluated. The steady shear and dynamic rheological measurements have shown that composite blend exposes non-Newton, shear-thinning behaviour. The results of dynamic rheological measurements have shown a dominant viscous behaviour. The greatest values of apparent viscosity and viscous moduli were observed for blend with pullulan/sodium alginate ratio 1:1.

5. ACKNOWLEDGEMENTS

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ARTIFICIAL INTELLIGENCE IN PRINTING

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Abstract: *Artificial intelligence has entered into many aspects of our lives – from virtual assistants and Netflix's recommendations, to fraud prevention and autonomous vehicles. In this paper we present an overview of the current use of artificial intelligence in printing industry. We discuss what does it imply for printers and clients, and how it might be used in the future. Since the main idea behind creating artificial intelligence is to mimic the capabilities of human mind, it does not surprise the fact that in printing it is mostly use for monitoring and decision making. Smart algorithms for choosing different layouts in order to minimize print waste, automated process control, creating targeted catalogues, are just a few examples. Even though the printing industry is one of the few not so disrupted by AI, it seems that the things are changing, and we might expect to see more of AI in printing in the near future.*

Key words: artificial intelligence, printing, automated process control, inspection systems

1. ARTIFICIAL INTELLIGENCE AND ITS BRANCHES

Artificial intelligence (AI) is usually defined as a branch of computer science whose goal is to build smart systems, those that can perform tasks in the same manner as humans. From the psychological point of view human intelligence is not a single characteristic, but a combination of different abilities: learning, reasoning, problem solving, perception, and using language (Colom et al., 2010). Hence, the goals of artificial intelligence are to simulate those traits to higher or lesser extent, depending on the application. AI can be divided into many branches such as machine learning, natural language processing, expert systems, robotics, speech and vision processing (Chopra, 2012; Ip, 2017). Of interest for this work are machine learning and vision applications (image processing and machine vision).

Machine learning main focus is to use the data and algorithm in order to imitate the way humans are learning (IBM Cloud Education, 2020). To be regarded as intelligent, a system should be able to adapt to the environment, to learn from the example data or past experience (Alpaydin, 2020). Machine learning relies on the statistics in building mathematical models, so the goal is first to train the model and later to make it efficient on the new set of data. Many times, this term is used interchangeably with deep learning, while in fact deep learning is a subfield of machine learning (IBM Cloud Education, 2020; Alpaydin, 2020). The main difference between the two is that in deep learning the system does not depend so much on human intervention to learn, meaning that most of the feature extraction and processing is automated (IBM Cloud Education, 2020).

Machine vision is another interesting branch of AI where the goal is to make a system able to detect and understand the scene. Machine vision systems use camera to detect the scene and computer vision algorithms to process images and make conclusions and decisions based on the results. Industrial application of machine vision includes: positioning, identification, verification, measurement, flaw detection etc. (Teledyne, 2022). Object recognition is not only important in industrial application, but also in everyday lives (face recognition for example) and the whole process usually employs some deep learning model.

2. AI IN PRINTING

2.1 Checking files for printing

Before printing starts, it is essential to check files for any potential errors. Evaluation can include both visual and automated inspection, where latter is usually done by the preflight option/software, which can detect and correct the most common errors (RGB objects, missing bleed, ink coverage, transparency, spot colors etc.) (Enfocus, 2022).

Some issues, however, were not so easy to correct. One of the examples are files with low resolution images, or small images that should be printed in large formats. If the original was not available in higher resolution, and there was not enough information to resize the image properly, the only solution used to be image replacement.

Today we can rely on AI to solve this problem. The algorithm behind Gigapixel AI (Topaz Labs, 2022a) is able to upscale and enhance low resolution image by up to 600%. It is based on machine learning where algorithm was trained with millions of photographs, in order to reconstruct instead of interpolate information (Topaz Labs, 2022a). This makes it a perfect choice for preparing small images for printing. Figure 1a shows the result of resolution improvement in case when extreme pixelation is caused by compression, while Figure 1b demonstrates recovering details of a very blurred face.

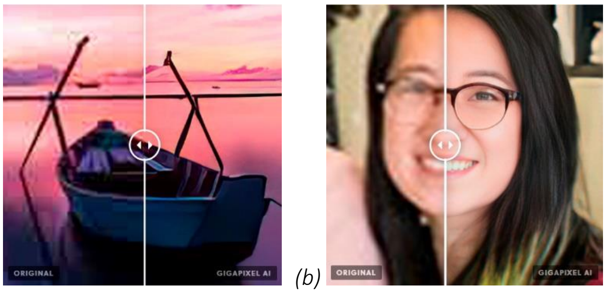
(a) (b)


Figure 1: Improving image resolution with Gigapixel AI – (a) correcting extreme pixelation, (b) recovering details and textures in low-resolution image (source: Topaz Labs, 2022a)

Topaz Photo AI, a new solution from the same company (Topaz Labs, 2022b), address not only the resolution problem but also noise, sharpness and focus. It assesses the image and automatically chose the right correction by first solving noise and sharpness, then performing face detection and enhancement in case there are faces in image and, at the end, increase the sharpness of the subjects in an image in order to create better visual focus (Topaz Labs, 2022b).

In addition to the abovementioned, AI can increase the list of things that can be evaluated in a print ready file. One of the most popular solutions are artwork proofing and proofreading. Artwork proofing uses so-called *visual inspection AI* where comparison between two documents is made. Either the print-ready or the step-and-repeat-file can be compared with the customer proof file (EyeC, 2022d; Vijau, 2021). Any difference is marked, alerting the operator. Similarly, proofreading systems that compares print ready document with various text sources are good solution for checking for any errors regarding text.

The biggest disadvantage of these systems is the necessity for the reference. In order to detect the flaw, system has to have an "ideal file" - approved artwork or the source text, which is not always the case. If the pre-press operator is preparing material for printing, the AI based solutions can be used to validate raw text data and correct any spelling or typographical errors. Some of these solutions can even correct the style and grammar, if that is what a customer would allow, of course. However, for artwork evaluation, if referent file is missing, still there is a need to rely on visual inspection done by a human operator, or some other software solution.

2.2. Process setup and quality control

Maintaining high print quality and consistency while increasing production speed and print runs is by no means an easy task for operators, and leaves no room for errors. It is essential to choose correct parameters for each printing process in order to ensure the best reproduction for chosen substrate-ink combination, as well as the fastest possible press setup. During the printing process, the errors should be spotted on time and the correction should be done as fast as possible. This is precisely why in print quality control there is a need for limiting human involvement, replacing the operator with a system that can detect errors and correct them on the fly.

If there are many parameters that had to be chosen before the print start, and that should be changed during the process, it is not easy for an operator to determine how each one of them influences the final result. Computers have no limit in that sense. AI algorithm can be fed with the huge number of parameters and the corresponding results, and can detect patterns that might not be obvious to a human.

Preset 2.0 implemented in Heidelberg Speedmaster presses is one of such examples (Heidelberg, 2022). Data from 600000 print jobs was used to train the algorithm which detect patterns, identify potential and generate basic settings for the press, autonomously and without human intervention (Heidelberg, 2022). Besides choosing the starting parameters, thanks to another AI solutions (namely Intellistart 3, Wash Assistant, Powder Assistant, and Color Assistant), the process is also controlled automatically (Heidelberg, 2022). During printing, the chosen initial setups and quality parameters are collected and evaluated, the patterns are found and learnt, and the results are used to optimize the production. Intelligent job changes are also possible, leading to the higher efficiency.

So-called *self-monitoring presses* enable adequate print setup entirely without human intervention. For example, Xerox iGen 5 is a press equipped with many sensors that send information to AI algorithm in order to automatically adjust the press (paper alignment, image quality and so on) for the best possible output (Pavlovic, 2018). Data about the press are sent back to manufacturer and analyzed in order to provide better performance, and to determine the necessity for software update or a service (Pavlovic, 2018). This personalized assessment provides longer lifespan of a press and more efficient production.

Besides color control, and other options mentioned previously, the quality control can be extended to many other parameters. It can be realized in the form of the inspection system, that can perform two tasks: identifying the error and changing printing parameters or compensating the defect when possible (CVisionLab, 2022; EyeC, 2022a). These systems can be incorporated offline and inline, where latter provide more efficiency. The system comprises of a camera and image analysis software that compares the original (digital master image) with the image of a printed page. Margins of errors are defined for every part of interest, following the preestablished tolerances for each printing process. The machine vision system can inspect the whole sheet or only the control stripe, make the adjustments where possible (ink setup for example) or informing the operator in case action is needed (EyeC, 2022a).

Inline systems can be implemented both of sheetfed and web presses and can detect color variations, missing inks, registration problems, streaks, misprint spots, hazing, doubling, hickeys, scratches and other errors that commonly occur in the process (EyeC, 2022a; EyeC, 2022b; IVS, 2022). Reproduction of text and artwork can also be assessed. Some systems can check the readability of printed text, verify pharmaceutical traceable text (EyeC, 2022a; IVS, 2022), assess content conformity with approved artwork and provide bar codes verification by evaluating contrast, defects, decodability, edges, reflectance etc. (CVisionLab, 2022).

Registration errors, as well as color variations, can be corrected automatically in case the manufacturer provide closed loop register control (Heidelberg, 2022; Pavlovic, 2018). The outcome is a waste reduction, faster setting up and running the press, as well as minimal involvement of press operator. As concluded by Heidelberg: "*When it comes to configuring intelligent job changes, ink profiles, washup programs, or other complex, dynamic parameters, an intelligent algorithm will always be more effective, more efficient, and faster than a human*." (Heidelberg, 2022)

Apart from the abovementioned, machine vision systems can also be employed to keep track of production aspects not directly related to printing. Cameras in conjunction to AI can monitor the environment and alert in case of safety rules violations, thus preventing the accidents. Under-utilized resources, uncontrolled access violation and other aspects related both to productivity and safety can also be controlled (Vijau, 2021).

2.3. Finishing inspection systems

Machine vision systems find their place in finishing inspection systems as well. They can be used to verify folding cartons, labels, leaflets, flexible packaging, multiple-page samples, or cylindrical packaging (EyeC, 2022c). The same errors as in printing can be assessed, as well as cracking, presence of saddle stiches, glue integrity on perfect bound products, coatings uniformity etc. (FSI, 2022).

Another interesting application is Braille inspection system (EyeC, 2022e) that assess the quality of embossing, content, layout and placement of Braille in accordance to relevant standard.

2.4. Workflow solutions

As computers can process huge amount of information, it is no wonder that AI solutions are also found in print production and workflow solutions. Hence, apart from software for quality control and process setup, there are more complex solutions integrating and automating each step of the printing process, from job submission, management, imposition, preflight, to printing, finishing, job accounting etc. (Xerox, 2022; Vijau, 2021).

In job submission, for example, smart software can monitor machine load and detect which press would be the best option for a current job (Xerox, 2022; Vijau, 2021). AI is also successfully used to quickly analyze different document layouts and determine the best option which would minimize the paper waste (Xerox, 2022). The automation provided by AI increase productivity and minimize errors, leading to the more efficient production.

2.5. AI in 3D Printing

Even though 3D printing is an additive manufacturing, and not printing in a classical sense, we will just briefly comment the application of AI in this important domain.
In 3D printing AI can be used for remote defect detection (Paraskevoudis, Karayannis & Koumoulos, 2020), to control the material flow (Brion & Pattinson, 2022), as well as for automating the workflow (AMFG, 2022). Software packages based on AI are also able to evaluate and optimize design files by implementing machine learning in generative design approach (Vasilev, 2022). 3D models are created and optimized based on user requirements, ending up with the most efficient solution for a given application. In this way, significant reduction both in design complexity and material usage can be achieved.
A neural network tool was also successfully used to propose entirely new material for 3D printing, such that satisfies requirements related to application, production and estimated costs (Conduit et al., 2019). By learning the properties of many different materials and the effect they have on the final product, the algorithm proposed new nickel-based alloy that is more suitable for a given application than any commercially available material.

2.6. Relationship with clients

Processing vast amount of information is also useful for personalizing printed products, as well as for direct mail and catalogues (Pavlovic, 2018). Adequate analysis of customer data allows creating mailings that better reflect customers' interests and needs, increasing the sense of connection with the company.
Better mutual connection can also be established through good communication. Failure to understand what customer wants can be costly to the company. Clearly determining the customer expectations is especially important today, when most of the "talking" is done via messengers.
Apart from chat bots, that are widely integrated in websites and mobile apps (Vijau, 2021), pre- and post-sales communication in printing sector can also be done via print bots. Pioneered by HP, print bots are essentially improved versions of chat bots offering the guidance through the whole process of print ordering. While chatbots assist customer by replying the questions, print bots are doing much more – they allow customer to upload photos, preview the chosen products (by creating a realistic mockup), make changes and ultimately send the file to the chosen printer or a printshop (Vijau, 2021; Zebra Instant, 2018). And all that without leaving the messaging app (Figure 2). Most of print bots are connected with print-on-demand companies that take care of order fulfilment (Zebra Instant, 2018).

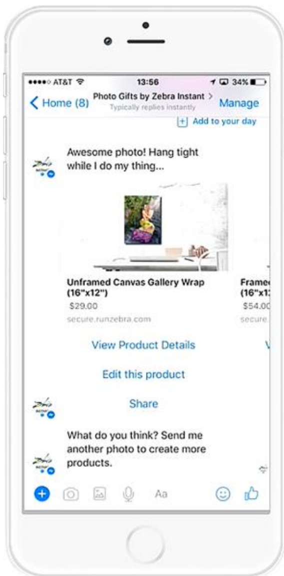


Figure 2: Zebra Instant print bot interface (source: Zebra Instant, 2018)

The potential of print bots in its early days was acknowledged by Facebook, that partnered with HP and included its print bot in beta version of Messenger in 2016. Even though this collaboration is now over, the potential of such solutions for quick ordering of printed products is undisputed.

3. CONCLUSION

Unlike other industries, up to now printing has been rather slow in adopting AI. However, things are changing, and we are seeing more of automatization, personalization and problem solving done by AI in this sector. From the inspection systems to print bots, AI solutions are gaining more importance, mostly due to their unpreceded speed and accuracy. With the burst of AI in all sectors, the prices are going down, so even the small print shops can benefit from it.
It is clear that the printing devices are evolving to leverage AI, IoT (internet of things) and cloud solutions. This will most certainly benefit users, but only if security and privacy issues are considered and addressed properly. Looking of the trajectory of a change, it is reasonable to assume that all the operations that can be, will be automated in the future. Increasing print speed and quality, while reducing waste and costs will still be a priority, as well as improving user experience.

4. ACKNOWLEDGMENTS

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INFLUENCE OF MULTILAYERED FILMS CONTAINING CELLULOSE NANOCRYSTALS ON THE PROPERTIES OF JAPANESE PAPER

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Abstract: *Cultural heritage objects are precious witnesses of the past, so our mission is not only to preserve them for future generations, but also make them available or open to the public. Among most fragile historic materials are paper-based materials. They are susceptible to various forms of damage and deterioration, and their preservation presents a challenging task for conservators. In recent years, the use of advanced materials with unique properties has been growing at an increasing rate, even in the traditionally slow-changing cultural heritage sector.*
This study models how historic paper would be affected by application of multiple coating layers containing different quantities of cellulose nanocrystals (CNCs). In our study, a 4 % CNCs aqueous suspension was used to treat the samples. In order to form a uniform layer, bar-coating method was used, and in addition, a specific layer thickness was formed in both single and multiple passes. The prepared samples were analysed for their optical properties (colour coordinates, yellowness, opacity, gloss), physical properties (Taber stiffness, weight, thickness) and surface properties (roughness). An increase of wet film deposit thickness (single layer applications) resulted in an increase of paper thickness, grammage, gloss, opacity, yellowness, the ΔE value and Taber stiffness, while its average surface roughness decreased. Multi-layer applications have gradually decreased paper thickness, while Taber stiffness remained unchanged.

Key words: Cellulose nanocrystals, nanocellulose, paper conservation, Japanese paper, coatings

1. INTRODUCTION

Cultural heritage objects are precious witnesses of the past, so our mission is not only to preserve them for future generations, but also make them available or open to the public. Among most fragile historic materials are paper-based materials. They are susceptible to various forms of damage and deterioration (Aleksić, Cigula & Pasanec Preprotić, 2022), and their preservation presents a challenging task for conservators. In recent years, the use of advanced materials with unique properties, such as nanocellulose, has been growing at an increasing rate, even in the traditionally slow-changing cultural heritage sector.

The term nanocellulose (NC) refers to nanoscale biomaterials derived from cellulose – an abundant, renewable, biodegradable and sustainable material. Apart from physical and chemical properties inherited from cellulose, nanocellulose possesses other unique properties, interesting to various research fields and industries. In order to achieve its optimal performance in a specific application, nanocellulose is usually modified.

Of the three main types of nanocellulose materials (cellulose nanofibers, cellulose nanocrystals and bacterial nanocellulose), cellulose nanocrystals (CNCs) are most commonly used (Huang, Xiaozhou & Dufresne, 2019). CNCs are rod-like nanoparticles with an average length of 100 to 200 nm and a diameter ranging from 5 to 20 nm (Ngo, Danumah & Ahvazi, 2018). They are traditionally prepared by acid hydrolysis of cellulose fibres with a strong acid (Mautner et al., 2018), although alternative methods are actively being developed in recent years. As properties of nanocellulose are affected by both the cellulose source and treatment conditions (Santmartí & Lee, 2018), method development for the preparation of crystals has become an intense research topic (Kontturi, 2018).

CNCs are known for their large specific surface area, thermal stability, low density, high crystallinity, great elastic modulus (Huang, Xiaozhou & Dufresne, 2019; do Nascimento et al., 2021), excellent tensile strength (Grishkewich et al., 2017), as well as optical transparency (Huang, Xiaozhou & Dufresne, 2019). These properties make CNCs a potentially desirable material for a wide range of applications – among which is conservation of cultural heritage materials. However, successful introduction of new materials to the heritage field requires thorough analysis and validation of both short- and long-term consequences of such application, as some of the materials can damage the historic object or change its appearance.

In recent years, all three types of nanocellulose have been evaluated for several treatments in conservation of wood (Walsh et al., 2017; Hamed & Hassan, 2019; Walsh-Korb & Avérous, 2019), painting canvas (Kolman et al., 2018; Nechyporchuk et al., 2018), silk (Wu et al., 2012) and notably – paper (Dreyfuss-Deseigne, 2017; Dreyfuss-Deseigne, 2017a; Völkel et al., 2017; Ghorbani, Samanian & Afsharpour, 2018; Operamolla et al., 2021). Previous studies have shown that CNCs are a promising material for consolidation of historic paper (Operamolla et al., 2021), and a natural polymer enhancer (Li et al., 2021), also omnipresent in coatings, adhesives, and within paper and pulp industry. Although nanocellulose as a coating agent is still being widely researched, it is well known that both thickness and formula play a crucial role in its performance (Li et al., 2021). However, studies in paper conservation have been dealing more with issues such as surface functionalization and removal of CNCs (Operamolla et al., 2021) and haven't considered in detail how paper properties are affected by different amounts of CNCs present. For these reasons, we aimed to investigate how different CNC quantities and layering affect optical, physical and surface properties of paper. It is expected that different quantities of CNCs and order of application of the layers will affect properties of paper and highlight benefits and drawbacks of both single- and multi-layer application solutions.

2. MATERIALS AND METHODS

All measurements were undertaken at 25 °C and 50 % RH.
Japanese handmade paper Takogami B (43 gm^{-2}, 70 % Kozu + 30 % Pulp, felt side (Japico-Feinpapier-VetriebsgmbH)) was used as the model paper.
The NC from this study originated from tree cellulose and was supplied by Nanocrystacell as a ready-made 4 % CNC aqueous suspension (hydrophilic, 90.3 % crystallinity, 1.04 g/cm^3 density, 10 – 15 mm wide and 150 – 300 long).
pH value is a crucial parameter for successful application of new materials and its compatibility with the original materials is of utmost importance. Another parameter that requires compatibility between the materials is viscosity, which is described as the measure of a liquid's resistance to flow. Low viscosity is a desirable property of coating materials, as it enables better flow into the pores of the substrate (Horie, 1987; Conservation Unit of the Museums and Galleries Commission, 1992). However, aqueous dispersions of CNCs are known to form gels even at lower concentrations (Ngo, Danumah & Ahvazi, 2018). To characterize suspension properties, we performed pH measurements and dynamic viscosity measurements using a WTW 340 pH meter and a RheolabQC rotational rheometer (Anton Paar GmbH). The viscosity was determined in a constant shear rate mode with the value of 0.02 s^{-1}.
CNC suspension was first redispersed with a magnetic stirrer set to 1000 rpm for 5 minutes, before ultrasonication with a Hielscher UP100H homogenizer. Ultrasonic time was divided into two 5-minute cycles, with amplitude control adjusted to 100%. Although commonly utilized application methods in paper conservation include a brush, a spray or a syringe, we utilized a non-conventional coating method with controlled speed and pressure to achieve a repeatable wet film deposit (RK Print Coat Instruments, 2022). The suspension was applied onto the paper substrate with a pipette. The K Control Coater, model 202 (RK PrintCoat Instruments Ltd) was used to spread the suspension at the speed of 4 m/min. In order to obtain different wet film deposits, we used coating bars #2 (12 µm), #3 (24 µm), #5 (50 µm) and #8 (100 µm). Some samples were coated in a single pass (single layer - SL) and others by gradually applying coating layers (multi-layer - ML), as recommended (Baglioni, Chelazzi & Giorgi, 2015). After applying each layer, samples were left to air dry. The wet film deposit thicknesses and coating bars used are shown in Table 1. Weight and thickness of the dry samples were measured with a digital analytical electronic balance (Mettler Toledo XS205, sample size 38x80 mm) and an EnricoToniolo DGTB01 digital micrometer with the weight pressure of 49.03 kPa.

Table 1: Wet film deposits

	Wet film deposit (µm) / coating bar (No.)			
Single layer (SL)	12/2	24/3	50/5	100/8
Multi-layer (ML)	12/2	24/2+2	48/2+2+3	96/2+2+3+3+3

2.1 Optical properties

To determine if any of the visually undesirable effects had occurred due to the application of CNCs, we investigated the associated parameters (CIE LAB coordinates, opacity, yellowness and gloss). Yellowness is commonly mentioned in relation to paper or pulp in need of a bleaching treatment, discoloration of aging paper (Feller, 1987) and paper exposed to different conditions (Johnston-Feller, 2001), but should also be considered when applying new materials. Since Japanese paper is of natural colour (slightly yellow), we measured both yellowness (according to ASTM E313) and opacity, using a Techkon SpectroDens device with measuring geometry of 0°:45° (Techkon, 2021). The measurement settings included the following: standard illuminant D65, a standard observer angle of 10 degrees and M1 measuring conditions. The unit was calibrated to absolute white. To measure opacity, we used a standardized ChromaChecker B&W Backer, in compliance with ISO 5-4 and ISO 13655.

CIE LAB coordinates (L* a* b*) were also measured with a Techkon SpectroDens device using the following settings: illuminant D50, a standard observer angle of 2 degrees, M1 measuring conditions and the sample on a white backing. The coordinates were used to calculate the colour difference (ΔE_{ab}) (Mokrzycki & Tatol, 2011).

As excessive shine can change the overall appearance of the paper surface, it is necessary to maintain acceptable levels of gloss during the conservation treatment. We investigated gloss levels using an Elcometer 407 Statistical Glossmeter with the standard measurement angle of 60°.

2.2 Surface roughness

Gloss, among other factors, depends on surface roughness (Wang et al., 2009). Surface roughness is an important parameter in determining the amount of coating applied (Pino, Pladellorens & Colom, 2010; Alam et al., 2012), as well as the method of application (Pino, Pladellorens & Colom, 2010). As applying coating layers also changes surface properties of paper, we measured average roughness (R_a) of the samples using a MarSurf PS 10 device (Mahr Federal Inc.).

2.3 Mechanical performance

A coating layer is intended to provide a certain mechanical reinforcement of the weakened paper, although enhanced structural strength is not always the primary goal of conservation treatments. Either way, the treated paper should retain some elasticity to avoid breakage. However, stiffness of the material, also known as an elastic modulus, is described as the resistance to being deformed elastically (Conservation Unit of the Museums and Galleries Commission, 1992). To measure the stiffness of paper according to the TAPPI T 566 method, we utilized a Lorentzen and Wettre bending tester (code 160). The instrument settings included the following: touch speed of 5°/s, touch force of 2 mN and bending length of 25 mm.

As reversibility of the treatment with CNCs has been established by previous studies (Operamolla et al., 2021), we didn't include it in our research. It should also be noted that actual treatment of historic paper would require an analysis of both composition and degradation status prior to the application (Baglioni, Chelazzi & Giorgi, 2015).

3. RESULTS AND DISCUSSION

All measurements were repeated for at least 6 times, and tables and figures in this section report average values and standard deviations.

The pH measurement of the suspension resulted in a neutral value (pH value = 7.32), which is recognized as safe for use in paper conservation (Henry et al., 1989). The viscosity of the 4% aqueous suspension following the ultrasonication resulted in 890.4 ± 8.1 mPa·s, which is labelled as low viscosity (Horie, 1987). To achieve good penetration into the substrate, the suspension is expected to have low viscosity, as well as high surface tension (Conservation Unit of the Museums and Galleries Commission, 1992).

As shown in Figure 1, weight and thickness of the Japanese paper used in this research varied. The initial grammage was calculated higher than specified, measuring 46.83 gm^{-2} for paper coated by SLs and 49.30 gm^{-2} for paper coated by MLs. Application of the coatings had also increased the grammage. However, an increase of grammage proved to be more dramatic in the paper containing SLs (up to 5 gm^{-2})

Although the grammage of nearly all the samples increased with layer thickness, it seems that thickness itself decreases with addition of layers (ML).

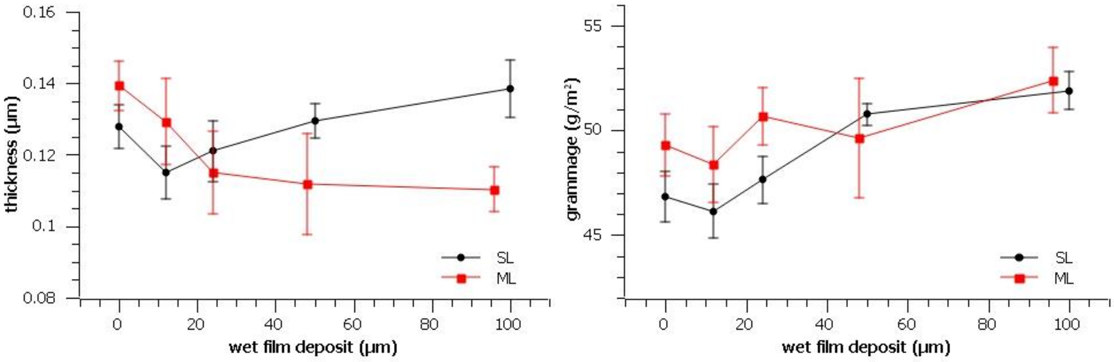

Figure 1: Changes in thickness (left) and grammage (right) of the samples in relation to wet film deposit thickness

Figure 2 shows changes in average roughness (R_a) due to the addition of coating layers containing CNCs. It seems that both SL and ML applications result in a decrease of roughness of the Japanese paper. However, when compared to the SL applications, the ML applications had decreased paper roughness more dramatically. These findings are consistent with previous results, in which ML applications had also resulted in a decrease of paper thickness.

The decrease in both thickness and average roughness of paper could be a result of the coating's penetration into the pores and crevices of the paper. In ML applications, this effect is even more dramatic, as each layer dries and forms a new surface to which the next layer is deposited.

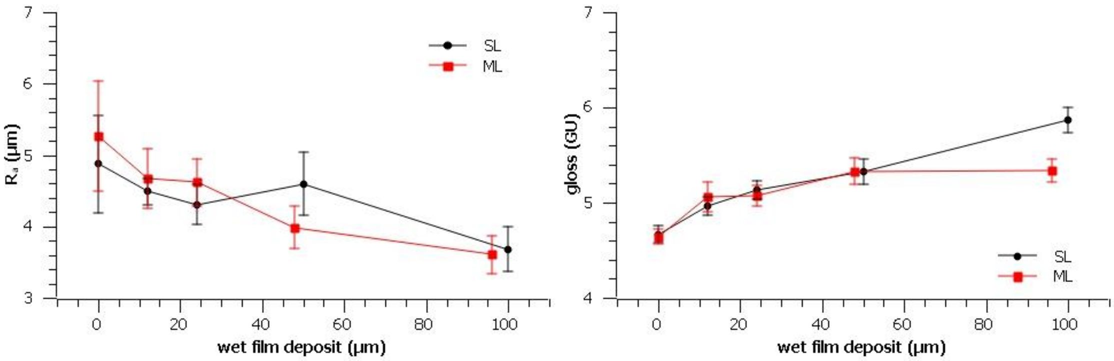

Figure 2: Average roughness R_a (left) and paper gloss (right) in relation to wet film deposit thickness

The data shown in Figure 2 indicates that both SL and ML applications have little effect on the gloss of Japanese paper. As expected, larger amounts of the CNCs will slightly increase gloss (up to 2 GUs).

Figure 3 shows that larger amounts of CNCs also result in colour changes. These changes manifest themselves in the form of darkening of the samples, causing the decrease of the CIE L* coordinate by 2 units (from 89.28 to 87.33 on paper gradually coated up to 5 times). Additionally, the colour of the samples shifted to even more yellow, causing an increase of the CIE b* coordinate by nearly 2 units (from 13.70 to 15.58 on the sample with wet film deposit of 96 µm).

Increased yellowness and darkening of the material have also been observed in other polymers used as consolidation agents of wood (Horie, 1987).

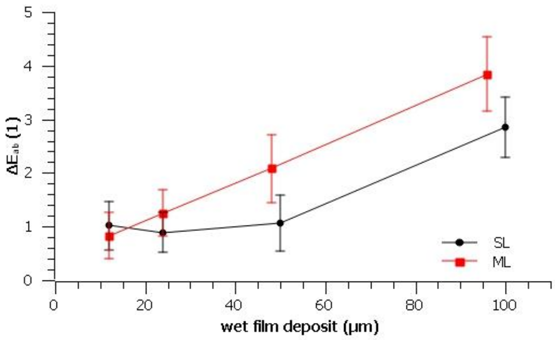

Figure 3: Color changes in relation to wet film deposit thickness

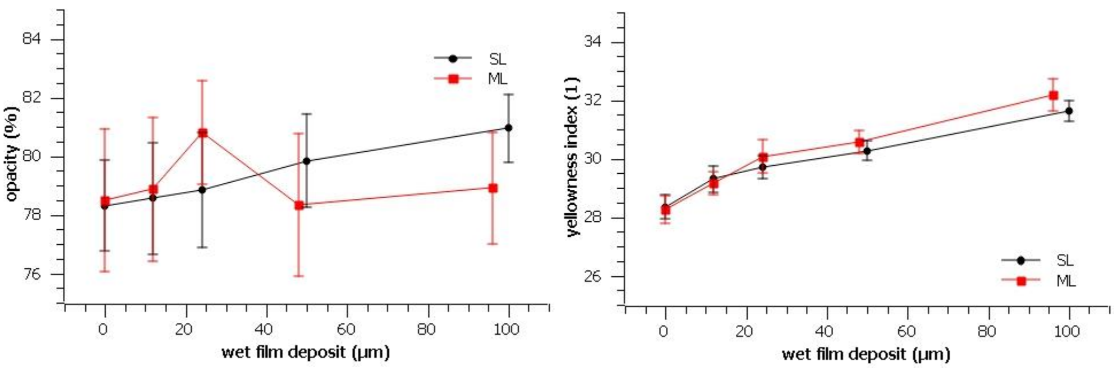

Figure 4: Opacity (left) and yellowness index (right) of the samples in relation to wet film deposit thickness

The data show that the opacity of the paper samples coated by a single layer of CNCs has increased with wet film deposit thickness but does not change for samples coated in MLs (Figure 4, left). This occurrence could be a result of better incorporation of CNCs into the paper structure, as seen in the aforementioned results for thickness and surface roughness (Figure 1, Figure 2). It should also be noted that standard deviation of the opacity measurements is larger than that of other measurements, which can be attributed to the non-uniform structure of the handmade paper.

We also observed that the yellowness index (YI) increases with the increase of wet film deposit thickness in both the SL and the ML coatings (Figure 4, right), which is consistent with colorimetric change ΔE_{ab} (Figure 3).

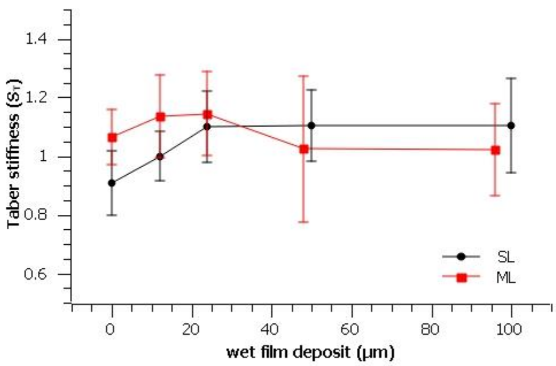

Figure 5: Taber stiffness of samples in relation to wet film deposit thickness

The results of Taber stiffness measurements shown in Figure 5 indicate that the stiffness of the samples coated by a single layer of CNCs increases up to a certain amount of the crystals added (wet film deposit of 24 µm), beyond which it remains constant. However, the stiffness of the samples decreased after the same amount (wet film deposit of 24 µm) was gradually added (MLs). It should also be noted that changes in the stiffness values of the samples vary from 0.1 S_T (ML coatings) to 0.2 S_T (SL coatings).

4. CONCLUSIONS

We conducted this research to determine the influence of different quantities of CNCs on the properties of Japanese paper, as well as benefits and drawbacks of both single- and multi-layer applications.
The results of the research showed that:

- An increase of wet film deposit thickness (SL applications) resulted in an increase of paper thickness, grammage, gloss, opacity, yellowness, the ΔE value and Taber stiffness, while its average surface roughness decreased.
- ML applications have gradually decreased paper thickness, while Taber stiffness remained unchanged. The decrease in paper thickness could be explained by penetration of the coatings into the pores and crevices of the paper. However, further research of the wetting properties and surface tension of the suspension needs to be conducted.
- The ΔE values for all coated samples did not exceed 3, which is considered the limit beyond which the human eye notices the difference. However, the ΔE values of the samples coated by a single layer of CNCs were lower compared to the ones coated by MLs.

Based on the results, it could be concluded that, although single- and multi-layer applications have affected paper properties differently in the short term, their long-term influence on paper is yet to be evaluated after performing accelerated aging tests.

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CIRCULAR ECONOMY THROUGH CUSTOMISED 3D PRINTED PRODUCTS: A CASE OF SOUVENIR

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Abstract: *Nowadays, the circular economy model is basically built on the efficient use of resources and the maximization of the product's lifetime as long as possible, by recovering, reusing and recycling existing materials and products. Comparing circular economy with the new trend of customized products, there is an opportunity for the production of personalized products with less associated environmental costs. As a key factor can be considered the 3D printing technology, which is already widely accessible, offering customisable possibilities without expensive tooling based on individual specifications. Furthermore, the opportunity for recycling and degradation of different plastic materials and the creation of a filament for 3D printers has large impact on the product life cycle. The aim of this study is to highlight the management of recyclable plastic by creating new customized products. Souvenir industry has been chosen as a representative example which covers a big number of different products offering simultaneously a mass customized character.*

Key words: Circular Economy, Customized Products, 3D Printing, Souvenir

1. INTRODUCTION

The circular economy as a part of sustainability has as main target to protect the environment, improve economics, and promote social justice. Circular economy seeks to completely improve resource efficiency by reducing the waste and keeping materials, products, and services in circulation for as long possible. Nowadays, It is one of the most powerful concept to address the climate crisis, and material recovery. The whole concept is based on the replacement of the current linear model of 'take – make – waste' by the circular model of 'make –use -recycle'. The development of new processes and technologies creates opportunities for changing manufacturing activities such as the supply and flow of materials with many possible sustainability benefits (Gebler, Schoot Uiterkamp & Visser, 2014). Those changes promote Circular Economy by improving the efficiency of the resources. As a representative example can be considered the technology of 3D printing, also known as additive manufacturing.

Nowadays, different technologies permit objects to be scanned, manipulated into files and then to be printed (Kietzmann, Pitt & Berthon, 2015). The related technology is not anymore so expensive and specialized, conversely has become accessible, both in price and the use with extremely user-friendly interface simple and safe enough to use in a domestic setting. The advantage of the technology use is that it generates opportunities to produce customized products. In the case of souvenir visitors are able to adapt, modify or transform existing souvenirs or to choose new one, totally different from the existing. As the technology is becoming more and more available, it may be possible to consider souvenirs as dynamic objects which involve self-development and creativity by developing customized objects rather than mass produced items.

2. LITERATURE SURVEY

This technology of 3d printing as opposed to the other manufacturing methodologies, which are based to subtractive methods, is a process of creating a three-dimensional models layer-by-layer using CAD systems. This additive process whereby layers of material are built up to create a 3D part has as a result to create less material wastage. 3D printing process can use a variety of 3D printing materials, including thermoplastics, metals, resins and ceramics building models with different processes such as binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and VAT polymerization (Izdebska-Podsiadły, 2022). While the other manufacturing techniques are still more suitable for high volume and much faster mass production, 3D printers becoming faster and faster allowing to work on larger scale production. Furthermore, the low cost of 3d printers promotes the use of this technology into homes, universities and different companies. The continuously development of 3d printing enhanced the research for the controlling mechanical properties of 3D printed parts (Kyratsis & Tzetzis, 2018; Meretis et al., 2022) such as tensile yield strength, modulus of elasticity, shear yield strength, hardness etc.. Furthermore, a comparison between virgin material of filaments and recycled material showed that both filaments are almost similar to the mechanical properties of 3D printed samples. This fact promotes additional development in recycling 3D printed filament (Mikula et al., 2021; Lanzotti et al., 2019), mainly by managing to obtain recycled filament from waste and used it for the creation of samples and prototypes. Despeisse et al. (2017) proposed a research agenda to determine enablers and barriers for 3D printing to achieve a circular economy. They explored how can a more distributed manufacturing system based on 3D printing create a circular economy of closed-loop material flows and what are the barriers to a circular 3D printing economy. They concluded that the characteristics of 3D printing align well with sustainability and circularity principles and hold significant promise for moving society in a more sustainable direction. The implementation of 3D printing into the industrial system delivers triple bottom line benefits. Clemon & Zohdi (2018) developed a framework that identifies the stress contributions, and their variation, to reduce product development time and costs, which could greatly speed up material recycling and reuse for improved infrastructure materials, low-cost 3D printer filament, and reduced waste towards a more circular economy.

Souvenir industry covers a huge number of different samples that can be created. Souvenir is an object related to memories and psychological connections which owner has from a past experience. As souvenir can be considered any object that purchased and transported home by any traveler and offers him the opportunity to transform the intangible moments and feelings during a visit into tangible memories. Souvenirs are the tangible reminders of unique moments and occasions. Souvenirs are an important part of the tourist economy and many people are directly and indirectly involved in their production, distribution and sale with most of them be related with local produced objects with traditional methods. As 3D printing is a continuously developing technology, 3d printed samples like souvenirs can be considered as dynamic objects which involve visitors for the development of customized objects. Anastasiadou & Vettese (2019) proposed the 3D printed souvenirs as the new type of souvenir as they examined visitor preferences and managers views on 3D printed souvenirs that were mass produced but individualized within a heritage retail environment. The visitors were able to interact with the digital making process. The findings suggest that while there is interest in designing and personalizing souvenirs using new technologies, there are also intellectual and ethical challenges which need to be addressed. Qiuxia, Rahman & Wenhong (2022) examine the development and strategies of souvenir design and its future directions. They reported the outcomes of a thematic review analysis examining souvenir research from a design perspective, addressing the knowledge and methods required in practice-based souvenir design. The result suggests among others that future research trends in souvenir design should focus on customer-oriented product design and sustainability for promoting local culture and economies.

3. PROPOSED METHODOLOGY

This study is based on the replacement of a portion of virgin PLA by a recycled HDPE (High Density Polyethylene) from used bottle caps to produce 3D printing samples. Three different machines were used, a shredder, a dryer, and an extruder with a puller. In the beginning the bottle caps were cleaned as it is critical that the shredding is done with clean HDPE without any contaminants. The cleaning was done with hot water and cleaning fluid for deleting any labels that caps may have. When the bottles were fully cleaned, they were left to dry. Then, the caps were placed into a shredder (SHR3D-IT shredder), to converted into small granules. Shredder must be cleaned properly in order to not contain any old material from previous use. Contaminated granules with other materials may give bad results in the final filament. The next step is the elimination of any moisture complication that may occur within a polymer. Moisture can affect seriously the quality of the produced 3D printing filament. For this reason, we used the AIRID polymer dryer (approx. 50°C inside the chamber) where the amount of the granules dried for three hours improving with this way the properties of the produced material by the elimination of moisture. After the mix of 40% of recycled HDPE and 60% pure PLA the amount of the material placed to the COMPOSER Series 450 filament maker from 3Devo. 3DEvo's extrusion machine allow to transform plastic pellets (new or recycled) by warming and melting the granules pushing them in order to extrude filament with 1.75mm diameter in the temperature of 220-230oC into a quality 3D printing filament. Figure 1 illustrates the steps of the described process.

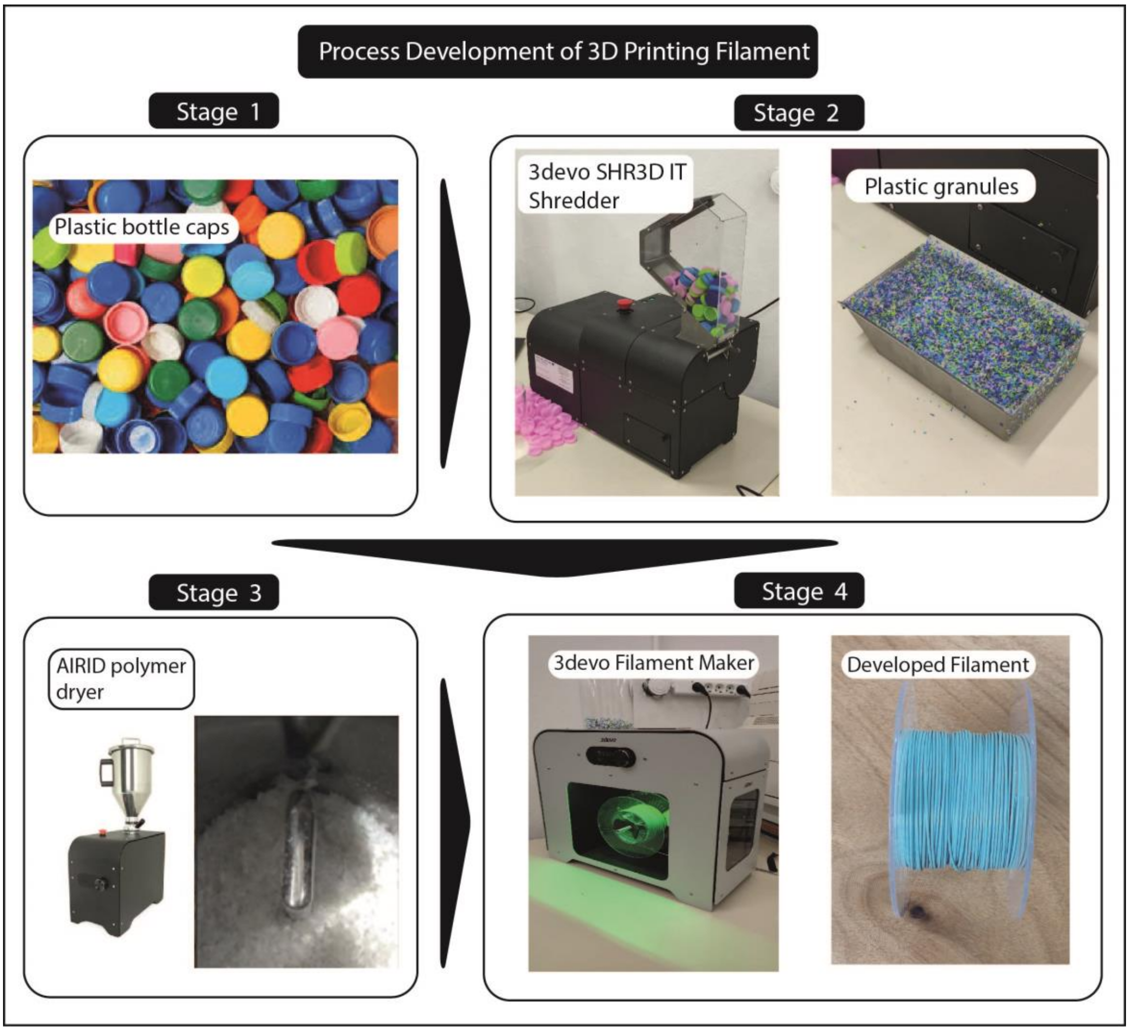

Figure 1: Manufacturing process 3D printing filament.

4. CASE STUDIES

According to User Centered Design (UCD) process users are at the center of the product design. User's requirements, objectives, and feedback are now necessary in the design process where the satisfaction of the user's needs and wants considered as a priority. Every decision during the process is assessed according to whether or not it delivers value to the users. Furthermore, User-centered design gives a way of adding an emotional impact into the products. Based upon technology is now feasible the user involvement with a limited experience in the editing and creation of designs and customized parts which are difficult or impossible for traditional methods to produce.
3D scanning technology rebuild all the necessary information about physical objects in three dimensions in a digitally world with precise dimensions. The scanned data can be used for the analysis, design and development. This technology offers a lot of opportunities for customization. There are many facilities that allow users to choose or scan a 3D model and take back their own 3D printed copy model. The combination of 3D scanning and 3D printing technology can produce actual object archetype without the need of conventional techniques. Products of different sizes can be 3D scanned and be printed with the exact dimensions. The development of any prototype can be easily possible. 3d scanning done with the help of DAVID SLS-3 scanner. DAVID SLS-3 scanner uses the structured light 3D scanning technology generating fast colored 3D scans with scan size between 60-500 mm. The equipment includes also a HD Video projector with a large focus range and stable glass calibration panels. The 3D scans can be exported into common 3D file formats for processing in other applications such as 3D printing, archeology heritage, works of art, computer animations etc.

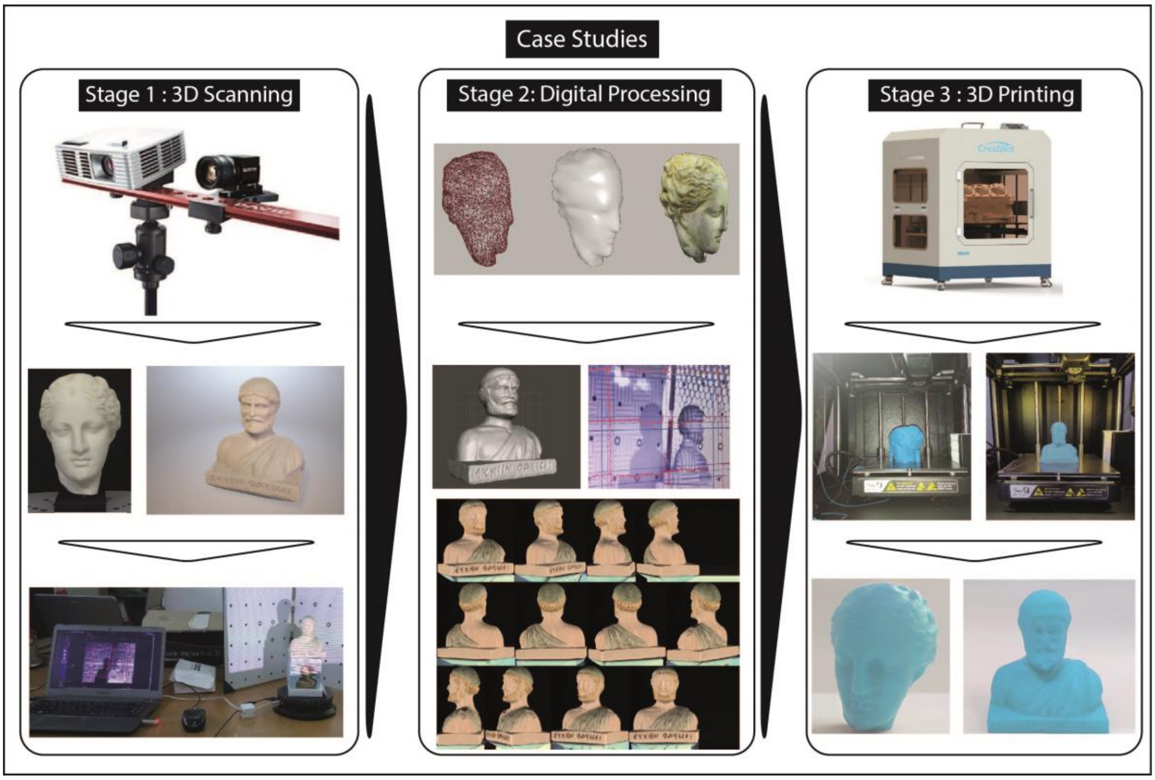

Figure 2: Case studies development.

A prototype design tool Meshmixer Autodesk, Inc. software used for the creation of 3D high-resolution dynamic triangle meshes and for checking the models for printability and orientation. This kind of tool efficiently ensure the quality of 3D models by recognizing the issues before it proceeds to print.

A Creatbot D600Pro 3D printer was used for the creation of souvenirs. Its feeding system support high-speed printing, accuracy can reach high to 0.05mm and Nozzle Temperature Up To 420 ℃. There are two extrudesr with the one of them equipped with 260°C hotend, and It is able to print with PLA, ABS, Nylon, Carbon fiber, etc. and the other one equipped with 420°C hotend which is made of martensite steel is able to print high performance materials. In this study, as representative examples have been developed products like the 3d printed statue of Hygeia, an ancient Greek goddess who ensuring good health for body and soul and a statue of 'Odysseus the ingenious' a king of ancient Ithaca, Greece (Figure 2).

5. CONCLUSIONS

Circular economy is built in the renewal of the components and materials. It manages the waste as a part in the manufacturing process so decreases the production of the pure materials. Materials, parts and components are used to regenerate other products as can be repaired, reused, reconditioned, and finally recycled. Nowadays, the matter of plastic recycling has become one of the most important concerns of environmental protection and waste management. The waste materials as a source of materials for filament production for 3D printing is beneficial both economically and environmentally. They reduce material costs, CO2 emissions and energy consumption. Recycling plastic waste has a great potential and benefits but needs investments and consumer knowledge. The On-demand 3D printing can offer a database of souvenirs that can be send by e-mail and then be created by 3D Printers. The no need of transportation or standard production methods the object carbon footprint is reduced to the minimum. As tourism industry grows souvenirs are becoming critical for promoting country's image and culture. This study proposed the way some of souvenirs could be manufactured with the aim of new technologies reducing their impact on the environment. On-demand 3D printing also saves on tooling costs and provides an advanced time-to-market.

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NUMBER PLATE RECOGNITION USING TEMPLATE MATCHING TECHNIQUE

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Abstract: *The purpose of this study is to propose an approach to number plate recognition using digital image processing techniques in Matlab. The template matching method serves as the foundation for the suggested methodology that is thoroughly discussed and illustrated within a graphical user interface. A few limitations are mentioned along with the application of the methodology. Finally, suggestions are made for future research and methodology enhancement.*

Key words: Number Plate Recognition (NPR), Optical Character Recognition (OCR), Template Matching, Digital Image Processing, MATLAB

1. INTRODUCTION

The leading factor for the development of digital image processing in the last few decades is the need to extract information from images and interpret certain content from images. Systems using image processing techniques may be affected by camera resolution, low visibility, environmental and weather factors while recognizing objects. Therefore, there is a necessity to create a system capable of providing user-relevant information based on digital images that are used as input in different methodologies, especially in the field of license plate recognition.

The main goal of this paper is to present automated license plate extraction and character recognition that are subsequently written into a text file. The characters on license plates, which are easily readable by humans but not by algorithms, are typically used to uniquely identify vehicles. In addition, the methodology for license plate character recognition is presented by using MATLAB, which supports digital image processing techniques. License plate recognition technology works based on converting image data from the camera into a character format that enables further processing in a specific application area.

In this paper, the emphasis is on the recognition of the characters of license plates in the Republic of Serbia. The proposed methodology is presented, textually described and visually presented with a real example. After a thorough review and testing of the proposed methodology, the observed limitations were addressed, and at the end, based on the presented and analysed work, the conclusion was drawn along with directions for future work and improvement are provided.

2. THEORETICAL FOUNDATIONS

Digital image processing in the last couple of decades has been improved by implementing operations on the image to obtain an enhanced image or extract required information. The MATLAB development environment was utilized in this research due to the fact that solutions in the field of digital image processing, in general, require experimental work that includes simulation and testing with large sets of sample images (Gonzalez, Woods & Eddins, 2009). Different approaches which has been implemented in Matlab, used different image formats as an input in approaches accomplished with numerous techniques for eliminating certain parts of image that provide easier classification (Anderla, Culibrk & Delso, 2013).

The image, in general, can be defined as a two-dimensional function $f(x, y)$, where x and y represent the spatial coordinates, the pixel positions, and the amplitude f that is in the pair of coordinates (x, y) is called the intensity or grey level. An image is referred to as a digital image when its x, y, and amplitude values f are all finite (Gonzalez, Woods & Eddins, 2009). In other words, a digital image is a representation of a two-dimensional image using a finite number of dots, commonly called picture elements or pixels (Marques, 2011). Enhancing the visibility of the characters used for the future identification of the vehicle is the primary goal of applying digital image processing in the field of license plate recognition.

This paper represents the use of MATLAB as a development environment that uses digital images as input parameters for methodology. MATLAB stores digital images in the form of a matrix, where each pixel in

the image corresponds to one element of the matrix. Consequently, an image can be defined by a two-dimensional array separately arranged in rows and columns (Goyal, 2010).
Number Plate Recognition (NPR) is a technology that uses Optical Character Recognition (OCR) on digital images to recognize license plate characters based on input image. License plate recognition can be configured to save camera images for license plate text, and others can additionally include driver photos in the case of need. The systems typically use infrared illumination to allow the camera to take pictures and videos at any time of the day or night and in different weather conditions. Licenses are recognized with the aid of optical character recognition, which processes input images into textual format. Optical character recognition represents a technology for converting handwritten, typed, scanned text or text within images into machine-readable text (Ashraf, Arafat & Iqbal, 2019). The basic process of OCR involves scanning the text of a document or image and translating the characters into a code that can be used later to process the data. The process of optical character recognition consists of three necessary steps - image preprocessing, character recognition and post-processing. The results of optical character recognition strongly depend on the quality of the input data, notably in the field of digital image processing the results depend on the quality of the input image.
The first step involves the acquisition, which is responsible for acquiring one or more images of a vehicle containing a license plate. The next preprocessing step involves improving the quality of the image obtained from the previous step. The next step involves segmentation, which is responsible for dividing the image into its two main components, the relevant object and the background. Extracting feature is the following step, which aims to create algorithms responsible for encoding image content. The last step is classification, assigning a label to each character, and creating a string (or ASCII file) on the output, containing the license plate (Marques, 2011). Template matching is used for classification and represents an important topic in the field of Artificial Intelligence (AI) due to the fact it represents an approach that involves locating regions of interest. The original image represents the image in which we expect to find a match to the template, while the template image presents the image that will be compared to the original image. Simple template matching involves comparing the template image to the source image in a pixel-by-pixel shift. The template image is shifted one pixel at a time from left to right or top to bottom to allow the numerical similarity of the template to the overlapping image to be calculated. Both images are converted to binary images or black and white, and then template-matching techniques such as utilizing cross-correlation or the sum of absolute differences are applied (Swaroop & Sharma, 2016). This approach involves the use of a database that consists of numerous characters or templates. In order to achieve recognition, the input character is compared with each template and if an exact match is found, the result is obtained (Swaroop & Sharma, 2016). After identifying the characters, the character is converted to the American Standard Code for Information Interchange (ASCII) code, which computer systems can use for further use and manipulation of the text. Before saving a specific document for later use, users can resolve simple inaccuracies, proofread, and make sure that text is accurately identified.

3. OVERVIEW OF METHODOLOGIES FOR AUTOMATIC VEHICLE REGISTRATION NUMBER RECOGNITION

In the automatic license plate recognition system, license plates are extracted from the original images of the vehicle, which later serve as the basis for recognizing numbers and letters. The characters on license plates are used to uniquely identify vehicles in the majority of cases. For machines, a license plate is just an object in the image that has a certain intensity and brightness and for whose identification is necessary to create a methodology. Therefore, it is necessary to design a system capable of extracting relevant areas of the image, which are subsequently converted into the different formats with the aid of character recognition methods. The subsequent sections of this chapter will discuss and give an outline of the methodologies that have been proposed in the last decade.
The importance of the license plate recognition system, especially optical character recognition methods is affected by the need to reduce the human factor in this process, achieving a higher level of vehicle access control in a specific area, parking billing solutions, and automatic calculation of the time and money required for using specific services that are integrated with software. In the field of software engineering, the use of a systematic literature review is recommended in order to represent prior techniques in the field in an indisputable form and to eliminate subjectivity from that process (Stefanovic

et al., 2021). As a result of systematic literature review done in the field of number plate recognition, the most frequently used method for the optical character recognition step is the template matching technique, followed by the subcategory of neural network methods (Gutai et al., 2021). Subsequently, two approaches that stated high overall recognition rates were approaches (Shaikh et al., 2013) and (Mutholib et al., 2013) that used template-matching techniques.

The automatic license plate recognition system proposed by Xie et al. (Xie & Wu, 2014) consists of a series of steps. The first step is image acquisition, followed by image preprocessing, which includes edge detection, noise removal, and other operations. The next step involves the segmentation of each character. Character recognition is provided through a template-matching technique. The previously mentioned steps are shown on the GUI interface with the help of MATLAB and the printout of the license plate mark is printed with the help of the message box.

Bhat et al. (Bhat & Mehandia, 2014) proposed a license plate recognition methodology using MATLAB to help detect authorized and unauthorized license plates. The first step is image input, after which a series of morphological operations are used to detect the desired area and the threshold value is calculated using the Sobel operator. The removal of merged objects is the next step, while the segmentation of the license plate is provided by multiplying the previously processed image with a black-and-white image. The bounding box technique was used to retrieve the properties of a certain region and to segment each character, which is subsequently compared with the templates with the help of template matching. The result of the methodology is printed in a text file, which contains the license as well as the date it was read.

The methodology developed in the work (Sutar & Shah, 2014) as the first step involves the acquisition of the image of the vehicle. The license plate of the vehicle is extracted using image segmentation, after which the optical character recognition technology is used. The resulting data is then used to compare against patterns in the database that is followed by a signal which is given to the microcontroller to control the system. If the entered number plate mark contains an authorized character, then the green indicator light will turn on, while in the opposite case, the red light will turn on.

The following automatic license plate recognition system proposal (Tiwari et al., 2016) is implemented using MATLAB. After inserting the colour image in the MATLAB development environment, the user is subsequently asked to manually mark the license plate region from the colour image and crop it. Converting the image from RGB to HSV (*Hue Saturation Value*) and analysing hues, saturations and values is the next step. Image enhancement is provided using a histogram, followed by segmentation of each character from the image, and finally displaying the results in MATLAB.

The next approach (Dias & Ashan, 2016.) is based on vehicle detection, license plate region extraction and optical character recognition. The vehicle detection phase accepts a video as input, where a certain mask is applied and thus identifies a moving vehicle while the result of this phase is an image that is passed to the next phase. A series of image processing operations are performed within this phase, and the area containing the license plate is selected. The final stage involves optical character recognition, initial noise reduction and segmentation of each character as well as sizing and template matching.

Another approach to automatic license plate recognition presented in the paper (Pagad et al., 2017) was created to help specific institutions to identify unregistered vehicles. If the recognized license plate is found to be unauthorized, the vehicle number identified as unauthorized is sent as a text message to the designated authority, along with the current date and time.

The proposal of Stefanović et al. (Stefanović et al., 2017) for license plate feature extraction suggests an algorithm that includes image pre-processing, noise removal, a series of corrections, additional filtering in the case of difficult detection conditions, as well as additional processing in the case of distorted image region. Based on the segmented characters, using a free online tool for optical character recognition, a result was obtained in a specific format chosen by the user.

In the next approach by Tejas et al. (Tejas et al., 2017), a combination of digital image processing and the Internet of Things (IoT) was proposed. The documented efficiency of the proposed methodology is approximately 97.89%. After applying the methodology using MATLAB, the license plate of the vehicle is written and saved in a Notepad file. The information written in the file is constantly deleted and new information is transferred to the cloud using the automatic FTP data transfer protocol. The results of the read license plates are forwarded to the cloud for further interpretation and manipulation of the obtained data. It is stored within the tables, which provide vehicle tracking, while the administrator can also access the date, time and location data of a specific vehicle. The database facilitates modifications

and makes it easier to track specific vehicles assuming that all cameras of a specific geographic area are connected to the same server. The main goal of the search module is to know the registration number of the vehicle, then the entered number is searched in the database and all data from the database of that vehicle can be accessed by the authorized administrator in different locations.
Surekha et al. (2018) proposed a methodology whose main purpose was to provide support for parking services. As a result, it was necessary to record the time and date when the vehicle entered a certain parking area, as well as the details of the vehicle's license plate. The proposed license plate character recognition system uses a sensor network to activate the camera and a graphical user interface (GUI) to allow the user to control the complete process.
In the approach presented by Srinu et al. (2018), a license plate recognition system was proposed for recognizing and accessing vehicle data for surveillance purposes. It consists of three main steps of the methodology: image acquisition via a mobile application, a graphic user interface for tag recognition and a web page with vehicle information.
Based on a review of the literature and the previously proposed approaches, it was determined that methods connected to cameras that enable image acquisition make the methodology simpler to use because the images should be similar in terms of quality and size. The definition of success for any information system is rather subjective, because it depends on how quickly it responds to user requests and how well it increases user productivity (Stefanovic et al., 2020). In some approaches, the methodology was implemented and further processed with the aid of a graphical user interface, which is preferable to methodologies that simply list necessary steps without visual representation in a form of interface and make it considerably more difficult for the end user to use the proposed methodology. The proposed methodology within this work addressed these constraints by development of a methodology that will be represented in a form of GUI and custom developed for license plates in the Republic of Serbia.

4. PROPOSED METHODOLOGY

The methodology proposed for the automatic recognition of license plate characters based on an image is presented in this chapter, as well as the graphical user interface to support the mentioned system, which was developed in the MATLAB development environment with the help of techniques for digital image processing and optical character recognition, which will be described in detail. Experimental work was carried out on license plates of the Republic of Serbia, to identify improvements that can be proposed for the methodology in future iterations.
License plates that are primarily used within the proposed application are white, while the border is marked in black. On the left side of the plate, on a blue background, the abbreviation of the Republic of Serbia - SRB is written in white letters, which is excluded from the recognition process. The registration number of the vehicle is represented by a series of marks, at the beginning, the mark of the registration area is written in black letters, after that, the digits representing the registration number are separated with the help of the sign "-" from the letters in the two last positions (Figure 1).

Figure 1: License plate of the Republic of Serbia

Recognition of the Latin letter on the vehicle license plate consists of a combination of numbers from 0 to 9 and all the letters of the Latin alphabet and three additional alphabetic letters, namely "X", "Y" and "W". The first two marks in the series of registration marks are letters, after that there are digits in three or four positions, depending on the registration area, and finally, there is a combination of letters in the last two positions.

The objectives of the proposed methodology are:

- ensuring the exact location of the license plate area in the image, successful recognition of each character located within the previously recognized region and
- printing recognized characters in a text file for further data manipulation.

4.1 Methodology

The algorithm for extracting license plate features implemented in this paper requires an input image, followed by image preprocessing operations, localization of the position of the plate in the image, as well as segmentation of the identified plate. Aforementioned phases are followed by segmentation of special characters that are subsequently read with the help of optical character recognition, while at the end of the process, it prints the output of the process - the registration number written in a text file. A visual representation of the phases for the proposed methodology is shown in Figure 2.

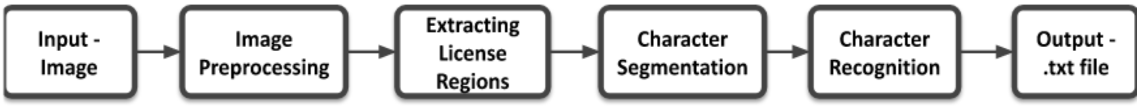

Figure 2: Phases of the proposed methodology

4.1.1 Input Image

The first step is providing an input image that serves as the basis for further steps. The input image may have light or dark image tones, low contrast images, blurred images, or noisy images. As it is not possible to claim with certainty that the input image is always of adequate format and quality, a series of pre-processing operations are carried out to ensure the highest level of character recognition success. Figure 3 shows the input image of the vehicle that was used to demonstrate the functionality of the methodology through a series of iterations.

Figure 3: Input image

4.1.2 Image Preprocessing

The main goal of preprocessing is to improve the contrast of the input image, reduce the noise in the image and minimize the image processing time. A colour image is converted to a greyscale image before image processing, and after noise removal and contrast adjustment, the image is converted to a binary image. After that, the operation of edge detection, dilation to remove small elements in the image, then filling of holes, and finally the erosion operation is performed. The remaining paragraphs of this chapter will discuss each of the aforementioned phases of image processing.

The first step of image preprocessing involves sharpening the image. Sharpening is achieved by subtracting the blurred version of the image from itself. Contrast is increased along the edges where different colours border, improving the visual impression. Image sharpening is followed by the conversion of the image into shades of grey. By converting the input image to a greyscale image, brightness reduction is achieved. It improves image noise reduction to a certain extent and also facilitates further image processing. Image noise mostly occurs during image acquisition or transmission. In order to remove noise, a filter is used that takes into account each pixel in the image and its surrounding pixels and replaces the pixel with the median of the surrounding values.

Adjusting the image contrast is the next phase, and contrast is defined as the difference between the lowest and highest intensity levels. The contrast of the greyscale image is transformed using adaptive histogram equalization. In the binarization step, the image is converted to black and white format, and the purpose of applying colour conversion is to reduce the number of colour scale ranges from the range of 0 to 255 to the range of 0 to 1. The resulting image contains white pixels against the background and letters that are represented by black pixels.

The following phase includes edge detection. The goal of edge detection is the identification of certain objects in the image, where the basic step is dividing the image into regions corresponding to different objects in the image. In most cases, it is followed by dilation which represents a type of morphological operation that adds pixels around an object in an image. It helps to fill in any unnecessary holes in the image, which will benefit in higher accuracy and also to enhance the borders of the subject by filling in the broken lines of the images. Hole filling is then applied to binary images where a hole is defined as a group of background pixels. One of the fundamental techniques for removing unnecessary elements from a binary image is erosion. The morphological erosion operation is used to discover the candidate license plate area and its results, and it also reduces the size of the object and exclude unwanted details from digital image that will aid license plate extraction.

Figure 4 shows a concrete example of the application of the mentioned steps on the input image from Figure 3.

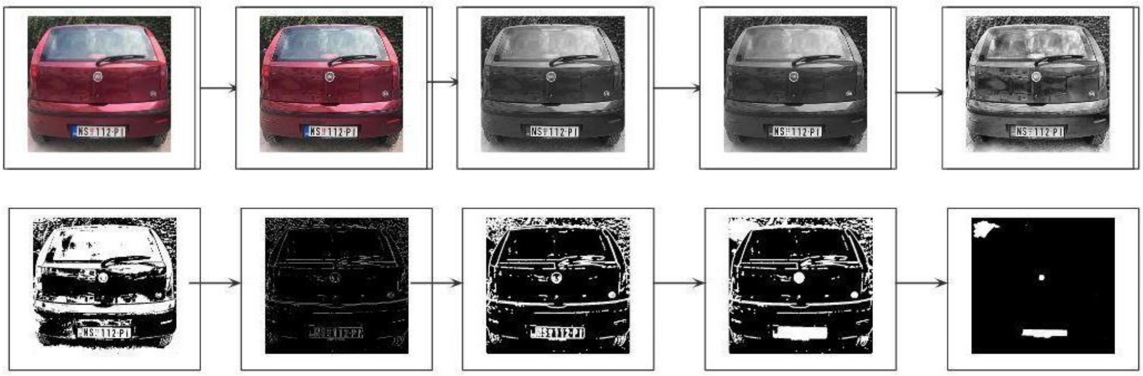

Figure 4: Image preprocessing

4.1.3 Extracting license plate regions

Segmentation of the license plate from the original input image is a crucial process in automatic license plate recognition because all subsequent steps depend on this step. The function used returns a set of properties for each connected component in the binary image. Based on a set of properties, segmentation operations were applied to the processed image and the representation of the segmented license plate is shown in Figure 5.

In addition, the removal of connected components from the binary image that have a value smaller than the defined pixel is performed, and thus the components that have a value smaller than the specified pixel are classified as non-digital components and are removed from the binary image. In this way, it is certain to find only numbers and letters on the segmented license plate without unnecessary elements such as the sign coat of arms or the SRB mark located on the left side.

Figure 5: Segmented license plate

4.1.4 Character Segmentation

The extracted region serves as the basis for adding a bounding box, which was used to mark the characters with a yellow line in Figure 6.

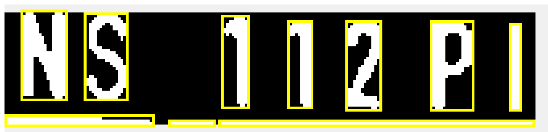

Figure 6: Bounding box around each character

In this phase, the characters in the license plate area are separated into individual images. In the proposed approach, character segmentation is performed using bounding box analysis (BBA). Marked characters are segmented by analysis into a certain number of sub-images that contain digits or letters. The display of character segmentation results and seven sub-images are presented in Figure 7.

Figure 7: Image of segmented characters

4.1.5 Character Recognition

Following phase is related to character recognition that is implemented by using template matching technique that recognizes a number or letter by comparing two images, the segmented character from the previous step, and the patterns created and saved in database within this step.
The establishment of a template database, which is made specifically for the demands of the methodology, is the first stage in the template-matching process. The base of 42 patterns contains the digits 0 to 9, the Serbian Latin alphabet with the exclusion of "LJ" and "NJ" and the addition of the "X", "Y", "Q", and "W" letters, as well as the sign coat of arms. The font used in the templates has been customized for the license plate used in the Republic of Serbia. Templates are binary files in the .BMP format that are 42x24 pixels in size and include all of the letters and numbers described previously and are shown in Figure 8.

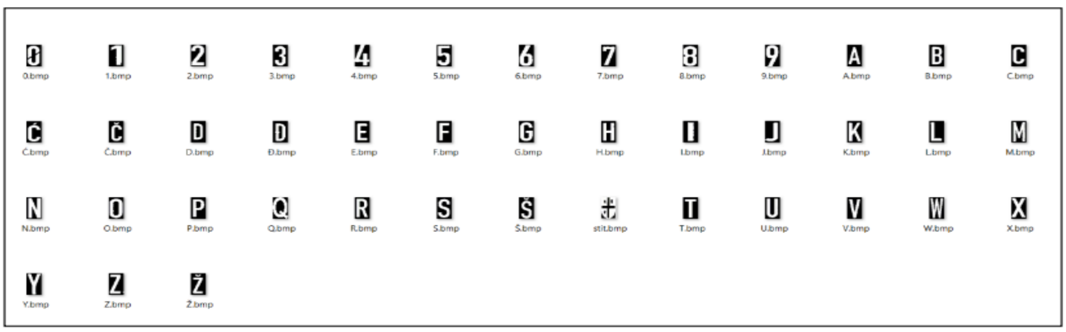

Figure 8: Template base

After creating database, the next step is to resize the image of the segmented character from the previous step to 42x24 pixels to ensure a comparison with the template images. A pixel-by-pixel comparison of the image and the template is performed for each possible position, sliding pixel by pixel.
In order to recognize a particular character, the input segmented character from the previous step is compared to each pattern to find an exact match or pattern with the closest representation of the input character. It is necessary to find the highest level of correlation, which can be defined as the degree of similarity between the segmented character and the template. When the highest level of degree of similarity is found, the character is written into a special matrix intended for saving the character. The procedure is repeated for each segmented character.

4.1.6 Output

The result of the previous series of steps and the result and output from the methodology is shown in Figure 9. The value of the license plate is written to the text file, which can then be saved for further manipulation of the data.

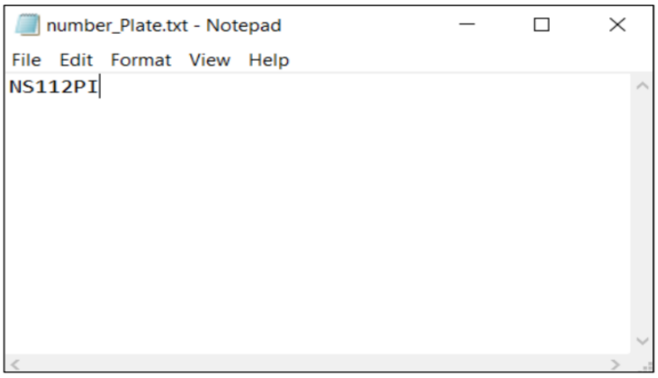

Figure 9: Printing of methodology results in a .txt file

4.2 Graphical User Interface (GUI)

The methodology will be presented to the end user in a graphical representation that was created with within the MATLAB. An interface that requires an image as input and converts it into a textual format using the previously mentioned image processing methods has been designed to facilitate the usage of the methodology. The end user just receives the final outcome of the methodology in a form of textual file, while the phases of image processing are not displayed within the GUI in order to retain transparency. A simple layout of the developed GUI application is presented in Figure 10.

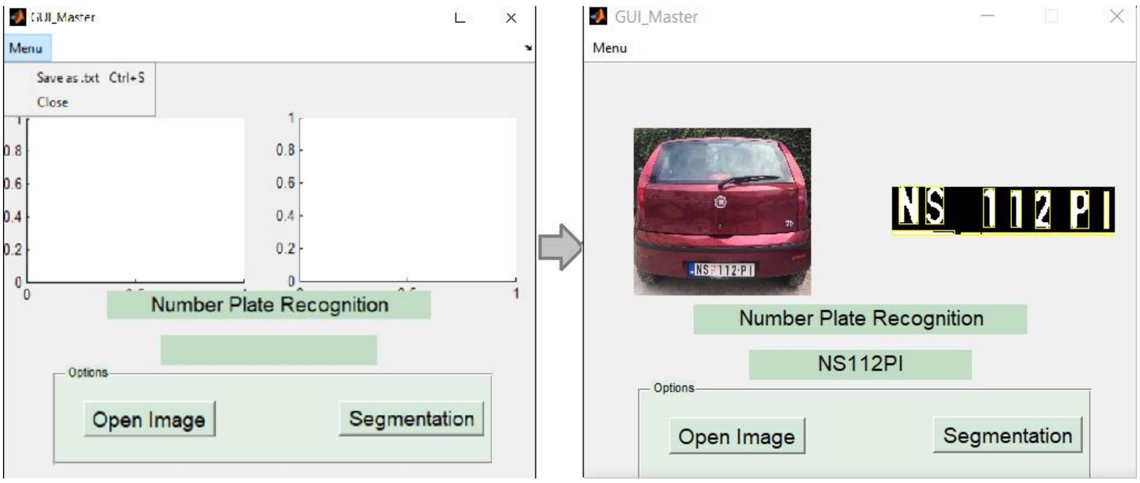

Figure 10: Graphical user interface

5. DISCUSSION

Limitations of the methodology were identified after testing the application through a series of iterations. Defining the limitations of the methodology serves as a basis for further improvements of the current version of the methodology and potential solutions to currently observed shortcomings. In order to draw conclusions and directions for future work, it is necessary to test the application on a larger set of different images.

Based on testing phase, it ca be concluded that the segmentation step was adequately performed in most examples, as well as the segmentation of all individual characters and the creation of sub-images. However, difficulties arise at the last step - character recognition, where the search for the highest level of correlation occurs, in some cases lead to the mismatch of letter and number characters as well as between letters. Due to the use of the application, it was established that certain numbers and letters are mixed up, specifically "O" and "0" or "B" and "8" or "6". A potential solution that arises is to define specific positions of letters and numbers within the license plate. If the license plates of the Republic of Serbia are observed, a template can be created by defining in which positions either a letter or a number can occur. The first two positions always contain letters, while the next three or four fields (depending on the region where the vehicle is registered) contain numbers, and the last two positions of the plate again contain letters. This method would eliminate the possibility of misreading similar characters, in the specific case of digits and letters.

The difficulty that occurs when reading the characters of license plates from the Republic of Serbia is also mixing the letter "C" with "Č" or "Ć" in conditions of poor visibility or low image quality. Also for letter designations "Z" with "Ž" and "S" with "Š", however, by applying a series of operations to improve image quality and correct the imaging angle, these difficulties could be overcome.

The proposed methodology is sensitive to pattern mismatch when the segmented character does not contain the same font as the patterns. Changes in the structure of the input characters have a negative impact and the matches of certain characters are not found in their corresponding letter or digit patterns. Different fonts and the lack of a universal font used by all countries would make character recognition considerably simpler with the aid of the template matching technique. Depending on the regulations of the country in which license plates were issued, they possess different characters, letters, digits, fonts, and background colours. Vehicles from different countries or states can use the same font, but the arrangements on their license plates may differ. It would require a considerable amount of time to make this methodology global, not just for license plates registered in the Republic of Serbia, because the current database of templates would need to be enhanced with all potential fonts, digits, and characters.

6. CONCLUSIONS

The importance of license plate recognition systems integrated with optical character recognition techniques, is influenced by the need to minimize the human element in this process, achieve a higher level of vehicle access control in a particular area, for example in parking billing solutions, and automatically determine how much time vehicle has spent in certain area and charges that are needed to be paid after the use of specific services. If the proposed methodology is used in monitoring the parking lot, then it is necessary to provide a connection with a database where the time of entry to the parking lot of a certain license plate and the time when someone should exit it would be automatically entered. By calculating the time spent in the parking lot, monetary compensation would also be calculated. A similar example is the possibility of use in the parking service, where it is possible, based on an image and characters, to check in a certain database whether parking has been paid for a certain region or not and for what period of time. If it is a matter of vehicle registration, a database of registered vehicles is also necessary, with which every result of the methodology would be compared, and if there is no such record in the database, the conclusion is reached that the car with certain license plates is not registered.

Based on the aforementioned potential fields of use, this methodology offers a broad spectrum of applications, and future research will be concentrated on enhancing it. The direction of future development can be focused on the elimination of the limitation of optical character recognition, which is reflected in the mixing of letter and number marks within the license plates of the Republic of Serbia. A potential solution to the problem is the definition of specific positions where you can expect a letter mark and where a numerical one. Consequently, the success of recognizing the registration number of a certain license plate would be increased. In the future, it would be important to apply the methodology to a larger set of images in order to accomplish and demonstrate the level of success of the methodology, as well as provide more relevant data related to the overall accuracy of the methodology. In the matter of digital image processing, if a universal camera was used for the acquisition of images that serve as an input parameter in the proposed methodology, the problems of different image quality, lighting, contrast and other external factors that greatly affect optical character recognition could be solved.

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PACKAGING ADDED VALUE

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INVESTIGATION OF MECHANISM AND EFFECTIVENESS OF METAL NANOPARTICLES IN SELF-STERILIZING PACKAGING

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Abstract: *Microbial contaminants intimidate food safety and shelf-life. Metal nanoparticles (NPs) have become a leading area of interest and research in barrier packaging materials that ensure food safety. Traits such as small size, high surface-to-volume ratio and multi-functionality make them ideal materials for producing self-sterilizing packaging. Numerous metal NPs have proven to fight against a wide range of pathogenic microbes through various methods. Further, metal NPs exhibit more biocompatibility than metal ions. This study investigates the role and the mechanism of action of the various NPs in self-sterilizing packaging. AgNPs, TiO_2NPs, MgONPs, ZnONPs, AuNPs, FeONPs, Cu-based NPs and SnO_2NPs have been explored for their biocidal action in self-sterilizing surfaces and food packaging applications in this work. The size, shape, surface structure, surface reactivity and other environmental factors (like pH) influence the biocidal properties of these metal NPs. From the literature survey, it was inferred that it was necessary for the metal NPs to be smaller than 50 nm in size to exhibit effective biocidal action against pathogenic microbes. The mechanisms followed by the metal NPs against bacteria and fungi include disturbing the cell wall, the metabolic process by inducing reactive oxygen species (ROS) and/or the DNA synthesis mechanism. It was inferred that AgNPs, MgNPs and ZnONPs are some of the NPs that have a significant share in self-sterilizing surfaces. Being expensive, the works of literature on AuNPs and their application in this subject are very few. This paper aims to study the biocidal behaviour and rank the effectiveness of these metal NPs to act as ideal materials for self-sterilising packaging.*

Keywords: Metal nano particles, self-sterilizing packaging, nano technology, nano particle Synthesis

1. INTRODUCTION

In food products, microbial spoilage is one of the major reasons for food deterioration. The major factors affecting the growth of microorganisms are moisture content and pH of food, storage temperature, humidity and type of packaging. The microorganisms can be classified based on the temperature range in which they can survive and thrive. Psychrophiles or psychrotrophic bacteria can survive at very low temperatures from 0°C or lower to about 20°C whereas mesophilic bacteria propagate well between 20°C and 45°C. The microorganisms that grow above 45°C are called thermophiles. Moulds can adapt to a broader temperature range than bacteria while yeasts cannot survive in the thermophilic range. Yeasts generally grow in the psychrophilic and mesophilic temperature range. Food additives such as salt, sugar, acids and weak carboxylic acids such as sorbic acid, acetic acid and benzoic acid are used to prevent or slow down the growth of microorganisms. However, there is a growing demand for replacing chemical preservatives to ensure food safety and extend the shelf-life.

Packaging materials play an important role in extending the shelf life of food products. They protect the food from deterioration by providing passive protection against the migration of water vapour and gases such as oxygen and carbon dioxide from the atmosphere into the package. Active packaging technology is a branch of packaging science that deals with packages that provide added functionalities in addition to being a passive barrier. Antimicrobial/Self sterilizing Packaging is a type of active packaging technology wherein antimicrobial agents are either blended into or coated on the surface of the packaging materials to extend the shelf life of the product. Metal and metal oxide nanoparticles (NPs) have been reported to be effective against bacteria and other microorganisms (Staron et al., 2021).

Nanoparticles' are solid particles that range from 1 to 100 nanometres in size. Due to their small size, nanoparticles have a high surface area-to-volume ratio than their larger material counterpart. Despite being small, they are able to produce quantum effects. The nanoparticle's properties are mainly determined by its size, shape, and surface. Different nanoparticles are being synthesized using metals like silver, gold,

magnesium, zinc and titanium by chemical, physical and biological methods (Figure 1). Physical methods are expensive and require large amounts of energy just to maintain the optimal conditions of the process. Even though chemical methods are affordable and high-yielding, they produce harmful by-products and the toxic chemicals in the liquid medium get absorbed on the surface of the nanoparticles synthesized. Biological methods using fungi, enzymes or plant extracts prove to be eco-friendly alternatives to the physical and chemical methods. Because these nanoparticles can be engineered to play a specific role, their use spans various industries. The growing interest in metal NPs led to promising results that make them suitable for producing antimicrobial and antiviral surfaces and coatings.

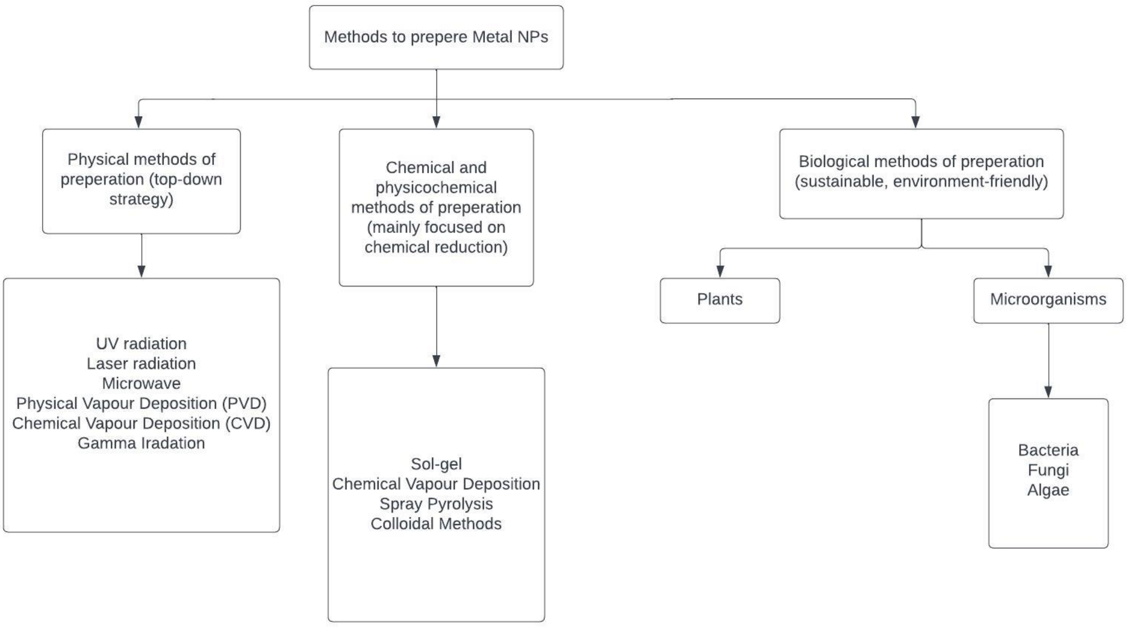

Figure 1: Chemical, physical and biological methods

In this research paper, an attempt has been made to review the mechanisms of metal nanoparticles against microorganisms and their uses in food packaging. Different metal NPs namely Ags, TiO2, MgO, ZnO, Au, FeO, Cu and SnO2 have been analysed.

2. ANTIMICROBIAL MECHANISM OF METAL NANOPARTICLES

Bacteria can be classified as gram-positive and gram-negative bacteria based on the presence or absence of cell wall respectively. The cell wall of gram-positive bacteria is made of peptidoglycans, proteins and multiple layers of murein. However, in gram-negative bacteria, murein is single-layered. The metal NPs mainly affect the structure and function of the cell membrane. This is achieved due to the small size of the metal NPs. Anita Staron et al. (2021) have reported that in interaction with the bacterial cell membrane, the metal NPs affect the membrane integrity, induce oxidative stress, disrupt enzymes, and damage proteins and DNA. The NPs can also get converted into ions and disrupt the metabolic activities of the microorganisms. Moreover, NPs can attack the microorganisms without any direct contact by producing a reactive oxygen species (ROS) which in turn migrates to the surface of the packaging materials and reacts with them. This reaction causes the oxidation of lipids and proteins and the degradation of DNA.

Silver NPs defend against microorganisms by converting them into ions and interacting with enzymes and DNA. At the same time, the gold NPs are able to attach to the cell membranes and reduce the level of ATP and inhibit the binding of tRNA to ribosomes. Zinc NPs in addition to exhibiting similar silver characteristics, also generate ROS on their surface. Copper and Magnesium oxide NPs attack the cell membrane and disrupts the physiological activities of the cell leading to the death of bacteria. Aluminium oxide NPs also creates holes in the cell membrane resulting in the seepage of intracellular materials and the death of microorganism (Mozaffari et al., 2017; Gharpure et al., 2021). The antifungal properties of the metal nanoparticles are listed in Table 1.

Table 1: Antifungal Properties of Metal Nanoparticles

S.No.	Metal NP	Antifungal Effects Caused
1.	Ag	ROS were produced leading to damage to DNA, protein denaturation and leakage of the contentsof the cell. But it was reported that oxidative stress and membrane permeabilization are not the primary reasons for damaging *S. cerevisiae*. In the case of *T. asahii*, these AgNPs caused hyphae deformation and shrinkage, organelle degeneration and leakage of contents in the cytoplasm.
2.	ZnO	Inhibited growth of *C. albicans*
3.	CuO	CuONPs exhibited the same mode of action for bacteria and fungi like *A.niger* and *C. albicans*.
4.	Au	The interaction between AuNPs and Candida sp. inhibited the H+ - ATPase proton pump. This resulted in the inhibition of efflux of H+
5.	Mg doped ZnO	Due to the accumulation of Mg-doped ZnONPs in the cell membranes of *C.albicans* caused cell damage.

3. APPLICATION OF NANOPARTICLES IN PACKAGING

3.1 Silver

Silver is a transition metal. Hence, it has high electrical and thermal conductivity. Also, it is the most reflective metal. This metal has been used as an antibacterial agent in medicines since time immemorial. Silver is spoken for its healing properties. Nanotechnology makes it possible for us to incorporate silver nanoparticles into polymer materials to introduce or enhance antimicrobial properties. This has eliminated the use of silver ions as they form precipitation complexes that inactivate the metal. It has been proved that AgNPs are potentially safer to use and that their antibacterial properties can be enhanced by introducing additives (say, stabilizers) (Wolska et al., 2017).

Self-sterilizing composite polymers, custom packaging and contact surface sterilizers have been successfully produced by reinforcing AgNPs into a host polymer which acts as a matrix that holds the silver nanoparticles (Martínez-Abad et al., 2013; Castro-Mayorga et al., 2017). Also, it is possible to increase the bactericidal effects of the silver NPs by combining 2 metal nanoparticles together. For example, films that contained copper in combination with silver nanoparticles were reported to be more effective than just nanosilver. The nanocomposite films that contained both copper and silver were more effective in the bactericidal action against L. monocytogenes and Salmonella enterica typhimurium (Arfat et al., 2017). When Ag-Cu reinforced films were used as a packaging material for meat (chicken), positive results were obtained. It was observed that the LLDPE/Ag-Cu films showed an appreciative bactericidal activity against pathogens like L. monocytogenes, Salmonella typhimurium and Campylobacter jejuni. It was reported that the Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) values for AgNPs for Staphylococcus aureus were 0.625 mg/ml (Parvekar et al., 2020).

3.2 Zinc oxide

ZnO-NPs exhibit different morphologies. Also, they are capable of controlling the growth of broad-spectrum bacteria. It can be produced through different methods like Physical Vapour Deposition, Mechanochemical Processing, Hydrothermal Method, solution casting method, etc. (Kimet al., 2022; Channa et al., 2022). Studies prove that ZnONPs act as effective bactericidal agents against microbes like Escherichia coli, Pseudomonas aeruginosa, Klebsiella pneumoniae, B. megaterium, Pseudomonas vulgaris, and Campylobacter jejuni. E.coli and B. megaterium. However, B.subtilis (endospores) were immune to the bactericidal action of ZnONPs to a certain extent. The ZnONPs were effective only at 36% (20min) and 48% (60min) (Stoimenov et al., 2002). The US FDA considers ZnONPs as GRAS which assures food safety. These NPs are highly toxic to disease-causing pathogens and have a minimal impact on humans. This makes it a promising material to fabricate food packaging with bactericidal properties. Research proves that the mechanical properties, thermal stability and crystallinity of films made of PVA can be increased by reinforcing ZnONPs. The contact angle test proves that the water absorbency and the wettability of the PVA/ZnO nanocomposite films are lower than that of pristine PVA films. On testing the nanocomposite film for its oxygen transmission rate and permeability measurement, it was concluded that the addition of ZnONPs to the PVA did not affect the oxygen barrier properties and OTR. This could be due to the strong wetting between ZnO nanorods and PVA chains. Thus, the constant OTR suggests that ZnO did not introduce porosity and did not alter the structure of PVA. However, the OTR decreased minutely when the ZnO concentration increased (Channa et al., 2022).

3.3 Magnesium oxide

It is versatile in nature. It has been reported that when used along with biopolymers or petroleum-based polymers, desirable results were obtained that encourage active packaging (Ballesteros et al., 2021). It can be produced through different processes like solvent-casting, biosynthesis and colloidal methods (Swaroop et al., 2018; Samadi et al., 2021; Zhang et al., 2020; Abdel-Aziz et al., 2020; Mittag et al., 2019). The mechanical properties (tensile strength and elongation at break) on introducing the NPs have increased. This is because these NPs can block the crack on the surface of the film by absorbing the energy that causes deformation. On the contrary, it was observed that these metal NPs have a negative impact on the film when their composition exceeds 3 wt% because at this concentration, these metal NPs agglomerate with each other which deteriorates the polymer's structure (Zhang et al., 2020). The tensile strength of the PLA/MgO nanocomposite films produced by the solvent-casting method increased by 2 wt% loadings. This was attributed to the uniformity in the dispersion of the MgONPs in the films prepared (Swaroop et al., 2018). The nanocomposite films were observed to be thermally more stable than the pristine films on TGA analysis. The MIC for MgONPs against B. subtilis and E.coli were recorded to be 0.5 and 0.75 respectively. The MBC for MgONPs against B. subtilis and E.coli were recorded to be 1 and 1.5 respectively. The comparatively higher MIC and MBC suggest the fact that E.coli is more resistant to the MgONPs. The MBC value implies that the train is not multi-drug resistant (Bhattacharya et al., 2021).

3.4 Gold

Unlike bulk gold particles, AuNPs have unique properties that make them extremely useful for specific applications. This is solely attributed to their small size and the large surface area-to-volume ratio. Many studies have reported the mechanical properties (tensile strength, elongation at break, etc.) of polymer films have been enhanced because of the reinforcement of gold nanoparticles into the matrix. It was observed that PVA-glyoxal-AuNP films provided better preservation of bananas than the PVA-glyoxal-graphene oxide films with minimal black spot formation for up to five days which could possibly be due to the enhancement of mechanical properties provided by the AuNPs (Chowdhury et al., 2020). PVA/AuNPs films showed that there was a significant increase in the tensile strength, Young's modulus and a decrease in the elongation at break were observed in the films having PVA-GA cross-linking than in PVA films (Chowdhury et al., 2020). On testing for the dynamic viscosity of the nanocomposite films, the result suggested a decrease in the dynamic viscosity of the chitosan/ aminopropyl silane/AuNPs films owing to the homogeneity and the miscibility of the film. When tested for antimicrobial activity, these chitosan/aminopropyl silane/AuNPs films showed antibacterial activity against Salmonella bacteria. These bacteria cause Salmonellosis and other food-borne diseases. This is attributed to the inherent antibacterial activity and the positive charges present in chitosan, APTMS and AuNPs. The composite film interacted with the bacterial cell wall to damage it and eventually lead to the lysis of the bacterial cell (Virgili et al., 2021). The Minimum Inhibitory Concentration (MIC) for the AuNPs that were 7–34 nm in size were 2.93 µg/mL, 7.56 µg/mL, 3.92 µg/mL, and 3.15 µg/mL for E. coli, B. subtilis, S. aureus, and K.pneumonia, respectively. While that for AuNPs of size 20-40 nm were 2.96 µg/mL, 8.61 µg/mL, 3.98 µg/mL and 3.3 µg/mL for E. coli, B. subtilis, S. aureus, and K. pneumonia, respectively (Shamaila et al., 2016).

3.5 Titanium dioxide

TiO2 NPs are well-known, easily available and low in toxicity. It has gained much attention for its antimicrobial properties. It proved to be suitable for producing nano-blend food packaging films without deteriorating food safety when it was reinforced with PLA films. There was an increase in the tensile strength, elastic modulus and stiffness in the PLA/TiO2 and PLA/TiO2/Ag films. The cross-section showed that the PVA films became rougher with the introduction of the NPs (Li et al., 2017). On studying the gelatin biopolymer films reinforced with 1% (w/w) TiO2 NPs and saffron extract 2% (w/w), it was observed that the addition of saffron extract and TiO2 NPs increased the thickness and mechanical properties of the films and that the moisture content, water vapour permeability and solubility were reduced (Azimi-salim et al., 2022). It was studied that the pristine PLA films showed no antimicrobial activity on E.coli and Listeria monocytogenes. The films with a certain concentration of TiO2 NPs showed significantly reduced growth of the bacteria in the culture plate. This activity increased with the increase in the concentration of the NPs (Li et al., 2017). While for LDPE/Ag/TiO2 and LDPE/Ag + Cu/TiO2 nanocomposite films, it was observed that the maximum antibacterial protection to Tilapia was provided by the films containing 2.5% silver, 2.5% copper and 5% titanium dioxide NPs (Efatian et l., 2021). Thus, TiO2 NPs prove to be a promising material for producing nano-blend packaging films without deteriorating food safety (Li et al., 2017).

3.6 Tin dioxide, copper-based and ferrous oxide NPs

These nanoparticles have been already employed in multiple fields due to their electrical conductivity, ease of availability and antimicrobial properties. It was observed that the electrical conductivity increased by increasing the concentration of Indium Tin Oxide NPs (ITONPs) in the PANI films as the ITONPs filled the gaps present in the case of the pristine PANI (polyaniline on carbon black) films. There was no reaction happening between the metal MPs and the polymer. However, the NPs interact with each other. The disorderly arrangement of the polymer film increases when the NPs are introduced because the NPs widen the diameter of the spaces present in the matrix of the film. In other words, this suggests that NPs increase the crystallinity in the film. The surface roughness of the film containing 16 wt% of the NPs is 0.24 µm (Al-Bataineh et al., 2022). It was observed that coating FeONPs with, materials like polyvinylpyrrolidone (PVP), or polyethene glycol (PEG) increased the antiviral properties (Kumar et al., 2014). On analysis of CuNPs-C-PLA nanocomposite films, good antibacterial action was exhibited by the NPs against Pseudomonas spp. (Longano et al., 2012).

4. CONCLUSION

Self-sterilizing packaging is widely used in areas where pathogenic microbes are present. This seems to be a clever solution to any pandemic breakdown. Almost all metal NPs follow a similar mechanism of producing ROS in order to cause cell death for both bacteria and fungi. AgNPs are extensively used in commercial packaging and have increased the shelf-life of food products. Works of literature on the AuNPs in this subject are very few which might be because of its high cost. MgONPs exhibited practically significant properties when reinforced into a PLA film. Being safe and nontoxic, ZnONPs are being used in the packaging industry currently. Copper-reinforced cellulose nanocomposite packaging materials that were developed showed good biocidal activity against E.coli. Titanium Dioxide, Tin(IV) Oxide and Ferrous Oxide NPs prove to be good choices for producing a self-sterilizing packaging material.

5. CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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NEAR FIELD COMMUNICATION (NFC) TECHNOLOGY IN THE PACKAGING INDUSTRY

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Abstract: *Packaging that supports NFC technology is generally designed to be reusable, thus by reducing the environmental impact of packaging, consumers and businesses are presented with more opportunities to be more sustainable. The important thing here is that a company can be creative and add information about a product or company without a significant financial investment. For example, if a customer is interested in a product on the shelf, they can be granted information about the origin of the product or links to provide some feedback on social networks. Furthermore, sales can be promoted by offering the customer a discount, coupon, or added value to the buyer.*

NFC technology can offer many benefits when used with packaging, ranging from interactivity to product security validation.

NFC labels have unique identifiers that can be embedded in packaging to make consumers more interactive, secure, and more efficient in tracking, allowing packaging companies to offer better customer service and product safety.

The aim of this work is to perform a comprehensive literature review of the application possibilities of NFC technology and develop a methodology for the application of NFC technology to promote product sales efficiency.

Key words: NFC, smart packaging, food packaging, mechanical impact

1. INTRODUCTION

In today's complex retail market, brands and retailers must find new and innovative ways to engage with customers. In spite of the fact that 90% of smartphone owners use their devices in-store to search for products through search engines and online stores, companies need to recapture customers' attention through new technologies, says Gillian Ewers (2018). While millennials and Gen Z spend an average of 3:44 hours a day spend on their smartphones, 67 percent of them still prefer to shop in-store (Sterling, 2017), so there is a clear need to change the traditional retail marketing to a new approach that builds a bridge between the digital and physical worlds (Ewers, 2018).

For brand owners and retailers, NFC offers opportunities to develop direct engagement and increase customer loyalty. Such interaction is possible because NFC tags have unique identifiers per item, not just product type, therefore the content can be targeted and dynamic (different before and after purchase). These tags are small and can be integrated into the packaging without affecting the brand identity. NFC technology is also more resistant to cloning because the unique identifier prevents counterfeiting and allows the brand owner or customer to confirm the product's authenticity (Ewers, 2018).

Based on the researchers' insights, it was decided to analyse existing NFC technologies in the packaging industry. There are different types of NFC stickers on the market, and thus it is essential to analyse their potential and applicability to packaging. It is also relevant to investigate how the information written in the NFC tag’s memory is read after certain performance factors, such as cold, heat, humidity, mechanical abrasion, or other, would affect the NFC sticker. After the analysis, tables with the types of NFC stickers and their parameters have been compiled and grouped for further experiments. The selected information will be further recorded, the readability will be checked against a benchmark and the readability of the information after mechanical impact on the NFC sticker will be checked against the benchmark.

2. THEORETICAL BACKGROUND

Nowadays, there is an increasing trend to use diverse wireless technologies to retrieve miscellaneous types of data / various data. One of them is Near Field Communication (NFC) technology.
It is important to understand and analyse the applicability and trends of NFC technology for today's generation of consumers. One of the studies conducted by Noah Mooiman, Simon Andersson analyses (2022) the results obtained from a sample of N=5 Generation Z living in Sweden. They have focused on five themes that were identified: (1) Added value, (2) Brand image, (3) Ease of use, (4) Right product, and (5) Environmental concerns. During the experiment, the participants' identities were kept anonymous, and their names were labelled Participant A through Participant E. The researchers give more demographic information about the sample in Table 1 (Mooiman & Andersson, 2022).

Table 1: Participants' demographic information (Mooiman, Andersson, 2022)

	Age	Gender	Occupation
Participant A	24	Male	Self-employed
Participant B	21	Male	Employed
Participant C	22	Male	Employed
Participant D	22	Female	Self-employed
Participant E	20	Male	Student

In this experiment, to ensure that the participants could answer the given questions, they were informed about NFC and its use cases through a short presentation. In addition, use cases of NFC in product packaging were presented to the participants. The demonstration was done since the product packaging industry has not widely adopted NFC, and the participants were most likely not familiar with the topic. The presentations were, however, strategically placed after specific questions to give room for the interviewees to comment and present their knowledge of the phenomena first (Mooiman & Andersson, 2022).
From the data gathered through the interviews, a thematic analysis of the researchers was carried out, and five main themes were defined. These themes mentioned earlier were: added value, brand image, ease of use, right product, and environmental concerns. The results show the need for the NFC to add value for the customer, which might be seen as evident, but it is the key aspect that will enable brands to use NFC to strengthen their relationships with their customers. This view was repeated multiple times by all participants in the study. The user's experiences with an NFC-enabled product package will reflect the associated brand's image. The results suggest that a positive interaction would benefit the brand's image but also that a negative interaction would harm it. One of the critical things that a brand must get right to succeed in creating a good user experience is to match the right interaction with the right product. The increased ease of use features through NFC was seen as one of the main benefits enabled by the technology. Although there were some positive sides mentioned in association with the environment, this was also the main drawback mentioned in the interviews (Mooiman & Andersson, 2022).
In another article (Lathiya & Wang, 2021), the evolution of NFC transaction values between the years 2014 and 2024 was presented (Figure 1).

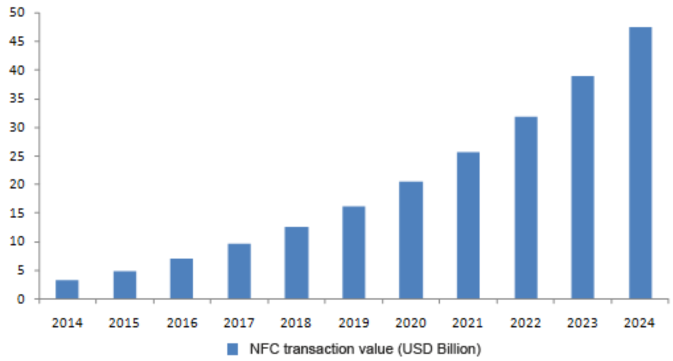


Figure 1: Global NFC Market, 2014 - 2024 (USD Billion) (Grand View Research, Inc., 2016)

In this article, the author states that from 2010 onward, new interesting applications of NFC were launched every year in the communication sector by technology giants such as Google, Apple, Samsung, NXP, etc. The industry players are constantly introducing new advances and improved technologies in NFC-enabled devices, which have taken the global market to 4.80 billion USD in 2015 and are expected to reach 47.42 USD billion by 2024 (Lathiya & Wang, 2021; Grand View Research, Inc., 2016).
The future of NFC technology is growing rapidly, as shown by the research data presented. This is due to the technology's easy applicability in areas ranging from the healthcare sector to the packaging industry. The following is a review of the research conducted on the application of NFC technology in packaging.
The researchers Zhong Ma and ect. (Ma et al., 2018), claim that the applications in detecting food spoilage, where the sensor with a high sensitivity that acts as a switch for a NFC tag needs to be developed, still remain a challenge. In this article, they developed a nanostructured conductive polymer-based gas sensor with high sensitivity of ΔR/R0 = 225% toward 5 ppm ammonia NH3 and unprecedented sensitivities of 46% and 17% toward 5 ppm putrescine and cadaverine, respectively. The gas sensor plays a critical role as a sensitive switch in the circuit of the NFC tag and enables a smartphone to read out about meat spoilage when the concentration of biogenic amines exceeds a set threshold. Furthermore, the authors envision the broad potential use of such intelligent sensing for food status monitoring applications in daily life, storage and supply chains. Reprinted with permission from ref. (Ma et al., 2018).

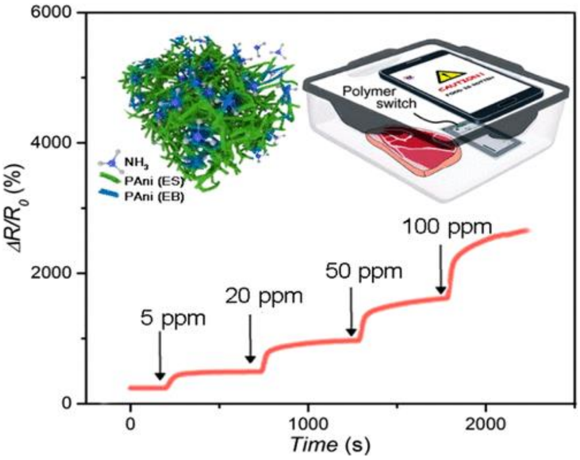


Figure 2: Food safety monitoring. Reprinted with permission from ref. (Ma et al., 2018)

The researchers (Ma et al., 2018) presented a novel NFC tag (Figure 2) for food spoilage detection with the advantages of a highly sensitive, printable nanostructured conductive polymer. Pablo Escobedo and ect. (Escobedo et al., 2020) have investigated a flexible strain sensor integrated with an NFC tag that can be better integrated into the packaging to detect food spoilage. The researchers (Nguyen, Tran, Chung, 2019) have developed a 2.5 cm × 2.5 cm sensor tag for a new method to read temperature and air pressure data and monitor the freshness of different types of food such as pork, chicken and fish during storage.
In the other article, author Jane Merchant (2022) analyses the NFC technology embedded into coffee packaging. The author says that many packaging manufacturers now use NFC as an interactive customer engagement tool. A customer can scan their coffee bag to access the detailed product information, as well as verify whether the product is authentic and has not been tampered with. This could be particularly useful for roasters and coffee shops, as transparency and origin information are aspects of specialty coffee that customers often look out for (Merchant, 2022).
The use of NFC technology in the packaging market is growing steadily. Therefore, the applicability of NFC stickers in packaging is very relevant. As research shows, NFC technology can not only provide information about the product/manufacturer (Merchant, 2022; Đurđević et al., 2019), directing us to a discount page but also provide information about the product's suitability for use (that is especially relevant in the case of food products) (Ma et al., 2018; Merchant, 2022).

3. RESEARCH PROCESS AND RESEARCH METHOD

There are many reasons to use NFC technology in the packaging industry. Firstly, packaging in the modern world is becoming more minimalistic, and manufacturers strive to use as little material as possible for packaging (from packaging material to printing). Therefore, NFC technology can be used instead of printing to convey product information (product quality, freshness and etc.).

Secondly, NFC technology allows interactive communication with the customer. This is particularly relevant for today's Generation Z, which is mainly interested in games and promotions.

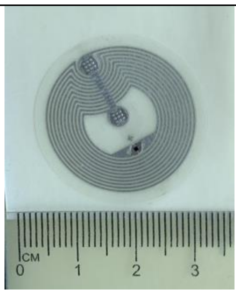
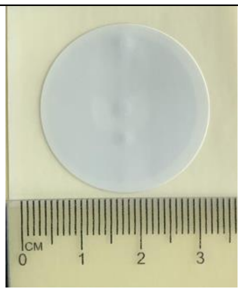
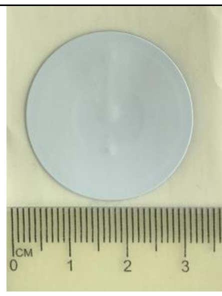
Thirdly, environmental friendliness. By moving away from printing on the packaging and using NFC technology to convey information.

Moreover, during the Covid 19 pandemic, many things have moved into the digital space, so using NFC technology for packaging can convey not only textual information about the product but also provide visual, more informative data.

It is, therefore, very important to analyse the possibilities and features of NFC stickers. To this end, a table of the technical characteristics of the stickers available on the market has been drawn up and classified into groups according to certain parameters.

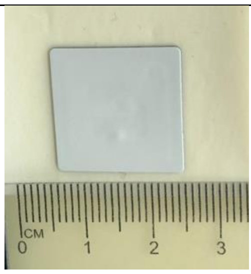
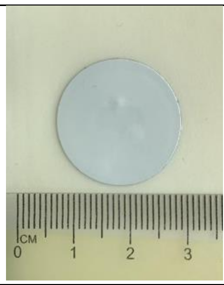
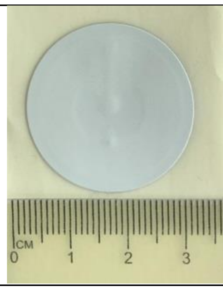
1. The first combination of NFC stickers consists of samples that have the same chip NTAG213 and diameter of 29 mm, but are produced on different substrates. More detailed information is provided below in Table 2.

Table 2: The data about the NFC stickers for the first experiment

Properties/NFC sticker type (product code)	ST710 Clear	ST711 White	ST706 On-metal
Picture			
Purchase from	Seritag	Seritag	Seritag
Diameter	29 mm	29 mm	29 mm
Label form	Circular	Circular	Circular
NFC chip	NXP NTAG213	NXP NTAG213	NXP NTAG213
Standard	ISO 14443A	ISO 14443A	ISO 14443A
Frequency	13.36 MHz	13.36 MHz	13.36 MHz
Data transfer (chip)	106 kbit/s	106 kbit/s	106 kbit/s
Memory (chip)	180 byte	180 byte	180 byte
User memory (chip)	144 bytes	144 bytes	144 bytes
Max URL Length (chip)	136 characters	136 characters	136 characters
Thickness	0.136 mm (upgrated)	0.19 mm	0.47 mm +-0.05 mm
Antenna Size	25 mm circular	25 mm circular	25 mm circular
Face Material	Clear PET Plastic	White PET Plastic	White PET Plastic
Adhesive	Acrylic, permanent	Acrylic, permanent	Acrylic, permanent
Water Resistance	Low	Low	Low
Water Rating	Water Resistant	Water Resistant	Water Resistant
Operating Temperature	-25C to 70C	-25C to 70C	-15C to 70C

2. The second combination of NFC stickers consists of samples that are all made for on-metal surfaces but are in different sizes and formats. More detailed information is provided below in Table 3.

Table 3: The data about the NFC stickers for the second experiment

Properties/NFC sticker type (product code)	ST730 On-metal	ST868 On-metal	ST706 On-metal
Picture			
Purchase from	Seritag	Seritag	Seritag
Diameter	19x19 mm	22 mm	29 mm
Label form	Square	Circular	Circular
NFC chip	NXP NTAG213	NXP NTAG213	NXP NTAG213
Standard	ISO 14443A	ISO 14443A	ISO 14443A
Frequency	13.36 MHz	13.36 MHz	13.36 MHz
Data transfer (chip)	106 kbit/s	106 kbit/s	106 kbit/s
Memory (chip)	180 byte	180 byte	180 byte
User memory (chip)	144 bytes	144 bytes	144 bytes
Max URL Length (chip)	136 characters	136 characters	136 characters
Thickness	0.48 mm	0.32 mm	0.47 mm +-0.05 mm
Antenna Size	16x16 mm	19 mm	25 mm circular
Face Material	White PET Plastic	White PET Plastic	White PET Plastic
Adhesive	permanent	permanent	Acrylic, permanent
Metal Surfaces	Yes	Yes	Yes
Real ScanStrength	21 mm – 25 mm (non metal) 6 mm – 10 mm (metal)	21 mm – 25 mm (non metal) 11 mm – 15 mm (metal)	21 mm – 25 mm (non metal) 16 mm – 20 mm (metal)
Water Resistance	Low	Low	Low
Water Rating	Water Resistant	Water Resistant	Water Resistant

Reference (Electronics notes, n.d.) states that there are four different types of NFC tags. The definition of each type is provided below:
Tag 1 Type: The Tag 1 Type is based on the ISO14443A standard. These NFC tags are read and re-write capable and users can configure the tag to become read-only. Memory availability is 96 bytes which is sufficient to store a website URL or other minor data. However, the memory size is expandable up to 2 kbyte. The communication speed of this NFC tag is 106 kbit/s. As a result of its simplicity, this tag type is cost-effective and ideal for many NFC applications (Electronics notes, n.d.).
Tag 2 Type: The NFC Tag 2 Type is also based on ISO14443A. These NFC tags are read and re-write capable and users can configure the tag to become read-only. The basic memory size of this tag type is only 48 bytes, although this can be expanded to 2 kbyte. Again the communication speed is 106 kbit/s (Electronics notes, n.d.).
Tag 3 Type: The NFC Tag 3 Type is based on the Sony FeliCa system. It currently has a 2 kbyte memory capacity, and the data communications speed is 212 kbit/s. Accordingly, this NFC tag type is more applicable for more complex applications, although there is a higher cost per tag (Electronics notes, n.d.).
Tag 4 Type: The NFC Tag 4 Type is defined to be compatible with ISO14443A and B standards. These NFC tags are pre-configured at manufacture, and can be either read / re-writable or read-only. The memory

capacity can be up to 32 kbytes, and the communication speed is between 106 kbit/s and 424 kbit/s (Electronics notes, n.d.).
From the definitions of the different NFC tag types, it can be seen that type 1 and 2 tags are very different to type 3 and 4 tags, having different memory capacity and makeup. Accordingly, it is expected that there is likely to be overlap in their applications (Electronics notes, n.d.).
Type 1 and type 2 tags are dual state and may be either read/write or read-only. Type 3 and Type 4 tags are read-only, data being entered at manufacture or using a particular tag writer (Electronics notes, n.d.).
The next stage of the study is to conduct mechanical experiments on different NFC stickers on selected packaging, taking into account the above-mentioned types of NFC tags:

1. Cold/heat resistance;
2. Moisture resistance;
3. Mechanical abrasion resistance.

The aim of the study is to analyse the readability of recorded information in NFC stickers after they have been subjected to specific mechanical properties. To investigate the transfer of information from stickers to a smart device after exposure to cold, moisture and mechanical abrasion. It is very important to investigate the speed of scanning and the accuracy of the information, as the Z-generation focuses the attention for a very short time. If the information takes a while to scan, the user will lose interest.

4. DISCUSSION AND CONCLUSIONS

Research shows that interactive and intelligent communication is essential for Generation Z. According to researchers, around 90% of smart device owners use them to access product information.
In addition, the packaging industry is increasingly using NFC technologies (more than 10 times between 2014 and 2024) to provide information about the product being purchased, from the product's composition to information about the product's fitness for use.
After the literature review and the development of the methodology, the next step is to investigate the readability of NFC stickers when exposed to certain mechanical properties (humidity, cold, mechanical abrasion). The parameters were chosen considering the most common problems encountered during the transport and/or storage of the products.

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DEVELOPMENT OF ANTIFUNGAL PACKAGING COATING FOR BREAD

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Abstract: *One of the main concerns in the world is health. The expansion of the food industry has also led to an increase in human morbidity. Therefore, nutrients, especially food additives, started to be more closely controlled after the emergence of scientifically proven threats. Even though these substances are strictly observed to ensure appropriate quantities and materials are used, consumer opinion is still negative towards them.*
Another crucial problem is the environment. Plastic waste generated in greater vast each year is accumulating and taking more and more space not only on land but also in water and even air. This is because plastic is cheap, strong and quickly made material leading to being the main type of packaging nowadays and creating this loophole situation. By combining naturally occurring substances, new packaging can be created to have the needed qualities.
The purpose of the study was to create the coating with the synergetic essential oils mix for bread to replace the usual plastic package with an environmentally friendly and mould-resistant option.

Key words: bread, paper packaging, essential oil, antifungal

1. INTRODUCTION

Various studies on sustainable materials are underway. However, their common drawback is the expensive and lengthy manufacturing processes that lead to the use of plastic again. Another most commonly used packaging type is paper. Because of absorbency and permeability, paper packaging is unsuitable for certain types of food, but if the plastic is inserted, the packaging becomes not recyclable. So, to overcome this problem, it is necessary to develop an all-natural packaging.
Most of the products sold in the market come with packaging. They all have different requirements to be used as packaging for different types of goods. When it comes to food products, they are subject to even stricter rules because their safety depends on their packaging. Packaging can not only help preserve product quality but also increase it. Proper selection of packaging materials can extend the shelf life of microbiologically sensitive foods.

2. METHODS

The bread was chosen from the market leader in Lithuania – which occupies 21,8% of the market share (Euromonitor International, 2022). For the experiment were selected three different names (A, B, C) for bread were. All of them are mixed rye bread, which does not have preservatives and contains grains and(or) seeds. This type of bread contains a lot of moisture. Table 1 shows the compositions of chosen bread types.
These three products are similar in composition. All three types use 11 components - water, rye flour, sunflower seeds, wheat flour, linseed, sugar, yeast, iodized salt, wheat fibre, rye malt, and flour processing agent ascorbic acid. Therefore, their recipes are similar. The difference between C bread is that its main ingredient is whole grain rye flour, and this good thing has more different components such as grains and other seeds.

Essentials oils

The types of plant Essential oils (EO) were selected by evaluating source information and the company's provided chromatogram with the exact quantity of each component.

- The selected source of carvacrol is EO of oregano (Origanum vulgare) with the main component amount of 57.36% (Kvapų namai, 2022);

- The EO of clove (Syzygium aromaticum) was used as the source of eugenol with its part in the mixture of 68.18% (Kvapų namai, 2022);
- Oil of lemon grass (Cymbopogon citratus) provides citral, which takes a 67.54% combined geranial and neral (Kvapų namai, 2022);
- Thymol was provided by the EO of thyme (Thymus zygis), which percentage in the mixture is 35.06% (Kvapų namai, 2022).

Table 1: Ingredients of tested types of bread (Kvapų namai, 2022)

Product	Ingredients
Seed bread "A"	Water, rye flour, sunflower seeds (15.4%), wheat flour, pumpkin seeds (10.3%), watermelon seeds (10.3%), flaxseed (9.0%), sugar, yeast, wheat gluten, iodized salt, wheat fiber, rye malt, caraway seeds, flour treatment agent ascorbic acid.
Black sliced bread „B" with seeds	Rye flour, water, wheat flour, sunflower seeds (13.7%), flaxseed (8.8%), pumpkin seeds (7.6%), sugar, yeast, iodized salt, wheat gluten, rye malt, barley malt extract, wheat fiber, flour treatment agent ascorbic acid.
7 grain dark sliced whole grain bread „C"	Wholegrain rye flour (23.9%), water, rye flour, wheat flour, sunflower seeds (6.5%), broken rye (3.3%), broken wheat (3.1%), barley malt extract, wheat gluten, barley groats (2.5%), sugar, flaxseed (1.3%), soy grits (1.3%), yeast, iodized salt, peeled sesame seeds (0.5%), wheat fiber, rye malt, caraway seeds, flour treatment agent ascorbic acid .

Packaging

The paper packaging, to substitute the plastic, was chosen by the company „Mayr-Melnhof Karton AG" (MMK). In 2016, this company created an innovative carton board specialized for foodstuff - FOODBOARD™. Its main distinctiveness:

- Is a food-safe carton board with a functional barrier that works;
- Mineral oils, phthalates, and bisphenol A are examples of unwanted ingredients that are protected in packaged meals;
- Cross-contamination is prevented throughout transport, storage, and at the point of sale;
- It is neither an extruded nor laminated compound, but rather a pure carton board solution;
- Is biodegradable, recyclable, and comes with an FSC® or PEFCTM certification;
- is offered on the brown reverse side (GT4) and light reverse side (GT5) recycled carton board (GT1) (MM BOARD & PAPER, 2022).

Base: 1 kg of soy wax was purchased from the online store soyacandles.lt. It is made 100% from soybeans, hydrolysed and comes in the flake form. Batch no. is 0018187963 with the 10th of September, 2021, date of manufacturing. Other important characteristics are indicated in Table 2.

Table 2: Parameters of soybean wax NatureWax C-3 (Soyacandles.It, 2022)

Criterion	Value
Storage temperature	15 - 25°C
Melting point	45°C
Maximum heating temperature	71.1 – 93.3°C

12 boxes were used of this study:

- 3 boxes – inner surface covered with 2 layers of soy wax;
- 3 citral and eugenol incorporated boxes – inner surface covered with 2 layers of the mixture consisting of 100g soy wax and 2 drops of lemon grass and 1 drop of clove EO;
- 3 citral and thymol incorporated boxes – inner surface covered with 2 layers of the mixture consisting of 100g soy wax, 2 drops of lemon grass and 3 drops of thymol EO;

- 3 carvacrol and thymol incorporated boxes – inner surface covered with 2 layers of the mixture consisting of 100g soy wax, 1 drop of oregano and 3 drops of thyme EO.

3. RESULTS

The pictures of bread on the 1 st, 3rd, 6th and 9th day are presented in Table 3.

Table 3: Results of bread shelf-life comparison

	"A"	"B"	"C"
1st day			
3rd day			
6th day			
9th day			

On the 9th day, signs of mold observed in the bread "A" and "C". Sample "B" was intact. As “C” specimen had the bigger affected space by the unwanted fungus activity, this leads to the conclusion that this type of bread is most susceptible for mold. This bread (“C”) was choosing to continue further tests.
The samples in boxes containing citral and eugenol EO mix coating at two designated times are exhibited in Table 4.

Table 4: Samples, kept in boxes with citral and eugenol coating, on 1st and 9th day

		1st day	**9th day**
1st sample	1st side		
	2nd side		
2nd sample	1st side		
	2nd side		
3rd sample	1st side		
	2nd side		

The bread slice in the 1^{st} box does not have any noticeable dissimilarities. However other 2 had observable changes: 2^{nd} sample had a fuzzy mold grown on the non-contact side, 3^{rd} had noticeable mold on both halves.
The photos before and after storage with a coating including citral and thymol are present in Table 5.

Table 5: Samples, kept in boxes with citral and thymol coating, on 1^{st} and 9^{th} day

		1^{st} day	**9^{th} day**
1^{st} sample	1^{st} side		
	2^{nd} side		
2^{nd} sample	1^{st} side		
	2^{nd} side		
3^{rd} sample	1^{st} side		
	2^{nd} side		

No mold formation was observed in samples stored in this type of packaging. Samples of bread before and after keeping in a paper box containing carvacrol and thymol EO with wax are presented in Table 6.

Table 6: Samples, kept in boxes with carvacrol and thymol coating, on 1st and 9th day

		1st day	**9th day**
1st sample	1st side		
	2nd side		
2nd sample	1st side		
	2nd side		
3rd sample	1st side		
	2nd side		

Any noticeable alterations were observed on these samples either.

4. DISCUSSION AND CONCLUSIONS

In the performed experiment, wax coating with synergetic EO mix capacity was evaluated. 2 layers of the wax coating were enough to reduce the paper's air permeability, and keep the bread moist and susceptible to mold. 2 of 3 tested pairs, citral with thymol and carvacrol with thymol, showed no growth after 8 days of storing in an active coating covered box. Both blends contain thymol, meaning it could be the main constituent determining the effectiveness. Control and eugenol-thymol coating samples demonstrated similar results, which means the mixture was not effective.

Second, precise concentrations, not approximate ones, are critical to produce synergistic effects. Only specific values of both components can create synergy. To determine the exact values of the materials, it is necessary to apply a larger quantity of the coating or to use more accurate equipment.

Finally, sensory analysis is required. It shows this may or may not be acceptable to consumers depending on the smell and may become an advantage or disadvantage.

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DEVELOPMENT OF A CONCEPTUAL SOLUTION FOR INTERACTIVE PACKAGING FOR OLIVE OIL

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Abstract: *Interactive packaging is associated with data transmission methods such as 2D barcodes, radio frequency identification (RFI), near field communication (NFC), electroluminescent displays (ELD), and augmented reality (AR) for packaging. Data on storage, distribution, and characteristics of packaged food are most often stored. Some of the important data on storage conditions that can be stored are temperature and relative humidity, and data on food quality from microbiological points of view are also important. All collected data is easily accessible and enables an efficient flow of information to the supplier or end-user or customer.*
The manuscript will present the development of a conceptual solution for functional interactive packaging for olive oil with radio frequency identification. The conceptual solution is designed with full functionality in terms of packaging materials because certain packaging materials such as glass can interfere with wireless contactless technology that uses radiofrequency to transmit information. In addition to all the above, sustainable design settings were considered during the development of the conceptual design, so that the product follows a combination of the latest trends in the process of designing packaging products.

Key words: conceptual design, packaging, RFID, sustainability

1. INTRODUCTION

One of the functions of the primary packaging products is the attractiveness of the design. When creating the design of the packaging product, the function of interactivity can be incorporated, to further attract customers and inform them about the product. In a survey conducted by the Austrian manufacturer of packaging products Constantia Flexibles, it can be noted that 69% of respondents would rather buy or take off the shelves a product with interactive packaging than a similar product with a traditional design, which confirms the attractiveness of such products (Constantia Flexibles, 2017).
Near-field communication (NFC) is a short-range data exchange technology based on radio-frequency identification technology and was designed by Sony and Philips in 2002. NFC communication protocols and data exchange formats are based on FeliCa Card RF Performance standards Certification Specification and ISO/IEC 14443 (Part 1-4) standards (Dantuma et al., 2018; FeliCa Card, 2021; ISO/IEC 14443, 2018; Motlagh, 2012). Information from NFC is transferred to another device (mobile phone or tablet) by electromagnetic induction, and the efficiency of connecting the device depends on the design, configuration, and settings of both antennas (Motlagh, 2012; Pretty, Prabaharan & Balamurughan, 2014). Data transmission is carried out at a distance from 2 to 5 centimeters, which ensures security against information theft during eavesdropping (Chang, 2014). It should be emphasized that the NFC function on mobile phones is not active unless the user activates it himself, which gives the user additional security. In addition to everything mentioned, the NFC tag is sensitive to the direction of action, which further prevents hackers. The NFC tag can be locked after encoding the data, which makes it impossible to change or add data. Most tags can no longer be unlocked. The mentioned security features contribute to the increase in the use of tags in packaging products.
That's how the English producer of the alcoholic drink Bombay Sapphire added augmented reality (AR) elements to the label. In this way, users, by scanning special labels, can enjoyed sound, images, and videos with detailed recipes and other information related to the product (Gilliland, 2018).
In addition to augmented reality, solutions with built-in NFC (Near-field communication) technology, described in detail in the next chapter, are receiving more and more attention. American wine producer Böen, in collaboration with SharpEnd and Guala Closures, has created the first aluminum wine closure with integrated NFC. To invite consumers to interact, they came up with the simple text "Tap our Cap" which normally appears on the ribbon around the bottle. In literal translation, it calls the user to action. This type of marketing tool is called CTA or call to action. By holding their smartphones up to the bottle cap, consumers instantly access wine information. In doing so, they verify their product and are then

transported to a virtual California farmhouse to unlock information about the wine they purchase, create, and share content, and build their own virtual wine cellar (We Are SharpEnd, 2021).

Through the cooperation of OTACA Tequila and Identiv, an NFC tag was installed on the bottle so that customers can authenticate and re-order the product using a smartphone. Customers could also find out information about the history of the brand. The first version of the packaging contained an NFC tag on the lid of the bottle itself along with the text because consumers sometimes did not notice the possibility of using it. To further emphasize the possibility of using interactive technology, the cap had a white layer and black printing above and below the place where the antennas were located (Cole, 2022).

Malibu's 'Because Summer' series packaging incorporates NFC technology to enhance the shopping experience for consumers. To notify consumers, they include an educational hanger for the neck of the bottle that informs that the bottle has NFC technology on the front of the bottle. Customers could be able to use three digital experiences, an interactive prize game, new recipes, and exclusive media to continue the summer feeling. In past campaigns, they collected data related to purchases and demographic data. Technological innovation from Malibu 'Coco-nect' - coconut serving cup for Malibu cocktails eliminates the need to wait in line at music events. NFC technology is included in packaging products and serves as part of a good marketing strategy (Newsroom, 2017).

The aim of the work is to design a packaging prototype for extra virgin oil according to the results of the survey so that the designed packaging would be attractive to consumers. The packaging would meet the standards of sustainable design with modern NFC tag technology.

2. METHODS

The scientific research shows the creation of a conceptual solution for the primary eco-packaging for olive oil, which combines the premise of sustainability and the features of smart packaging. NFC tag type 2, i.e., NTAG216 read-write model manufactured by the company NXP, is used to create the prototype of the packaging product. The NFC tag is applied to a transparent PET label (Figure 1). In Figure 1, the parts of the NFC tag are clearly visible, such as the antenna and the chip.

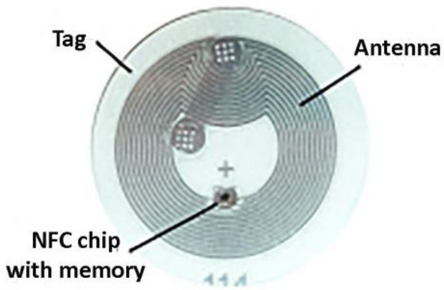

Figure 1: Photo of a sticker with an applied NTAG216

Table 1: Properties and characteristics of NTAG216

Properties	water resistance	incompletely
	transparency	completely
Technical characteristics	diameter	25 mm
	thickness	0,18 mm
	frequency	13.56 MHz
	data transfer speed	106 kbit/s
	read/write memory capacity	888 bytes
	password security	32-bit

The NFC tag is resistant to a certain amount of moisture from the surrounding atmosphere and, due to its small dimensions, is almost imperceptible to the eye (Table 1).

Saved records have a durability of up to 10 years, with the possibility of deleting about 100,000 times. The password ensures the preservation of old records and the correspondence of new records of the

owner. It should be emphasized that successive writing and deletion of records affect the consumption of memory (Web Cambridge, 2018).
NFC encoding was performed using the manufacturer's official application (NXP TagWriter). The application on the menu offers various functions that can be coded on the tag. In scientific research, a web address (link) is coded into the prototype, which points to an interactive personalized product page.

3. RESULTS

For the desired function to be saved and transferred to the NFC tag in the NXP TagWriter application, default records are stored and printed in Records. Open authentication on the mobile device and then encodes the NFC tag (Figure 2).

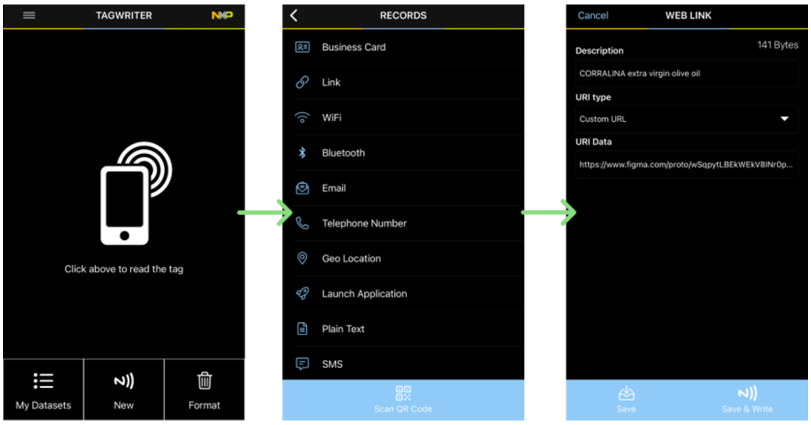

Figure 2: Encoding process through the NXP TagWriter application, part I

Considering the topic of the research, the desired link related to olive oils is being prepared, it occupied only 95 bytes. The mentioned enables the encoding of the NFC tag with other functions (Figure 3). As it was not possible at this time to write information about the conditions for product delivery such as temperature, humidity, light, and others (which can be added later), only the link was coded. Figma was used to create the prototype of the application (interactive web). The application was created to satisfy the informational and promotional needs of the customer while emphasizing the sustainability of the product through design solutions. The created application contains various information that normally appears on traditionally designed packaging (such as general information about the product, such as date and place of production, expiration date, and nutrient table), but in addition, it contains much more information about the manufacturer (brand story, contact form, social networks, gallery), a timeline showing of the maturation of oil over a certain period, tips for storing and using extra virgin oil, and ecological signs with additional explanations to the possibility of misinterpretation is eliminated.

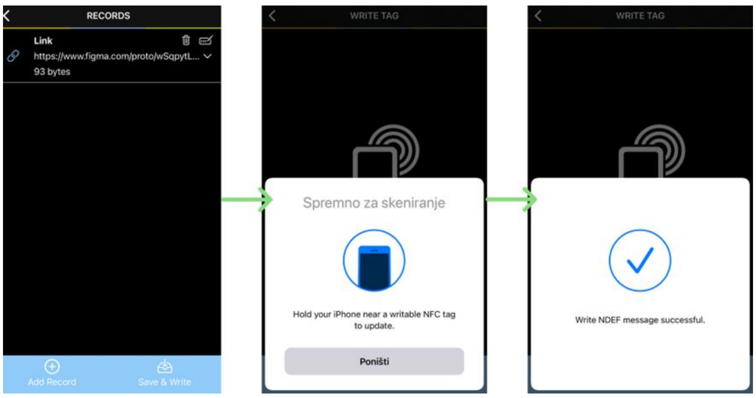

Figure 3: Encoding process through the NXP TagWriter application, part II

The steps of a photo montage of the initial screen of the conceptual solution of the interactive web with the corresponding menu are shown in Figure 4 (Web Behance, 2021). Information stored in the mentioned way is available to the customer, the website is easily updated, there is no need for printing and the consumption of printing materials can affect the environment. Printing inks and adhesives can contribute to air quality with the volatile organic compounds they contain in their composition, which contribute to the formation of L.A.-type smog. Paper production leads to air pollution with sulfur compounds of reducing characteristics, volatile organic compounds, and water oxidizing agents in the bleaching process.

Figure 4: The initial screen of the conceptual solution of the interactive web

After information storage, the NFC tag is applied to the glass packaging of olive oil. Bottles of 0.5 L and 0.75 L were used in this research. The choice of packaging material is related to the product to be contained. In the research, olive oil is studied, the nutritional properties and shelf life of which are best preserved in dark glass packaging. The dark color of the glass was chosen due to the impermeability of ultraviolet rays of light, which have a negative effect on extra-virgin olive oil, which is at the top of the hierarchy in terms of the quality of olive oils (Periyasamy et al., 2018). When ensuring the sustainability of the packaging material, glass has favorable characteristics, it can be recycled an infinite number of times. Attention must be paid to the negative properties of the mentioned packaging material, which is the weight that contributes to greater pollution during the transportation of the product. It contributes to the formation of greenhouse gases and L.A.-type smog, but the benefits of the selected material are more important than those listed. Another alternative for packaging material would be multi-layered materials that have a smaller mass but are difficult to separate or prepare for the recycling process of each individual material.

An NFC tag is applied to the packaging, above which a label with basic information about the product is applied (Figure 5). The enumerated forms the conceptual solution of the primary eco-packaging. The information printed on the label is the name of the brand, description of the product and its volume, statement about the ecological product (Caring for you & the environment), and notification about the possibility of using the NFC tag.

Figure 5. Primary eco-packaging for extra virgin olive oil

The design of the label and the interactive web is linked to two premises. One premise is related to survey research that suggests simplicity of design. The second premise stems from the fact that the minimalist design and colors from nature such as green suggest the naturalness and ecological awareness of both the packaging product and the olive oil. The language of writing on the label is English for the design to be suitable for a wider market, that is, for the conceptual solution to be applicable in a global context. The label was printed using the UV printing technique, to reduce the impact on the environment. There is no need to use printing plates, which contributes to the saving of materials, there is no emission of harmful chemicals that are used in the production of printing forms itself (Periyasamy et al., 2018). The mentioned printing technique was also chosen because of its suitability for smaller editions, and the printing of the label for organic oil production is related to smaller editions. When printing, UV drying inks were used that do not contain volatile organic compounds that have a negative effect on the environment, which was already explained earlier.

4. DISCUSSION

After naming the product and creating a prototype of the primary packaging proposal for olive oil from the described conceptual solution, it was presented to the respondents in the age group of 25 to 35 years. The group consists of equally represented persons of the female and male gender. Respondents' opinions about the experience while handling the prototype were recorded, as well as their attitudes and opinions about this type of packaging after the interaction. Based on their experience with eco-packaging, it is possible to see the advantages and disadvantages of the prototype. Part of the respondents asked for help with reading the NFC tag with a mobile phone. Not knowing how to handle the mentioned label should not be a problem if consumers become familiar with it and if packages with interactive features be more common in use. The inclusion of instructions for reading the NFC tag in the instructions for iPhone and Android users could contribute to more frequent use of the NFC tag. It is recommended to create such instructions on websites to avoid printing instructions with an increased number of pages compared to the previous ones, which would increase the unsustainability of mobile devices. It can be assumed that with more frequent use of the label, users will transmit the instructions orally, which is the most sustainable way of educating users about product packaging. Literature research showed possible implications of cultural differences on the adoption of NFC technologies that are operating in peer-to-peer mode (Özdenizci et al., 2010).

Half of the respondents with Android devices recognized the implemented technology and did not need help in interacting, i.e., reading the NFC tag. The good result could be explained by the young age group of the respondents. Once loaded, the used type of tag (NTAG216) worked well on all common NFC-enabled smartphones.

The functionality of the prototype was tested, and all the information stored on the tag could be read by the respondents. The described test is important because, in addition to the transparency of the tag, the aim is to reduce the size of the tag so that it is as little notice as possible on the packaging. Because of this, the impact point for the transmission of signals or information is smaller. The testing of the prototype showed the full functionality of the packaging product. The advantage of the used technology can be found in the fact that there is no need to install additional applications on mobile devices because most mobile devices could read NFC tags. It is evident from the above that the technology significantly contributes to the reduction in the utilization of the device's memory space.

Most respondents, 90% of them, positively evaluated the use of the prototype, and the same percentage of respondents expressed interest and desire to use the presented type of primary packaging. From the above, it can be concluded that training on the use of NCF is easy to master if it is needed at all, and respondents about the prototype point out good features such as the simplicity and speed of available information, transparency of content, and a different interesting experience. The advantage of the prototype, which was seen by all respondents, is the contribution of the design to the sustainability of the packaging product. Ignorance of NFC as a technology and the principle of its functioning led one respondent to doubt the theft of data from a mobile device, which is not a possible scenario.

For the information stored on the NFC tag to be complete, suppliers and representatives should have the knowledge and ability to supplement information about the environmental conditions in which the product was located at the time of purchase. In this way, all relevant information affecting the durability and quality of the high-quality product, which in this case is extra virgin oil, would be presented to the customer. To make the use of the NFC tag more complete, it can be combined with sensors or NFC that record temperatures, in which case it is not necessary to add data from the supplier or dealer, which makes it easier to use the product for packaging. In addition, tag data can be integrated with real-time location reading or fingerprint reading, and facial recognition can be integrated, which helps with transaction execution. A special contribution of the NFC tag is the development of interactive packaging adapted to people with disabilities such as the visually impaired. On the website, it is possible to display text and images in a larger font or larger dimensions, and it is also possible to program text readers.

5. CONCLUSIONS

In the packaging industry, a lot of attention is paid to the sustainability of packaging products, which is additionally emphasized when packaging organic products. Buyers of organic products are especially concerned about the sustainability of the entire product. Interactive packaging is interesting for customers because it contributes to customer information. By combining both trends, a product is obtained that can be maintained on the market for many years. The NFC tag can contribute progress to the production of packaging products, due to the possibility of storing information that speaks about the quality of food products such as extra-virgin olive oil. When applying an NFC tag to a packaging product, the amount of text on the label can be significantly reduced, which contributes to reducing the consumption of printing inks. In the mentioned way, the amount of materials used and the emission of pollutants into the air that contribute to the formation of L.A.-type smog are reduced.

In this research, was made the design of the prototype packaging for olive oil based on the survey data. Wanted to design a solution that has a design desirable to customers in addition to ecological aspects. For the NFC tag to be functional, it was necessary to create a website whose link will be stored on the tag. The dominant color in the design of the label and the page is green to emphasize the ecological suitability of the product as well as the connection with the green leaves of healthy olive wood and olive fruit. The color was supported by the surveyed participants in the survey.

Prototyping consisted of applying a transparent tag with stored information on the bottle and applying the label. After creation, the prototype was tested by the user, where uncertainties in the use of the NFC tag were noticed in places. The paper contains suggestions on how to eliminate the mentioned problem. The surveyed users like the prototype and would use it in their everyday life, by which it can be concluded that the prototype was successfully created. In addition to the desired functions tested by users, the prototype contains technical and design solutions that were fully functional. Which makes another reason why the proposed solution could be considered a successful proposal. In the future, it is planned to improve the stored functions on the tag and to test the durability of the prototype.

6. ACKNOWLEDGMENTS

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EXPLORING ODOR ASSOCIATIONS BASED ON PACKAGING VISUAL ELEMENTS

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Abstract: *Previous studies have shown that packaging design can influence people's expectations regarding product attributes. This study explored the role of packaging visual design in presenting a non-visual attribute (i.e. odor) by investigating consumers' responses to various graphic designs displayed on perfume packaging. Particularly, the aim was to examine how different visual elements (such as patterns, photographs and illustrations) influence product choices, preferences and odor associations. 136 people participated in the study, with approximately equal numbers of males and females. They were presented with 10 packaging samples. The samples were of the same shape and size but with different visual elements. The results of the experiment confirmed that participants associated highly recognizable objects with their specific odors. For example, a lemon pattern was paired with a fresh smell, and an image of a rose was paired with a floral smell. On the other hand, when packaging presented odor-neutral objects, the participants' responses were not uniform. The design which was associated with the largest range of smells was the one with a photograph of a human body, which was paired with three different perfume types (namely, floral, woody and oriental). When data were split by gender, the results suggested that men had a preference for regular and sharp visual shapes. Another relevant finding is that perception of perfume packaging can be influenced by age. Young participants mostly preferred abstract visual shapes for perfume presentations. The results of the choice task indicated that young participants were more sensitive to variations in design than mature participants. Furthermore, they associated most of the packaging designs with more than one type of smell. The findings can be useful for successful perfume packaging design, especially when young consumers are the main target audience.*

Key words: packaging; perfume; graphic design; expectations; choice

1. INTRODUCTION

Previous studies have shown that packaging can be used as a strong strategic tool which can influence consumers' expectations (Kovačević et al., 2022), their product evaluation (Petersson Mcintyre, 2013) and purchase decisions (Salem, 2018). Visual elements on packaging are noticed directly, so they facilitate the transmission of the message which the packaging aims to deliver. Therefore, they can stimulate the first contact between the product and a potential buyer. What is more, the visual elements can evoke particular sensations which are not necessary visual in their nature. Perfume packaging could benefit from this, since it often needs to convey information about a specific odor in order to contribute to the consumers' expectations of the product. Past research demonstrated that certain visual symbols can be paired with specific odors (Martino & Marks, 2000). According to Brianza et al. (2021), lemon odor is associated with rough textures, while rose odor is associated with soft textures and rounded shapes. Rounded forms can also be connected with vanilla smell or raspberry. In contrast, angular shapes are associated with citrus odors and pepper (Blazhenkova & Kumar, 2018; Hanson-Vaux, Crisinel & Spence, 2013). In successful packaging design it is necessary to understand the importance of the visual representation of smells (Silva, 2019). Thus, the main goal of our study was to investigate how different visual elements (such as patterns, photographs and illustrations) influence participants' odor associations. Past research showed that women are often more sensitive to the visual appearance of the product packaging than men (Lidón et al., 2018), and they tend to make purchases based on label design (Barber, Almanza & Donovan, 2006). However, in the case of perfumes it was found that men pay more attention to the perfume selection criteria (such as bottle design) than women (Tien-You, 2012). This confirms the findings of Baruk and Iwanicka (2016) who reported on how the participants' gender influenced their expectations of how the packaging will determine their buying decision. On the other hand, a Vyas's study (2015) showed no significant impact of gender in consumers' responses to packaging design. Given that previous research showed inconsistent findings, the aim of our study was to contribute to the better understanding of the effects of gender in the context of perfume packaging design.

As suggested by some studies, other demographic characteristics may play a role in consumers' perception of product packaging (Baruk & Iwanicka, 2016). Vyas (2015) found that age can influence the likelihood of selecting products with pictures on their packaging. Tien-You (2012) found that people aged below 35 put more attention to perfume selection criteria than those aged above 36. Again, as with gender, the age was not confirmed as a significant factor in all packaging studies. For example, Elango and Thansupatpu (2020) reported that different age range did not affect consumers' purchases of perfume. Thus, our study investigated the effects of both participants' gender and age.

2. METHODOLOGY

As used in recent packaging studies (Hall et al., 2021; Kovačević et al., 2022; Poslon, Kovačević & Brozović, 2021), an online questionnaire was used to collect the participants' responses. 136 adult consumers ranging from 18 to 65 years of age participated in the study. There were an approximately equal number of women (54%) and men (46%). Since later analysis used age as an independent variable, the age data were split into two groups. One group included young consumers (aged between 18 and 40 years, n = 72), while the other group included mature consumers (aged between 41 and 65 years, n = 64).

The design of packaging samples was carefully controlled. It consisted of pictorial elements such as patterns, photographs and illustrations. There was no text. A recent study showed that brand names influence the way in which consumers form olfactory imagery (Meng, Zamudio & Jewell, 2021) and therefore packaging samples contained no brand markings. To minimize the influence of colour (Schifferstein & Tanudjaja, 2004), all packaging samples were grayscale. The packaging visual design was presented on both the outer cardboard packaging and the perfume bottle. The samples were of the same shape and size but with different visual elements. The goal was to include a large amount of visual representations which could be used in packaging design. There were two packaging designs containing fruit, two designs presenting a piece of paper, two designs with floral depiction, two designs with animal representations, and two dark designs with elegant objects.

The questionnaire consisted of four parts. In the first part of the questionnaire, basic demographic data were obtained. In the second part, there was a series of choice-tasks. The participants were presented with five pairs of packaging designs (ten packaging designs in total). For each pair, they were asked to select the one which they consider more attractive. The packaging pairs are presented in Figure 1. In the third part of the questionnaire, all ten packaging samples were presented and the participants had to indicate the samples they prefer the most. The final (fourth) part consisted of odor association tasks and its goal was to get data about the consumers' scent expectations based solely on the packaging visual design. The participants viewed the packaging designs one by one and answered the closed-ended question "Which odor do you associate this design with?" by selecting one of the following options: "Floral", "Oriental", "Woody", "Fresh". These scents were also included in previous perfume-oriented works (Kim, 2013; Veramendi, Herencia & Ares, 2013).

There was no time limitation for completing the survey. The average completion time was approximately 3 minutes. None of the participants failed to answer any of the questions. The participants were informed that all the responses were anonymous and no identifying information was collected.

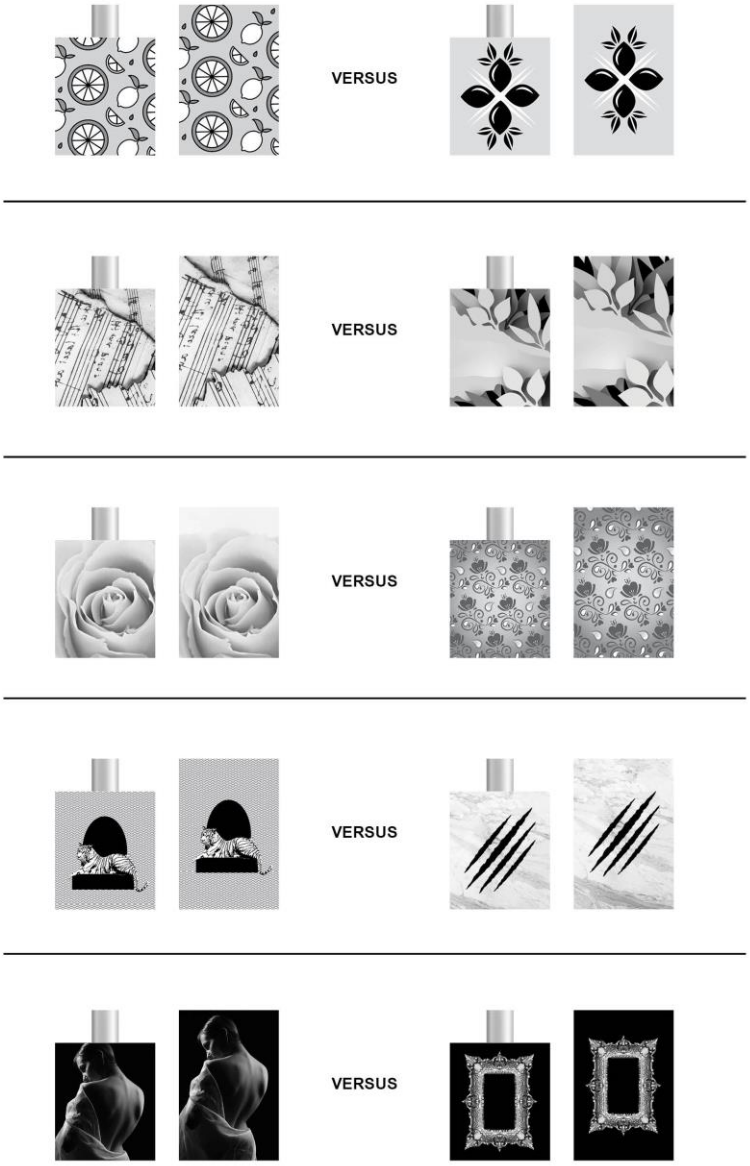

Figure 1: Packaging pairs used in the choice-tasks

3. RESULTS

3.1 Product choices

McNemar's tests were performed to analyse the results of the choice-tasks for each packaging pair by using IBM SPSS 23. The statistical tests were made with 0.05 as the level for statistical significance, unless otherwise noted.

For the young participants, the results showed a significant difference between packaging samples in all the presented packaging pairs. They selected the design with centrally-composed lemon graphic (70.83%) over the design with the continuous lemon pattern (29.17%), $p < 0.05$. They selected the paper-cut design (72.22%) over the paper photo (27.78%), $p < 0.05$. Furthermore, the design with the photo of a flower (86.11%) was selected over the design with the floral pattern (13.89%), $p < 0.05$. The packaging design with realistic animal representation (63.89%) was selected over the packaging with metaphorical animal representation (36.11%), $p < 0.05$. When choosing between two dark elegant packaging designs,

the young participants selected packaging with the frame (63.89%) over the packaging with the woman's body (36.11%), $p < 0.05$.
The mature participants were less sensitive to the packaging variations. There was no statistically significant difference between the packaging samples with the lemon ($p = 0.71$), the animal ($p = 0.38$), and the dark elegant designs ($p = 0.90$). However, similar to the young participants, they selected the paper-cut design (64.06%) over the paper photo (35.94%), $p < 0.05$. They also selected the design with the photo of a flower (73.44%) over the design with the floral pattern (26.56%), $p < 0.05$.
When the responses were split by gender, the results indicated a noticeable difference in packaging choices between women and men. The female participants selected the paper-cut design (80.82 %) over the paper photo (19.18%), $p < 0.05$, whereas there were no significant differences in these two packaging designs for the male participants ($p = 0.61$). On the other hand, there were no significant differences in packaging with the lemon designs and packaging with the dark elegant designs (both $p = 0.64$) for the female participants, while the male participants selected the continuous lemon pattern (80.95%) over the design with the centrally-composed lemon graphic (19.05%), $p < 0.05$, and the packaging with the frame (68.25%) over the packaging with the woman's body (31.75%), $p < 0.05$. The only concurrence between men's and women's choices was found in the case of the design with flowers, where both groups selected the design with the photo of a flower (91.78% of the women and 66.67% of the men) over the design with the floral pattern (8.22% of the women and 33.33% of the men), both $p < 0.05$.

3.2 Preferences

The consumers' preferences for packaging designs were calculated as the number of participants' selection in the third part of the experiment, in which they indicated the packaging designs they prefer the most when presented with all ten packaging samples at the same time. Figure 2 and Figure 3 show the number of selections for each packaging sample. The most interesting finding is that three groups of participants (namely, the young, mature, and female) preferred the design with the photo of a flower, followed by the paper-cut design. Only one group of participants (male), performed different choices. Men preferred the packaging with the frame, followed by the packaging with the centrally-composed lemon graphic.

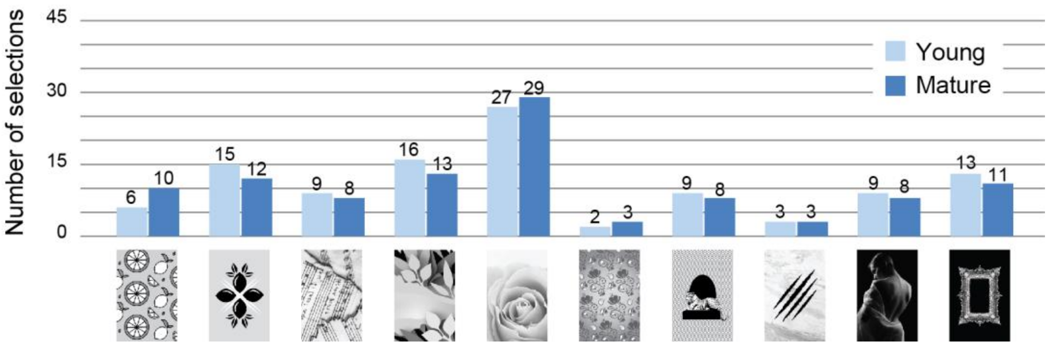

Figure 2: Young and mature participants' preferences

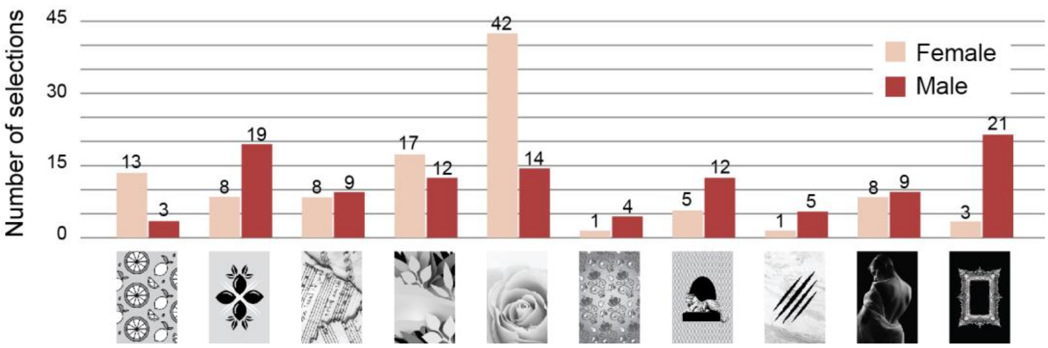

Figure 3: Female and male participants' preferences

3.3 Odor associations

The statistical significance between odor associations among the groups was analysed with McNemar's tests. A Bonferonni correction was applied, and therefore $p < 0.008$ was accepted to be statistically significant.

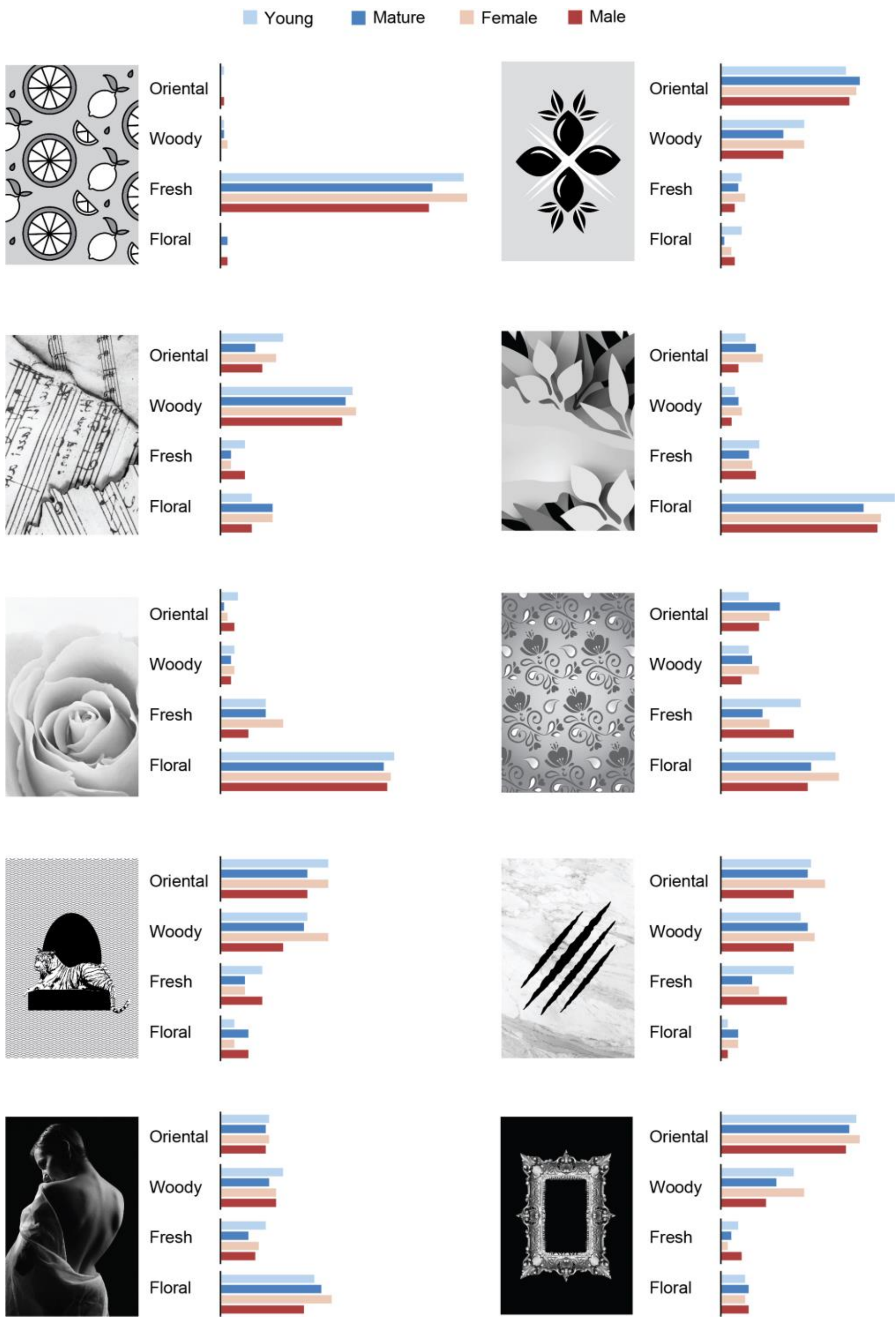

Figure 4: Packaging-odor associations (bars represent the number of odor associations)

Figure 4 summarizes the number of participants' odor associations. The design with the continuous lemon pattern was associated with a fresh odor by all the participants. Both the paper-cut design and the design with the flower photo were associated with a floral odor. For all the participants, the packaging design with the realistic animal representation was associated with both an oriental and woody odor, while the packaging with the metaphorical animal representation was associated with the same odors, but also with the fresh odor. For the other packaging designs, the associations with the odors varied across the participants' groups.

The design with the paper photo was associated with a woody odor, but young participants also associated it with an oriental odor. The packaging with the centrally-composed lemon graphic was associated with both an oriental and woody odor, but mature participants associated it only with an oriental odor. The mature participants associated the floral pattern design with a floral and oriental odor, whereas all the other participant groups associated it with a floral and fresh odor. The packaging with the frame was associated with the oriental odor by all the participants, but young participants and women also associated it with a woody odor.

The packaging with the photo of a woman's body evoked the most diverse associations. It was associated with a floral, woody, and oriental odor by all the participants, but young participants also associated it with a fresh odor.

4. DISCUSSION

The results of the study showed that the participants associated highly recognizable objects with their specific odors. For example, the lemon pattern was paired with a fresh smell, and the image of a rose was paired with a floral smell. The packaging design with the picture of a rose also contained a very soft texture which was found to be related to flower connotations in previous studies (Brianza et al., 2021). On the other hand, when the packaging presented odor-neutral objects (such as the human body or abstract shapes), the participants' responses were not uniform. The design which was associated with the largest range of odors was the one with a photograph of a woman's body, which was paired with three different odors (namely, floral, woody and oriental).

When data were split by gender, the results suggested that men had a preference for regular and sharp visual shapes, which was in accordance with previous research that reported on the men's inclination toward sharp (cubical) packaging shapes (Sivagnanasundaram, 2019). Among all the packaging designs in our study, they appreciated the centrally-oriented visual elements (such as the geometric form of lemons) and stable compositions (such as the symmetrical frame) which deviate from fully realistic representations.

Another relevant finding is that the perception of perfume packaging can be influenced by age. In the choice tasks, the young participants mostly selected the perfume presentations based on abstract visual shapes over the highly-recognizable images such as the photo of a human body or the photo of the pieces of paper. This finding was in contrast with previous studies in food packaging which reported on preferences for photos on food product packaging (Kovač et al., 2019; Kovačević et al., 2022). However, given that a food product can be more easily presented by realistic imagery than a fragrance product, this inconsistency between these results should not be surprising. Furthermore, the results of the choice tasks indicated that the young participants were more sensitive to variations in design than the mature participants. The mature participants responded differently only in two cases – when presented with two versions of the floral design and two versions of design presenting paper. In contrast, the young participants responded differently across all conditions.

The analysis of the odor associations revealed that young participants associated many of the presented packaging designs with more than just one type of odor. These findings can be useful for successful perfume packaging design, especially when young consumers are the main target audience. Since they indicate a high diversity, our results suggest that successful perfume packaging design requires a detailed examination of young consumers' perceptions before starting the creative process of packaging design. Better understanding of their inclinations, values and behaviours can lead to effective communication on perfume type and people's expectation of the products non-visual attributes, which can lead to greater consumer satisfaction.

5. CONCLUSIONS

This study explored the role of packaging visual design in presenting a non-visual attribute such as odor by investigating consumers' responses to various graphic designs displayed on the perfume packaging. The results indicated that different age and gender groups of consumers respond differently to variations in packaging design, at least when analysing their choices, evaluations and odor associations. This finding should be taken into consideration when developing new packaging designs and planning marketing strategies in the cosmetic industry.

The main limitation of the study was the online form of the survey, which limited the possibility of getting additional spontaneous explanations from the participants and a wider insight into their impressions regarding the perfume packaging. Given that the packaging samples were presented on the participants' personal screens, the viewing conditions could not be fully controlled. Despite the limitations, the study revealed important findings which can be useful for packaging experts in future perfume research. They suggest that both the participant's age and gender should be defined in testing the effectiveness of packaging visual design, especially when it comes to adequate odor associations.

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IMPORTANCE OF COGNITIVE ERGONOMICS IN PACKAGING DESIGN

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Abstract: *The consumer's interaction with packaging should be simple and intuitive. However, packaging is frequently designed in such a way that it is difficult to use, with text and labels that are difficult to see or understand. As a result, the prospective consumer may be discouraged from purchasing the product, or if the purchase has already been made, the ineffective handling of the packaging may result in a negative user experience, e.g. some users struggle to open the packaging. Due to the inability of the user to access the contents of the packaging, the user often experiences a feeling of frustration which may lead to accidents and injuries. This paper emphasizes the importance of cognitive ergonomics in packaging design. Cognitive processes, which involves how people think, make decisions and react, can be predicted, and lessons learned from studying these predictable responses can be integrated into good design.*

Key words: packaging, cognitive, ergonomics

1. INTRODUCTION

Packaging protects the product while also promoting its identity (Suzianti et al., 2015). During the product purchasing process, the consumer is making decisions while looking for a variety of similar products that are classified in the same product category (Kuvykaite et al., 2009). While serving many other functions such as ensuring the security of the product (Bozhkova, Spiridonov & Shterev, 2017), packaging is crucial for drawing consumers' attention and delivering the product's content (Wang & Chou, 2010; Chind & Sahachaisaeree, 2012). Among those available alternatives, the consumer would recognize attributes presented through packaging, which would later serve as the foundation for selecting a certain product from all available options (Wang & Chou, 2010; Chind & Sahachaisaeree, 2012).

Packaging plays a significant role in daily life and has the potential to impact people's quality of life. There are basic human factors that must be considered when designing packaging: physical abilities, mental abilities, personality and mood as well as cognitive processes. Neglecting these factors can have expensive design repercussions in terms of both financial cost and consumer performance and discomfort. Poorly designed packaging can lead to product spillage and waste, and at worst, physical injuries. This is followed by the need to expend time and effort to deal with the consequences, as well as the financial cost of having to repurchase the product. Almost inevitably frustration occurs, which is amplified and made worse by successive problems, potentially generating emotional anxiety and a negative state of mind. Failing to open and use packaging has some of the most significant psychological repercussions on consumers' quality of life, leading to a loss of autonomy and low self-esteem (Theobald & Winder, 2006).

2. COGNITIVE ERGONOMICS

Cognitive psychology is a branch of psychology that explores a wide variety of mental processes and enables us to comprehend how our brains retrieve information from the outside world, how we attempt to make sense of this information, and ultimately how this information affects our behaviours, such as when we are faced with product packaging that we wish to purchase, open, and use (Karwowski, 2005). Cognitive ergonomics is the study of how well a product's use matches the cognitive abilities of its users. Cognitive ergonomics focuses on the effects of mental processes such as perception, memory, information processing, reasoning, and motor response on interactions between people and other elements of a system (Karwowski, 2005; Hollnagel, 2003; Karmakar & Chowdhury, 2022).

Rather than being a design discipline, cognitive ergonomics is a knowledge base for designers to use as guidelines to ensure optimal usability of a product. Attention, information processing, sensation, perception, affordances and predictability of human errors are the most relevant aspects of cognitive ergonomics that relate to how we chose and use a product, areas that can teach us how to improve the design of packaging (Figure 1). (Theobald & Winder, 2006). Each aspect will be described in greater detail.

Figure 1. Aspects of cognitive ergonomics explaining consumer-packaging interaction

2.1 Sensation and perception

The initial step in our retrieval of information from the outer world is through sensation, which refers to the immediate response of our sensory receptors, located in our ears, eyes, nose, tongue and skin. As soon as we receive input from any of these senses, higher order cognitive processes jump into action, and we 'perceive' this input (Theobald & Winder, 2006). Perception is the interpretation of stimulations from surrounding environment. It is the point at which the raw sensory information is given meaning and is dependent on the individual, with his or her differing experiences, abilities, culture and expectations, or even the emotion that the consumer is experiencing at the time, as well as situational factors connected to the scenario concerned. As we could sense different products by means of different senses, perception can be divided into five kinds: visual perception, auditory perception, touch related perception, smell perception, and the perception of taste (Theobald & Winder, 2006; Karmakar & Chowdhury, 2022).

2.2 Attention and information processing

Our sensory systems are actively gathering information coming from environment which is an overwhelming amount of data thrown at us every second of the day. To handle or manage this amount of information, we require a selective focus (attention) to certain amount of information since we possess only limited cognitive resources and thus have a finite attentional capacity. This capacity must be divided among a variety of tasks, some of which will demand more cognitive resources than others, depending on factors such, the consumer's level of skill, experience, and familiarity with the product, the consumer's psychometric profile, etc. Attentional capacity, however, is not solely determined by the cognitive workload that we can handle; it is also determined by the automaticity of the processes that are in place.
Cognitive processes differentiate between controlled cognitive processes, which are carried out consciously and intentionally, and automatic cognitive processes, which are not under conscious control. Controlled processes require conscious attention, incurring a greater demand on our cognitive resources and limiting the amount of work we can complete at once. Automatic processing takes place when we carry out tasks that are either very simple or, in our eyes, so well-practiced that we can finish them without paying attention. Therefore, attention, as a part of cognitive process, is important for choosing information of interest and processing huge amount of information, particularly when it comes to distinguishing a product packaging from rival products. As everyone knows, good design can catch the attention of consumers and create strong competitiveness in the target market (Pathak, 2014; Theobald & Winder, 2006; Karmakar & Chowsdhury, 2022).

2.3 Perceptual affordances

The term affordance was initially used by Gibson (1977), a cognitive psychologist, in his attempts to describe how people perceived the world around them. Affordances, in Gibson's terms, could be defined as the cues (or clues) that we use to make sense of the world around us. Physical objects can serve a variety of functions. A rock can be moved, rolled, kicked, thrown etc. The set of possible actions is referred to as the affordance of the object. Affordances provide strong clues to the operation of things: handles are used for lifting and carrying, while lids are used for opening (twisting). When affordances are utilized, the user knows what to do just by looking: no pictures, labels, or instruction is required. Complex things may require explanations, but simple things should not. The design has failed when simple things require images, labels, or instructions. When it comes to the consumer-packaging relationship, consumers must be able to pick up a packaged product and open it without having to think about how to open it or even where to begin opening it. The affordances indicate to us, subconsciously, properties and functions that may not be explicitly stated but are there to be perceived very quickly. When a person picks up a packaging to open it, the same object may provide different affordances (in this case, cues as to how it might be opened) to different people. However, knowledge of human perceptual processes, capabilities, and limitations, as well as experience with social processes, can be used to predict the most likely interpretation of opening affordances for a specific target consumer group. Affordances should lead the consumer subconsciously to the correct conclusions in terms of opening the products quickly, easily, and safely. Affordances may also be defined as true or false, with true affordances indicating that the packaging texture, shape, colours, etc. provide cues that will, if followed, allow the packaging to be opened easily. As an alternative, packaging that is challenging to open might have misleading affordances (false affordances), which would mean that the majority of customers would be actively misled into attempting to open the packaging incorrectly by the cues provided. False affordances are frequently the main offenders in a poor design. If consumers are unable to figure out how to open packaging or use a product, it should be regarded as having a defective design. However, poor design can also include packaging that incorporates true affordances, but are beyond most consumers' physical capabilities to open - for example, the opening of jar lids, which is often discussed as a problematic action (Yoxall et al., 2006; Chang, Hoa & Su, 2008). In this case, it is obvious how one should open them, but the physical act of doing so is frequently extremely difficult. Consumers will naturally and intuitively know how to open the packaging and be able to do so without having to read any instructions if the packaging has been well designed and displays true affordances (Theobald & Winder, 2006).

2.4 Human errors

Errors in human behaviour are classified into two types: slips and mistakes. The difference between the two is that mistakes are committed on purpose, usually due to a mistaken belief that what the person is doing is correct. Slips, on the other hand, are the result of automatic (or automated) behaviour, which occurs when an individual's goal is correct but there is an error in carrying out the actions required to achieve the goal (Theobald & Winder, 2006; Karmakar & Chowdhury, 2022). It is conceivable, when applied to consumer behaviour, that cognitive limitations could result in errors when opening a packaging. This could happen in one of two ways: first, the consumer might use automatic processing because they are so accustomed to performing specific actions when opening packaging that they experience error due to lack of controlled processing of task-related information. Second, the majority of packaging is opened by customers who are occupied with various other activities, like listening to the radio. Distraction while opening packaging can result in accidents or errors. Some of the factors that can cause error are demographic traits, skills, training, experience, emotional state, and stress (Nemeth, 2004). Misleading information especially in combination with wrong assumptions are likely to induce errors. The nature of the packaging design may also, as previously mention, lend itself to errors. Designers should take the time to simulate any slips that could occur as a result of trying to open and use packaging, and they should then work to change the designs to lessen or completely eliminate the occurrence of such slips.

3. VERBAL AND VISUAL STIMULI OF THE PACKAGING

As self-service marketing grows in popularity, providing adequate product information to customers is becoming increasingly important. It contributes to the creation of a positive brand image, a positive perception, and a compelling reason to purchase a product (Pathak, 2014; Reimann et al., 2010). Fitzsimons et al. (2002) argue in a review paper that consumer choice behaviour is a mix of conscious and unconscious influences, with nonconscious influences playing a significant role. Nonconscious influences are defined as stimuli that the consumer does not consciously perceive, the consequences of consciously perceived stimuli, and decision-making processes that take place completely outside of awareness (Pathak, 2014). According to Kollöffel (2012), consumers tend to rely on information that can be presented either as verbal or visual stimuli. The way information is processed is determined by an individual's thinking style which differs among consumers and according to Witteman et al. (2009) can be divided into intuitive and rational (Kollöffel, 2012; Kahneman, 2003). Intuitive style is defined as automatic, fast, effortless, implicit, and associative processing that involves emotions and is guided by habits. The rational style characterized by reasoning requires slow, laborious, and serial deliberation and processing, which occurs more consciously (Overduin, 2016). Silayoi and Speece (2004) proposed that visual elements of packaging trigger emotional responses while verbal elements trigger cognitive responses during the purchasing decision-making process.

3.1 Visual stimuli

According to Solayoi & Speece (2007), visual stimuli comprise the product design through graphics (e.g. colour, typeface, images) and structural elements (e.g., shape, size, and materials) (Pathak, 2014). They attract attention, evoke sensory expectations, affect perception, and transmit and communicate the companies' messages and its underlying meaning (Chrysochou & Grunert, 2014; Underwood, Klein & Burke, 2001). Visual stimuli have the ability to produce emotions and related physiological responses, they are associated with the emotional component of the decision-making process and those stimuli are often noticed prior to verbal packaging information (Underwood & Klein, 2002; Silayoi & Speece, 2007; Becker et al., 2011). These stimuli frequently have a greater impact than verbal ones and can change a consumer's decision to buy a product (Underwood, Klein & Burke, 2001). For instance, a picture can process sensory data through imagery and produce a complete mental image of the product (Underwood & Klein, 2002; Underwood, Klein & Burke, 2001). A picture could inspire people to imagine what the product would taste like (Olson & Mitchell, 2000). Colour also has the power to influence how people feel or act. For instance, the colours blue and green evoke feelings of security and calm, red and yellow evoke feelings of warmth and cheerfulness, and black is viewed as a symbol of power. Thus, consumer behaviour can be influenced by using suitable colour in packaging design (Pathak, 2014).

3.2 Verbal stimuli

Verbal stimuli include information about the product, its attributes and the packaging technology. Packaging technology transmits information about e.g. the degree of environmentally friendly material. The verbal stimuli are more associated with the cognitive part in the decision-making process (Silayoi & Speece, 2007). According to Verbeke (2008), consumer choices are greatly influenced by information. Nowadays there is an increased attention towards packaging labels (Silayoi & Speece, 2007). This result might be explained by a growing awareness regarding the wellbeing. It is essential to provide a balanced amount of information on the labels since insufficient information might be inaccurate and misleading, while too much information might cause confusion, misuse, misunderstanding, and indifference (Grunert, 2002; Silayoi & Speece, 2007). Additionally, too much information may cause cognitive overload due to limited information processing capabilities (Chrysochou & Grunert, 2014).

4. CONCLUSION

The packaging gives an opportunity to attract and influence potential consumers. Besides being the first impression consumers obtain of the product, packaging is also the last impression before the final purchase decision. By incorporating cognitive ergonomics in packaging design, consumers' attention can be drawn to the product, and ultimately, they could be persuaded into purchasing it. Even more importantly, if the packaging design is in line with the cognitive abilities of the consumer, it will ensure a good user experience, affecting the brand's leadership potential. Cognitive ergonomics ensures that a product's use corresponds to its users' cognitive abilities by utilizing visual information clearly and effectively, allowing the packaging to be used intuitively and easily. The cognitive ergonomics of packaging assists the target demographic in meaningfully understanding and distinguishing one brand from another, as well as associating themselves with the product.

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SOLUTIONS OF SUSTAINABLE PACKAGING IN FOOTWEAR AND APPAREL INDUSTRY

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Abstract: *Footwear and apparel industry creates large amounts of waste, which cause environmental concerns through all value chain. Therefore, the aim of our research, as systematic review, was to identify, summarize, and evaluate existing sustainable packaging solutions in the apparel and footwear industry. The study followed the principles of a systematic review,research methodology, using a website search; Phyton programming language libraries were used to develop a web scraper. A sample included apparel and footwear brands that operate internationally around the World. The qualitative analysis method of thematic content clustering was then used to identify, summarize, and evaluate the results. The results have shown that less than half of the brands announced their long-term commitment to switching to sustainable packaging. Less, 84 brand have certificates for all or certain types of their packaging. There are 60 brands that offer reusable packaging services through collaboration with packaging providers. Only 52 of 400 brands have invested in eco-friendly packaging solutions and 32 joined to Responsible Packaging Movement and Ellen McArthur foundation. We found out that most of the brands with the sustainable statements and packaging solutions are from Europe (54.50 %). Others are from North America (28.25 %), Australia (10.10 %) and Asia (3 %). As expected, the clothing categories with the most sustainable packaging solutions are clothing for women and men, less footwear and accessories. The results of our study suggest that sustainable packaging is highly dependent on the social and environmental impacts, as well as the business and supply chain circumstances associated with each product packaging system. Apparel and footwear brands are generally committed to finding better packaging solutions for their products, although innovation in this area is still reluctantly shared.*

Key words: packaging material, certificates, packaging solutions, sustainability, circular economy.

1. INTRODUCTION

Synthetic materials such as polyethylene, polypropylene etc. are still the most used packaging materials in fashion industry such as footwear and apparel. With plastic reuse still limited, these materials alone represent a large and rapidly growing segment of municipal solid waste. Although synthetic plastic packaging has several positive properties, such as low cost, light weight, flexibility, transparency, and impermeability, it poses a serious threat to the natural environment.

Until the adoption of sustainable packaging is proven to reduce costs, apparel and footwear retailers lack the business case for purchasing more sustainable packaging, despite the potential to advance their sustainability intentions. Considering that these industries have only relatively recently committed to sustainable packaging, there is still a lack of scientific evaluation of sustainable packaging advances. The apparel and footwear industry produces large amounts of products and therefore also packaging items, which has increased in the pandemic times. As the Global Commitment Report 2020 presented, the average post-consumer recycled content (PCR) for packaged goods and retail signatories increased 22% year-over-year, reaching 6.2% PCR overall for 2019. This increase was contributed to a slight decrease in the total volume of virgin plastic these companies used in their packaging over the same period, down 0.1%. It was also reported, that 65% of packaged goods and retail signatories' plastic packaging was reported as being reusable, recyclable, or compostable — an average increase of around 1 percentage point across signatories reporting in both years (The Global Commitment Report, 2020).

The United Nations Environment Program estimates that 8.3 billion tons of plastic have been produced worldwide since the 1950s, of which about 60% is discarded (Chamas et al., 2020).

When presenting waste hierarchy (Figure 1) in terms of packaging, it is important to prevent and reduce the negative impacts caused by the generation and management of waste and to improve resource efficiency.

Figure 1: The packaging waste hierarchy.

The first urges retailers to consider the nature of the packaging itself and to choose reusable packaging options whenever possible. The second strategy emphasizes the need to consider broader packaging systems and a combined collection, sorting, and recycling infrastructure, rather than thinking solely about how to improve packaging materials or features per se (The Global Commitment Report, 2020). To help retailers implement viable packaging improvement strategies, Glock and Kim (2015) and Vadakkepatt et al. (2021) presented research showing that the use of reusable packaging encourages shoppers to return the material to manufacturers. Similarly, Lapkin, Joyce, and Crittenden (2004) argue that retailers need to encourage their suppliers to reuse manufacturing waste and scrap material to make new products, ultimately reducing the amount of material that ends up in landfills (Lapkin, Joyce & Crittenden, 2004). Nevertheless, there is a lack of academic evaluation of the existing evidence on sustainable packaging in this sector, so there is no clear understanding of what type of "sustainable packaging" is already available. Therefore, the aim of our research was to identify, summarize, and evaluate existing sustainable packaging solutions in the apparel and footwear industry before the pandemic times around the world.

2. METHODS

The research followed the principles of a systematic review research methodology via website searching as described by Stansfield et al. (Stansfield et al., 2016). Because this study focuses exclusively on apparel and footwear brands' sustainable packaging solutions, we evaluated primary sources of relevant information on the brands' official websites and from available sustainability reports for this systematic review.

Namely, the research was performed in stages as presented:

1. Planning the research: outline the study purpose, objectives, and research methodology to reduce the possibility of researcher bias.
2. Executing the research: advanced analytical techniques of textual or data mining were utilized. The web scraper directly accessed the World Wide Web using Hypertext Transfer Protocol (HTTP) and identified the names of 400 brands that use sustainable product packaging in an automated manner. Python's library pulled the brand names, and information from the websites.
3. Screening records for relevance and data management: manual verification of websites, records screening, and data management was performed. To determine the final sample, we strictly followed the protocol and determined the relevance of the primary sources based on the predefined criteria for the selection of the web sources. The quality assessment at this stage

aimed to ensure that only primary sources that provided direct evidence for the research topic were included in further analysis, while all other sources were excluded as inappropriate (exclusion criteria 1 - non-English language websites were excluded; exclusion criteria 2 - all other sources that were not primary or did not relate exclusively to clothing and footwear were excluded).

4. Data analysis: an iterative data analysis, which involved exhaustive, repetitive assessments of all records was done. The qualitative analytical method thematic content clustering was done (Braun & Clarke, 2006). All themes and memos were included in an Excel table to facilitate constant comparisons in the analytical process (Braun & Clarke, 2006; Finfgeld - Connett, 2014).
5. Synthesis and results reporting: we synthesized the findings and reported the results. Careful consideration of the research findings resulted in the sustainable packaging framework.

3. RESULTS AND DISCUSSION

The main objectives of this research were to present practical understanding of what kind of sustainable packaging is used in the mentioned sector and to evaluate the existing packaging solutions in the terms of brands around the world.
This study showed that 400 international apparel and footwear brands are committed, to varying degrees, to better packaging solutions for their products. To reduce packaging waste generation, brands are investing in seven different packaging strategies (including rethink, reject, reuse, reduce, reuse, recycle and rot), which we have termed the 7R's framework for sustainable packaging (Figure 2).

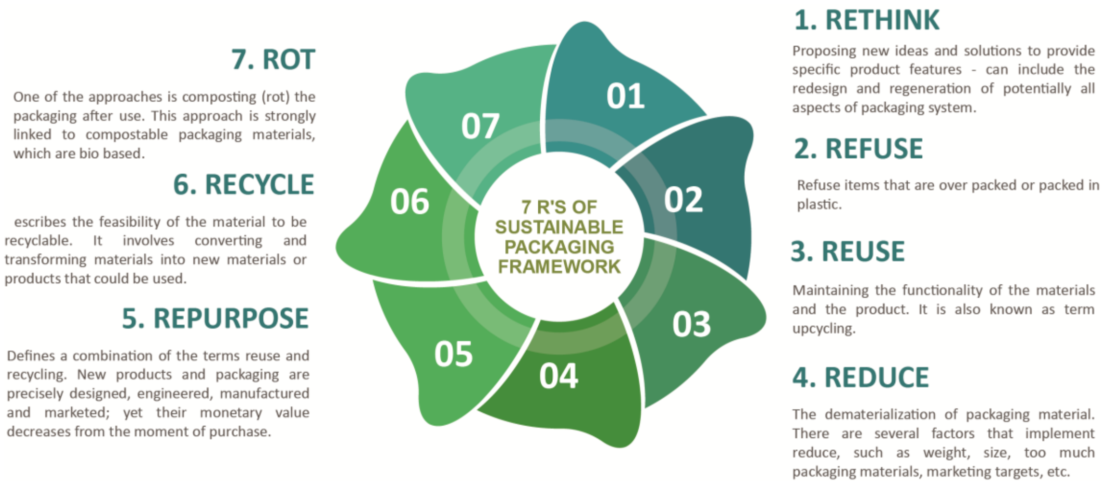

Figure 2: The 7 R's of sustainable packaging framework.

According to sustainable packaging framework presented above, the brands were also ranged to 7 strategies, as presented in figure 3. The packaging framework strategies is detailed presented in our previous published analysis (Jestratijević et al., 2021).
Among analyzed brands, more than a half of brands are using reduce sustainable packaging strategy and only 5 % a repurpose. Brands also offered reusable and recyclable packaging either on their own or through collaboration with third party packaging providers. Namely recyclability was mentioned by 53 % of brands such as packages made from recyclable plastic, paper or textiles. Higher percentage (32 %) of explored brands stopped using conventional plastic, refused to use disposable plastic (polypropylene, polyethylene) bags and are committed to "plastic free-policy". In such cases, consumers are asked to bring their own packaging, since there is no packaging available at the store.
There are other barriers to sustainable packaging that deserve special research attention. For example, new bio-based materials are often touted as better and safer alternatives. However, there is insufficient research to demonstrate the efficacy and functionality of these sustainable packaging alternatives in the apparel and footwear sectors. Moreover, many of the beneficial packaging materials are not yet ready for commercialization, as our findings confirm. Therefore, shortly after their market introduction in the future, it will be important to investigate their benefits and trade-offs.

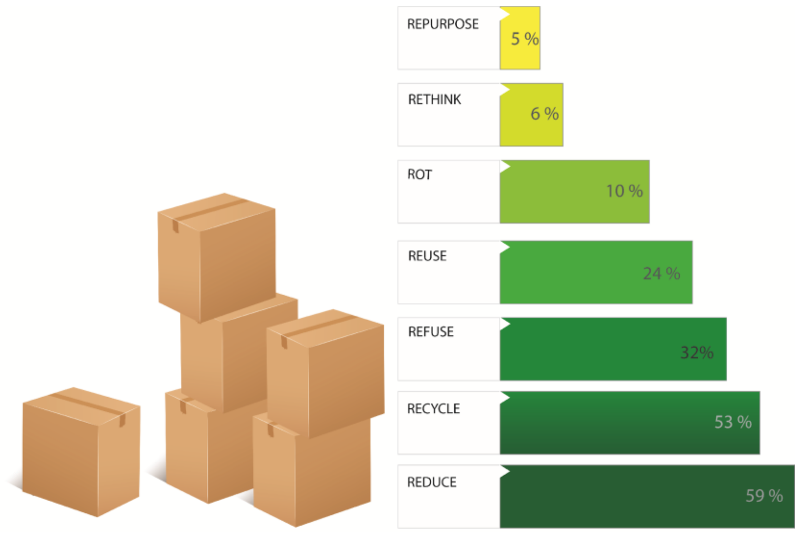

Figure 3: Percentage of footwear and apparel brands that use one of the 7 R's packaging solutions.

According to our research, the results have shown that footwear and apparel brands are involved also in sustainable packaging strategies such as The plastic global commitment, Noissue eco packaging alliance, One tree planted, The responsible packaging movement and Re:Pack. Namely, there are 60 brands that offer reusable packaging service such as Re:Pack (Figure 4). 8% (N=32) of brands have joined the Responsible Packaging Movement and/or the Ellen McArthur Foundation to rethink current packaging solutions and create circular solutions for plastic waste. These brands reject the use of single-use plastic bags in their stores and have already adopted paper-based packaging alternatives. 15% of brands offer reusable packaging in partnership with third-party suppliers. For example, brands frequently partner with Re-pack and Noissue Eco Packaging Alliance, each of which offers reusable and recycled or compostable packaging for e-commerce. In addition, 21% of brands reduce the negative impacts of their packaging by improving the quality and recyclability of packaging components by accepting legitimate third-party certifications for all packaging or, more often, for its components (e.g., GRS, GOTS, FSC). For most of these brands, packaging is fully recyclable, while in some cases packaging can be reused (e.g., reusable organic fabric packaging can be used as gift bags or scarves). Nevertheless, some of the brands invest in eco-friendly packaging solutions, replacing conventional plastic materials with biodegradable and compostable alternatives (e.g., compostable TIPA packaging, plant-based packaging). Finally, 43% of brands advertise their long-term commitment to transitioning to sustainable packaging, admitting that they are either testing sustainable prototypes at the moment or do not yet have improved packaging solutions.

Figure 4: Number of brands with included sustainable packaging strategies.

The distribution of the brands with the sustainable packaging solutions, green certificates and strategies around the world are presented in Figure 5. As seen, most of the brands, that include solutions with sustainable packaging are from Europe (54.5 %), after that North America (28.3 %) and less other countries around the world.

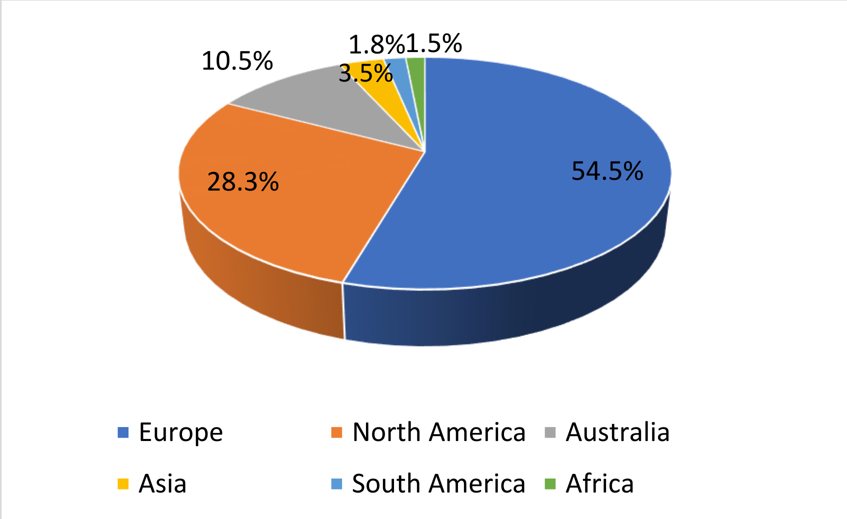

Figure 5: The distribution of analyzed footwear and apparel brands that include sustainable packaging solutions around the world.

5. CONCLUSIONS

Retailers can use framework to establish new or revised criteria for advancing sustainable packaging solutions. Depending on the type of products companies offer, some changes may be easier to test and implement than others. Therefore, the 7Rs approach is as a step-by-step path to sustainable packaging that is mutually inclusive and includes complementary approaches. This collection of the data was performed from November 2020 till January 2021, therefore any changes in sustainable packaging solutions, that were made after that time, were not collected. This research found that among the 400 brands analyzed, unique complexities were found in the packaging systems available. These complexities forced retailers to consider different sustainable packaging solutions and logistical approaches that are key to improving the overall packaging of the brand.
This study represents an important achievement for sustainable packaging in the footwear and apparel industry.

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CONSUMERS' SOCIO-DEMOGRAPHICS INFLUENCE BETWEEN PURCHASE INTENTION AND ACTUAL BEHAVIOR OF ENVIRONMENTALLY FRIENDLY GROCERY PACKAGING

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Abstract: *Grocery aisles in the United States provide the shocking realization that plastic packaging dominates the grocery industry. This realization raises the question of whether consumers are purchasing food that is not wrapped in plastic but in environmentally friendly packaging. For some consumers, finding food products wrapped in environmentally friendly packaging is not easy as it is not widely available in many United States grocery stores. This study adapted the Theory of Planned Behavior to investigate the relationship between purchase intention and purchasing behavior toward environmentally-friendly grocery packaging. This quantitative study collected 487 usable responses targeting a population of US consumers over 18 years old who purchase groceries. This study uncovered novel findings. This study supplied a fresh perspective on socio-demographics' role in environmentally friendly consumption, confirming that predominantly younger, unmarried consumers are likelier to act upon their intentions by purchasing environmentally friendly grocery packaging. The hope is that these findings provide marketers with fresh insights into the characteristics of consumers willing to purchase environmentally friendly grocery packaging. Results can also give government agencies and brands a clearer perspective on ways to increase consumers' knowledge of environmentally friendly packaging consumption.*

Keywords: Environmentally Friendly Grocery Packaging; Consumer Behavior; Socio-Demographics; Sustainable Consumption; Packaging Waste

1. INTRODUCTION

Every day, hundreds of millions of consumers purchase items from grocery stores to sustain themselves or their families. Many of the products are wrapped in single-use packaging and are thrown away shortly after purchasing. The average household will use over 500,00 tons of plastic food packaging within a year (Douek, 2021). Many food brands and grocers have sought to increase their sustainable packaging solutions to bring forth more environmentally friendly alternatives to combat the increasing amount of plastic packaging. Packaged food brands in the United States, such as Boxed Water is Better, Celestial Tea, & No Evil Foods, are heading the change by providing consumers with environmentally friendly packaging alternatives within the food industry (Fagundes, n.d.). These brands have supplied customers with packaging composed of materials that are not single-use plastic but packaging materials that are recyclable or biodegradable. Outside of the United States, supermarkets are combating packaging waste by reducing over 800,000 tons of plastic waste each year (Glenza, 2019). Due to this realization, companies are altering their sustainability and corporate social responsibility initiative goals to aim for a switch to recyclable, reusable, or compostable materials within the coming years.
Many consumers are unaware of the long-lasting impacts of plastic packaging. Packaging types such as plastic and Styrofoam have long lifespans regarding their biodegradability, taking hundreds of years for the materials to break down. A plastic coffee pod takes around 500 years to break down, while plastic bottles take more than 450 years to biodegrade (WWF Australia, 2021). Due to their long lifecycle, many plastic materials have disastrous effects on the biodiversity of ecosystems around the world. One of the most recognized disruptions occurs in the ocean, where wildlife is often depicted as entangled in plastic materials or even dying with large amounts of plastic in their stomachs (Kam et al., n.d.). Humans are not exempt from this occurrence as most of the public ingests microplastics daily due to their presence in our water and food supply (Alberts, 2020). Plastic pollution is everywhere, making it nearly impossible to escape the effect of excessive plastic consumption. Many might argue that the improvements in packaging should be the retailer's responsibility. However, many retailers ignore the need for more environmentally friendly packaging. Others are finding new ways to approach the issue and are actively trying to take on this challenge. Jestratijevic et al. (2021) investigated retailers' promotion of

environmentally friendly packaging, which suggested that 36 out of 487 sampled brands were rethinking their current packaging strategies to appeal to more sustainability-concerned consumers. In comparison, 287 out of 478 sampled brands in that study had some plan for reducing their packaging by improving its quality and recyclability (Jestratijevic et al., 2021). These findings provided insight into how companies are approaching their environmental footprint. This comes as many consumers expect brands to take more responsibility in offering environmentally friendly packaging.

Even though environmentally friendly packaging has become more accessible to a broader demographic of consumers, many barriers deter individuals from making a more permanent transition to purchasing environmental-friendly packaging. Consumer preferences are shifting to higher adoption of the action of purchasing environmentally-friendly grocery packaging in the United States. The Global Green Technology and Sustainability Market are predicted to increase by 22.5% or $38.15 Billion by 2027 (ReportLinker.com, 2021). Furthermore, around 54% of consumers consider sustainable packaging when buying a product (Manning, 2021). It is expected for the sustainability industry to grow as more environmentally friendly grocery items become available. As consumers' purchase intention for the environmentally friendly product increases year over year, companies will have to address these emerging needs to maintain their standing in the food market.

To the researcher's knowledge, this is the first study to investigate the socio-demographic variable's effect as a moderator between consumers' intentions and purchasing behaviors towards environmentally friendly grocery packaging. Including socio-demographic variables intended to provide insights into which demographic groups have the most substantial moderating effect on the relationship between purchase intention and actual behavior. This moderation analysis investigated the influence of each socio-demographic variable's strength on the relationship between purchase intention and behavior towards EFGP. The socio-demographic variables examined in this study included: Age, Income, Gender, Education, and Marital Status.

1.1 Age

Age is a socio-demographic variable utilized to understand how different age groups approach EFGP. Segmenting the variables into groups helped provide an understanding of which demographic groups are more willing to exhibit environmentally friendly behaviors. Many studies specifically studied the particular age group's intention for environmentally friendly behaviors. Smith et al. (2016) investigated only younger consumers to understand their behaviors toward environmentally friendly shopping bags. A meta-analysis of age and pro-environmental behaviors found that older consumers were motivated by social norms and conservation behaviors (Wiernik et al., 2013). Zhoa et al. (2014) found that older consumers were more likely to perform pro-environmental behaviors such as recycling, which could result from their experiences in different social events. Fisher et al. (2012) also found that consumers over 55 were more likely to perform environmental actions. Due to current literature pointing to heightened pro-environmental behaviors for older individuals, findings suggested that the older the individual, the higher the likelihood of them performing environmentally friendly behaviors.

H1. The influence of intention on behavior is stronger for older consumers compared to younger consumers.

1.2 Income

Understanding income's role in purchasing EFGP is crucial in understanding which variables most influence the behavior. Within this research, income was distributed into groups by income brackets. Previous literature investigated income's role in how consumers decide to purchase environmentally-friendly packaging alternatives. Typically, most environmentally friendly products come at a premium price, questioning whether consumers are willing to pay more (Walker, 2021). Literature has found that income plays a significant role in the decision process of purchasing environmentally-friendly packaging (Orzan et al., 2018). Research also found that those who make over $100,000 are typically more socially responsible, leading to their consumption behaviors for EFGP (Park et al., 2012). Income has a role in environmentally friendly behaviors such as separating trash from recycling (Fisher et al., 2012). Research pointed to higher incomes having a significant role in environmentally friendly behaviors, translating to purchasing behaviors. Based on the information presented, we hypothesized:

H2. The influence of intention on behavior is stronger for consumers with a higher income compared to consumers with a lower income.

1.3 Gender

Understanding how gender plays a role in consumption behaviors is essential for managerial implications of best reaching either gender with a curated message. Many studies found a gender gap between men's and women's environmental sustainability, of which there has been evidence that many factors produce this gap (Brough et al., 2016). Literature found that women have stronger attitudes toward environmental quality and are likelier to perform environmentally friendly behaviors (Diamantopoulos, 2003; Fisher et al., 2012). Women are also more likely to be more environmentally conscious than men (Park et al., 2012). Overall, women are found to place more value on environmental sustainability, which supported the following hypothesis:

H3. The influence of intention on behavior is stronger for women compared to men.

1.4 Education

An individual's education level has been found to be a telling variable of an individual's environmental sustainability. This variable gauged the highest level of education obtained and compared it to the moderating effect between purchase intention and self-reported purchases. Literature found that education level correlated to environmentally friendly behaviors compared to other socio-demographic variables (Zhoa et al., 2014). Those who obtained a higher level of education had a higher percentage of respondents who claimed that they purchased recyclable bags (Fisher et al., 2012). Another study found that those with higher education are more concerned about the environment and knowledgeable about environmental issues (Tilikidou, 2007). The literature pointed to the understanding that the higher the education level, the higher the likelihood that they perform environmentally friendly behaviors, which can also be translated to purchasing EFPG. This understanding of education's role in environmentally-friendly behavior allowed us to claim the following hypothesis:

H4. The influence of intention on behavior is stronger for those with higher education compared to those with lower education.

1.5 Marital Status

Marital status can play a role in purchasing behaviors because most decisions are made jointly if the couple is married (Editors of Consumer Reports, 2008). Literature found that married individuals are likelier to shop for environmentally friendly products (Mehmet & Gul, 2014). Married people are more likely to purchase previously sustainably produced foods (Robinson & Smith, 2002). This finding can come with the expectation that these foods will also be wrapped in environmentally friendly packaging. Analysis of this variable provided a better understanding of how marital status plays a role in the consumption behaviors of EFGP. This variable was tested to see how marital status influences the actual purchasing behaviors of EFGP. Based on the information presented, we hypothesized:

H5. The influence of intention on behavior is stronger for married consumers than for those who are not married.

2. METHODS

This study employed a quantitative survey to collect consumer data and investigate the consumer purchasing behaviors of EFGP. The survey examined the research variable's attitudes toward EFGP, Environmental Concern, Subjective Norm, Perceived Behavioral Control, Purchase Intention, and the consumer's self-reported purchasing behaviors toward EFGP. The dependent variables in the conceptual framework were purchase intention and purchasing behavior. Based on the survey prompts, the purchasing behavior was collected by having respondents report their behaviors. This inclusion aimed to better understand consumers' actual behavior when purchasing food items in environmentally friendly packaging. Kopplin & Rausch (2020) collected data from respondents on their self-reported purchasing behaviors, further understanding their actual behaviors when purchasing sustainably. The independent variables in this study were environmental concerns, attitudes, subjective norms, perceived behavioral control, and socio-demographic variables. The relationships between the independent and dependent variables led to a better understanding of the purchasing behaviors for EFGP. The study also investigated if and how socio-demographics affect purchasing behaviors.

3. RESULTS

A total of 487 usable surveys were collected. Most respondents were males representing 57% of the sample, with females representing 43% of the sample (Table 1). Most respondents were 18 – 34 years old, making up 61% of the sample. 54% of the sample had a bachelor's degree, with 86% earning $79,000 or under a year. The majority of the sample were married, with 67% of respondents reporting in this category. The Single/Never Married category made up 30% of the sample.

Table 1: *Demographics of Respondents*

Demographics	N	%
Education		
Less than High School Diploma	4	1%
High School Diploma or GED	23	5%
Some College, but no Degree	68	14%
Associates Degree (e.g., AA, AS)	41	8%
Bachelor's Degree (e.g., BA, BBA, BS)	264	54%
Master's Degree (e.g., MA, MS, Meng)	81	17%
Professional Degree (e.g., MD, DDS, JD)	2	0%
Doctorate (e.g., PhD, EdD)	4	1%
Total	487	100%
Gender		
Male	279	57%
Female	207	43%
Total	486*	100%
Age		
18-24	104	21%
25-34	194	40%
35-44	107	22%
45-54	45	9%
55 and Older	37	8%
Total	487	100%
Income		
$0 - $29,999	118	24%
$30,000 - $49,999	168	34%
$50,000 – $79,999	136	28%
$80,000 - $99,999	51	10%
$100,000 and over	14	3%
Total	487	100%
Marital Status		
Single/Never Married	147	30%
Married	327	67%
Separated	1	0%
Divorced	12	2%
Total	487	100%

Note. Totals are different because of missing data

The socio-demographic variables included are Age, Income, Gender, Education, and Marital Status. A moderating analysis was conducted to investigate the interactions between purchase intention and behavior of EFGP. This interaction was investigated to understand the socio-demographic variables' effect in moderating the relationship between purchase intention and actual behavior. The variables for marital status and gender were recoded to binary variables to improve the statistical analysis of the variables. The items within the gender category were Male and Female and were recoded to display as Male, with

Male valued at 1 and Female valued at 0. The items with marital status were recoded to Single and Married, so the variable was recoded to display Married, with Single valued as 0 and married valued as 1.
The interaction analysis of socio-demographic variables between the relationship of actual behavior and provided a clear view of how the variables interaction with the two contructs. The socio-demographic showed that Age (H1) was not supported with a (p=0.396), while hypothesis 2, posited the moderating influence of income, was not supported (p=0.807). Education (H3) also was not supported (p=0.615) that the interaction between actual behavior and purchase intention will be strong with higher education levels compared to those with lower levels of education. The interaction for gender was not supported (p=0.303), providing the understanding that gender does not have a moderating influence on actual behavior and intention. Lastly, the influence of marital status on the relationship between actual behavior and purchase intention was significant (p=0.033).
To the researcher's knowledge, these findings are novel, with previous studies not having investigated this relationship in the context of environmentally friendly grocery packaging. Even though hypothesis 5 was not supported, it is understood that socio-demographics can moderate the relationship between purchase intention and behavior. Unmarried consumers act upon their intentions by purchasing environmentally friendly grocery packaging. Furthering the analysis, we found that the demographic characteristics of single individuals consisted of primarily male consumers, with a more significant percentage of respondents between the ages of 18-24, with an income of $0-$29K, and with some college education. Those findings suggest that consumers within these socio-demographic characteristics are more likely to care about the environment and are willing to purchase EFGP. Findings from the moderating analysis might suggest that consumers are more concerned and sensitive to external factors (e.g., quality and price of packaging) when grocery shopping (Ferrara et al., 2020; Elgaaïed-Gambier, 2016). This analysis might indicate that income, age, gender, and education do not make consumers more likely to act upon their intention by purchasing EFGP. However, external factors might have a more significant role in their consumption behaviors toward EFGP than expected.
Although most unmarried consumers are 18-24, we can argue that age plays a moderating role in the relationship between purchase intention and behavior. Consumers within the age range of 18-24 are considered to be in the Gen-Z generational cohort. These consumers are highly concerned about environmental conservation and preserving the world for future generations (Wang et al., 2022). Their consumption behavior is directed towards environmentally friendly products as it has been found that the cohort often voices their concerns about environmental issues and consciously attempts to minimize their waste (Corey, 2021). Since most of the single respondents are within this age group, it can be assumed that generational values also play a role in their consumption behaviors.

4. DISCUSSION

The objective of this study was to analyze socio-demographics' role in moderating the relationship between purchase intention and purchasing behaviors. In this analysis, Age, Income, Gender, Education, and Martial status were investigated to clarify their power in the relationship. This study concluded that unmarried consumers act upon their purchasing intentions in purchasing environmentally friendly grocery packaging. These findings provide insight into how consumers act upon their intention by purchasing EFGP when grocery shopping. One factor that might lead single consumers to perform environmentally friendly behaviors is having more freedom to purchase items that align with their values. They can factor environmentally friendly items into their budget when grocery shopping. Furthermore, most unmarried respondents fall within the Gen-Z generational cohort, who all have strong values for environmental preservation and strong intentions to purchase products that have environmentally-friendly qualities.
Despite Age, Income, Education, and Gender not having a moderating influence on the relationship between purchase intention and behavior, findings from this analysis can provide more insight into environmentally friendly grocery consumption. The moderating effect of each of the variables (Age, Income, Education, and Gender) was not found to influence consumers to purchase EFGP; however, this might assist in providing more clarification of the role that a consumer's reluctance plays in buying EFGP. Results suggest that there are still many barriers contributing to consumers' consumption of environmentally friendly products, regardless of if the consumer has a higher income or great awareness of the negative influences caused by plastic packaging. Consumers in the United States are becoming increasingly more aware of the benefits that environmentally friendly packaging provides. As more

consumers become accustomed to EFGP, more socio-demographics might be able to moderate the relationship between purchase intention and behavior to EFGP.

5. CONCLUSION

This research provides managers a better understanding of the socio-demographic groups that they might be able to target for environmentally-friendly packaging solutions. Knowledge of how EFGP plays a role in the consumer behavior of various socio-demographic groups is pertinent in understanding which groups are more likely to purchase the packaging. This study provides insights into how single consumers are likelier to act upon their intention by purchasing EFGP. Marketing can develop new strategies to target these consumers. Furthermore, to gain more awareness of environmentally friendly grocery packaging, managers build resources and tools for consumers to become more educated on products packaged with environmentally friendly materials. Government agencies can also play a role in providing educational information on the importance of environmentally friendly behavior. There is currently a need for more consumers to understand the benefits and characteristics of purchasing environmentally friendly grocery packaging. Targeting all consumers more efficiently with pro-environmental messaging is critical to sustaining the effort already achieved in getting more consumers to perform environmentally friendly behaviors. Many municipal governments have already created new mandates for recycling which has helped reduce the amount of waste going to landfills (Leiber, 2019). However, more work is needed to ensure that all consumers correctly dispose of their grocery waste.

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INFLUENCE OF PACKAGING DESIGN ON THE QUALITY PERCEPTION OF CHOCOLATE PRODUCTS

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Abstract: *It is well established that the consumers can often judge the qualities of enclosed products solely based on the information obtained from the packaging. The shape, size and weight of the container, materials, visual design, and information influence the consumer's perception of the product and purchasing decisions. In the context of consumer's browsing through store shelves, the appearance of the packaging container can be the crucial factor for selecting a specific product for closer inspection and, therefore, can have the major role in purchasing process and consumers' decisions. The majority of chocolate bar packaging feature rectangular physical shape of the container. Therefore, using materials, finishing and, most importantly, visual design elements, the designers strive to differentiate the product from the competition on the store shelves while also communicating desired qualities of the product. The research in this paper is focused on the influence of colour and basic shape elements applied on packaging on the perception of quality attributes of chocolate products. In the first part of the research semantic differential questionnaire was used to evaluate perception of colours and basic shape elements in regard to pragmatic and hedonic quality aspects of confectionery products. For this part of the research, the stimuli were displayed outside of the context of packaging. For the main part of the research, both physical prototypes and digital simulations of the packaging were developed, with variations in dominant colours and basic shapes used for visual design of the packaging. AttrakDiff questionnaire was used for subjective evaluation of physical stimuli. Digital simulations, combined with eye-tracking equipment, were used to assess the visual inspection of stimuli when the participants were asked to search for a specific taste related property of the product. Fixation count and fixation duration were measured to establish which packaging designs gathered the most attention during the visual search for specific product traits.*

Key words: packaging design, colour, quality, visual design elements

1. INTRODUCTION

In today's world of abundance, many consumers are daily faced with buying decision. Variety of choices can make this decision a complex task, requiring significant cognitive and time investment. Therefore, most consumers aren't willing to invest themselves equally for every product they seek to purchase. Consumer food packaging is considered low involvement for majority of consumers, with many of the consumers feel no need to carefully consider product characteristics, thus making the packaging visual design a driver in the purchasing decision process (Silayoi & Speece, 2004).
Due to limitations of the packaged products, potential buyers are deprived of available sensory information which would help them form a judgment about the product they are trying to buy. In the case of food products, consumers are often unable to access the product and even visually inspect it. Smell, taste, and even tactile information is not available before making the purchase decision. So, the information obtained from the packaging is often the only measure of quality. Perceived quality is a cognitive responsive to a product, which influence product purchase decisions (Kumar et al., 2009). Although people pay most attention to visual properties of the product package in the retail environment, perception of taste is the second most important aspect for food products (Schifferstein et al., 2013). Therefore, information about taste properties is often present on food packaging through explicit or implicit cues.
Unlike explicit cues, such as brand logos, labels, statements or claims, which explicitly convey meaning to consumers in a deliberate, direct manner, implicit design cues comprise references that cannot be readily distinguished but can "make sense" when used in the right context (Karjalainen, 2007). Cues like shape, colour or even sound can modify consumer's perception of a product (Spence, 2012). Although the cues are visible to consumers, their effects and influence on the perception are often subconscious (Spence, 2012; Becker et al., 2011; Piqueras-Fiszman et al., 2011),
Influence of implicit design cues packaging on consumer perception and buying decisions has received a noticeable amount of research interest in recent years. It is well established that packaging or container colour has an influence on the perceived product qualities, including of taste (Piqueras-Fiszman et al.,

2011; Baptista et al., 2021; Van Doorn et al., 2014). The hue of the colour can be associated with certain taste properties or can impact the intensity of the product's taste when consuming the product (Van Doorn et al., 2014). Increasing the saturation of certain hues can also lead to perception of increase in taste intensity (Spence, 2016). Baptista et al. (2021) investigated the effect of colour of chocolate packaging on perception of flavour, taste, and liking. The Results show that yellow and pink were associated with sweetness, while the participants associated black with bitterness. However, stimuli used for research were simplistic versions of packaging, featuring only coloured wrapper and visible product, thus omitting most visual elements that can usually be found on chocolate packaging, with the authors stressing the need for additional research on more realistic packaging design.
Shape cue influence on packaging was often researched in the context of the properties of the physical container (Spence, 2012; Marques de rosa et al., 2019; Velasco et al., 2014), label shape (Spence, 2012; Marques de rosa et al., 2019) and typography (Kovač et al., 2013). Rounded container shapes are associated with sweetness while angular shape is associated with bitterness (Velasco et al., 2014). Becker et al. (2011) demonstrate that the container shape influences taste intensity, with products from angular packaging tasting more intense compared to rounded packaging. There is also a general preference of rounded over angular forms (Bar & Neta, 2006; Spence, 2012)

2. PROBLEM STATEMENT

Previous studies of the implicit effects of colour and shape of food packaging on consumer perception and expectations were mostly focused on the properties of the container or label shape (Spence, 2012; Marques de rosa et al., 2019), reducing or completely omitting visual design elements regularly featured on packaging (Baptista et al., 2021; Velasco et al., 2014). However, there are many cases where changes of the container shape are not practical of feasible. Studies which focused on visual design properties, featured a limited number of cues (Westerman et al., 2013; Kovač et al., 2019) or varied multiple design cues at the same time (Gunaratne, 2019).
In the present study, we investigate the influence of implicit packaging design cues of visual shapes and colour on the visual search for specific chocolate taste properties and perception of overall pragmatic quality, hedonic quality aspects of the product. The study consists of two experiments that are equivalent in procedure and differ in stimuli design cues that were varied. The goal of this research is to establish whether the use of different shape or colour visual cues impact consumers attention when searching for specific traits and whether the change in the implicit visual cues has an impact on the overall perceived quality of the packaging.

3. EXPERIMENT

3.1 Participants

Participants were randomly recruited amongst students and faculty staff at the University of Zagreb, Faculty of Graphic Arts. A total of 20 people participated in this study, 9 men and 11 women, with the participants' age ranging from 20 to 40 years old.

3.2 Stimuli

The stimulus material consisted of nine different mock-ups of chocolate bar packaging, divided into two groups. The basic form of the packaging is rectangular, which is widely used for chocolate bar packaging. Visual design of the primary display panel features centrally positioned logotype on a basic white shape, pattern constructed of basic shape elements and solid colour background. Impact of explicit packaging cues was kept at minimum, so the logotype was generic.
In the first stimulus group (shape group) the independent variable in the design was the shape of the pattern elements and the logotype background element (Figure 1). Four basic shapes were used across the samples: circle, square, rectangle and triangle. The approximate position and number of the elements were consistent across the designs. The colour used for pattern was orange (CMYK: 0, 34, 85, 0; RGB: 250, 179, 50), and the background colour was brown (CMYK: 35, 81, 63,31; RGB: 136, 69, 52) across all samples in this group.

Figure 1: Sample designs for the shape stimuli group

In the second stimuli group (colour group), the independent variable was background and pattern colours (Figure 2). Five different hues were used for background (Table 2), with pattern elements featuring a lighter tint of the background hue. Circular pattern was used across all samples in this group.

Table 1: Colours used for samples in the colour stimuli group

Name	Crimson red	Green	Blue	Brown	Orange
CMYK	17, 100, 37, 7	85, 10, 79, 20	85, 50, 0, 0	50, 90, 80, 50	0, 42, 78, 0
RGB	193, 0, 88	0, 132, 80	29, 113, 184	93, 36, 33	247, 165, 70
HEX	#C10058	#008450	#1D71BB	#5D2421	#F7A546

Figure 2: Sample designs for the colour stimuli group

Physical mock-ups were created for the purpose of subjective evaluation, while the digital simulations were used for the eye-tracking experiment. On the digital simulations, mock-ups were placed in a two-row grid, with two instances of every design sample presented at the same time to better reflect the scenario of browsing product shelves in the supermarket. The placement of samples in the grid was different for every stimulus.

3.3 Method and design

The research was divided into two parts and was conducted in a controlled laboratory environment. In the first part, participants visual search behaviour was observed when tasked with finding a specific taste quality of chocolate. Tobii X60 eye-tracking apparatus was used to track participant eye gaze data. The test was run and recorded using Tobii Studio 3.2.2. software. The stimuli were reproduced on a computer display in front of the subject at a distance of 60 (+/-3) cm. The dimensions of the viewing area were 32,5 cm x 52 cm and the display resolution was 1920 x 1080 pixels. After the introduction to the experiment and the calibration process, the participants were shown the examples of both shape and colour stimuli. Then they were tasked to find a product with a specific taste, after which the stimulus was shown. Participants were exposed to each stimulus for the duration of 7 seconds. One round of the experiment had a total of four tasks, which differed only by taste which the participants needed to search for: sweet, salty, bitter, and sour. Each participant completed two rounds of four tasks, one for each stimulus group. Measured was gaze duration to determine on which design participants focused the most when searching for specific product taste. The results were analyzed using SPSS software.

The second part of the research was subjective evaluation of the general product qualities and user experience. For this experiment AttrakDiff questionnaire was used. AttrakDiff (Hassenzahl et al, 2003) is a questionnaire based on the semantic differential method and designed to measure pragmatic and hedonic qualities of interactive products, as well as the product's overall attractiveness. The condensed version of the questionnaire, called AttrakDiff Short, which was used for this experiment, consists of 10 bipolar word pairs which are used to evaluate following dimensions of design: Pragmatic Quality (PQ), Hedonic Quality (HQ) and Attractiveness (ATT). For each word pair, the participants evaluate the product on the Likert scale with range from 1 to 7. Stimuli were presented in X-Rite The Judge II Viewing Booth, under the "daylight" light source preset (6500K CIE D65). All samples within each of the stimuli group evaluated were presented at the same time.

4. RESULTS AND DISCUSSION

4.1 Eye tracking experiment results and discussion

Prior to inferential statistics of the eye-tracking data, we have evaluated the data for normality with Shapiro-Wilk test which showed that the fixation duration datasets are non-normally distributed for both stimuli groups across all tasks. Therefore, only non-parametric statistical tests were used in the analysis. Total fixation duration (TFD) between samples in the stimuli group were compared by applying the Kruskal-Wallis test.

Table 2: Shape stimuli total fixation duration results

Task	Sample	N	Mean	Std. Error	Std. Deviation
bitter	circle	20	1.0610	.13571	.60693
	square	20	1.7820	.24807	1.10941
	rectangle	20	1.2480	.20927	.93586
	triangle	20	1.0055	.17946	.80256
sour	circle	20	1.0185	.14935	.66790
	square	20	1.0925	.14744	.65937
	rectangle	20	1.3840	.23030	1.02991
	triangle	20	1.6765	.29141	1.30321
salty	circle	20	.8365	.14295	.63928
	square	20	1.0970	.13910	.62208
	rectangle	20	1.2985	.22007	.98420
	triangle	20	2.1710	.27920	1.24862
sweet	circle	20	2.0505	.24760	1.10732
	square	20	1.0845	.12368	.55311
	rectangle	20	1.2600	.13123	.58686
	triangle	20	.9125	.17929	.80179

Table 3: Kruskal Wallis test results for the shape stimuli group tasks

	Bitter	Sour	Salty	Sweet
H	7,656	3,183	16,067	18,060
df	3	3	3	3
p	0,054	0,364	0,001	< 0,001

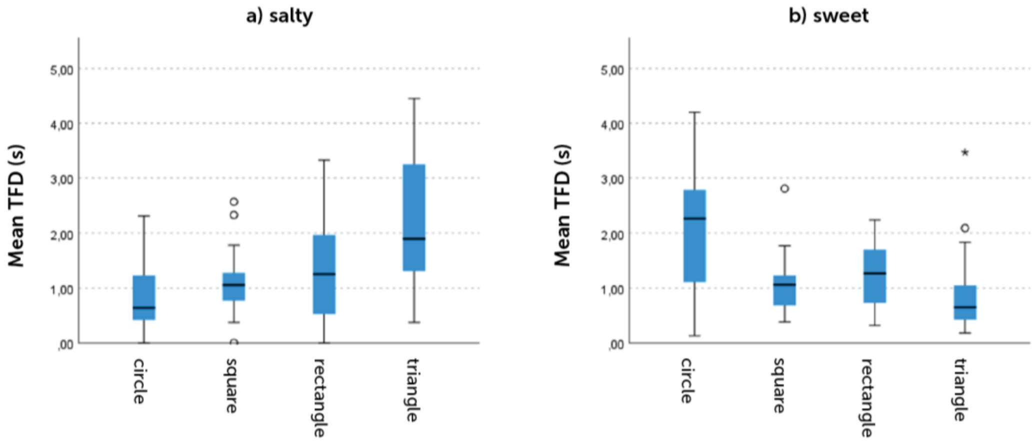

Figure 3: Boxplots showing mean total fixation duration for the shape stimuli group in the a) salty taste search task and b) sweet taste search task

Table 4: colour stimuli total fixation duration results

Task	Sample	N	Mean TFD (s)	Std. Error	Std. Deviation
bitter	crimson	20	.6875	.17991	.80458
	orange	20	.8785	.18085	.80878
	blue	20	.8055	.13589	.60772
	brown	20	2.2615	.42589	1.90462
	green	20	.5600	.12042	.53856
sour	crimson	20	1.0305	.25061	1.12076
	orange	20	1.3545	.25352	1.13377
	blue	20	.8390	.14515	.64915
	brown	20	.4125	.10092	.45131
	green	20	1.7410	.27380	1.22447
salty	crimson	20	.6715	.15224	.68085
	orange	20	1.3570	.25815	1.15446
	blue	20	1.4255	.33524	1.49926
	brown	20	.9785	.20291	.90745
	green	20	1.1290	.20118	.89971
sweet	crimson	20	.8405	.18279	.81748
	orange	20	.9895	.16128	.72128
	blue	20	1.2040	.16722	.74781
	brown	20	1.7745	.24423	1.09223
	green	20	.4765	.10021	.44813

For the shape stimuli group, there was statistically significant results of the total fixation duration for the salt($H(3) = 16{,}067$, $p = 0{,}001$) and sweet($H(3) = 18{,}06$, $p < 0{,}001$) taste search tasks (Table 3). *Post-hoc* Kruskal-Wallis test results indicate that there is statistically significant difference for the circle-triangle ($p < 0.001$) and circle-square ($p = 0{,}031$) pairs for the sweet taste search task, with circle having longer TFD in both cases (Table 2, Figure 3). There was no statistically significant difference for other pairs in this task. For the salt taste search task (Table 2, Figure 3), there is statistically significant difference for circle-triangle ($p = 0{,}001$) and square-triangle ($p = 0{,}041$), with triangle having longer TFD in both cases. Results for other pairs in this task show no statistically significant difference.

Table 5: Kruskal Wallis test results for the colour stimuli group tasks

	Bitter	Sour	Salty	Sweet
H	14,604	19,644	6,123	22,585
df	4	4	4	4
p	0,006	< 0,001	0,190	< 0,001

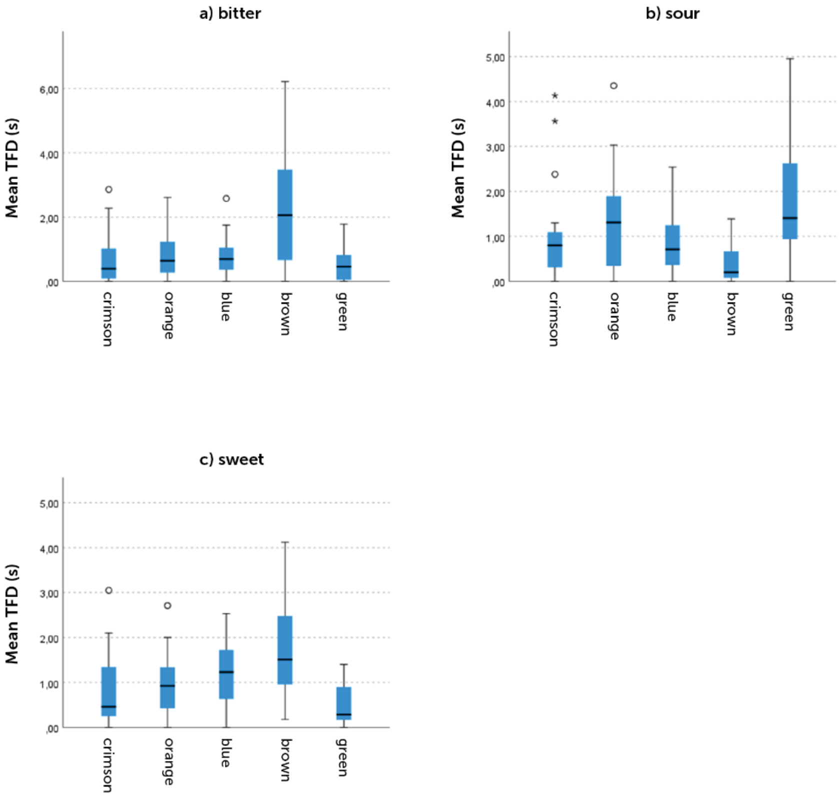

Figure 4: Boxplots showing mean total fixation duration for the colour stimuli group in the a) bitter taste search task, b) sour taste search task and c) sweet taste search task

For the colour stimuli group, Kruskal-Wallis test results indicate statistically significant results of the TFD for the bitter ($H(4) = 14{,}604$, $p = 0{,}006$), sour ($H(4) = 19{,}644$, $p < 0{,}001$) and sweet ($H(4) = 22{,}585$, $p < 0{,}001$) taste search tasks (Table 5). *Post-hoc* Kruskal-Wallis test results for bitter taste search task indicate statistically significant difference for the green-brown ($p = 0{,}007$) and crimson-brown ($p = 0.013$) with brown having a longer TFD in both cases (Figure 4, Table 4). For the sour search task there is statistically significant difference between brown and green ($p < 0{,}001$) and brown and orange ($P = 0{,}014$) with brown having shorter TFD in both cases (Figure 4, Table 4). Sweet taste task results show statistically significant difference for three colour pairs: green-blue ($p=0{,}016$), green-brown ($p < 0{,}001$), where the green had shorter TFD in both cases, and crimson-brown, where crimson had shorter TFD (Figure 4, Table 4). There was no statistically significant difference for other colour pairs.

Results indicate that difference in shape cues used for visual design of the packaging can have significant impact on visual search for sweet or salty chocolate taste. Round shapes were perceived as sweeter compared to angular shapes of square and triangle, while triangle gathered more visual attention compared to circle and square patterns. However, search for bitter and sour did not produce significant results, which could indicate that it's harder to associate those taste properties with specific shape cues.
Although colour cues also have significant impact on visual search in case of sweet, sour, and bitter taste, the relationship between colour pairs and taste are more complex. In both bitter and sweet search task, brown had significantly higher fixation duration compared to both green and crimson. This might be due to participants associating these taste properties with the colour closest to the colour of the chocolate bar itself. However, green had significantly higher TFD compared to brown when the participants searched for sour taste property.

4.2 Subjective evaluation results and discussion

Results from the subjective evaluation were analysed using AttrakDiff online analysis tool.

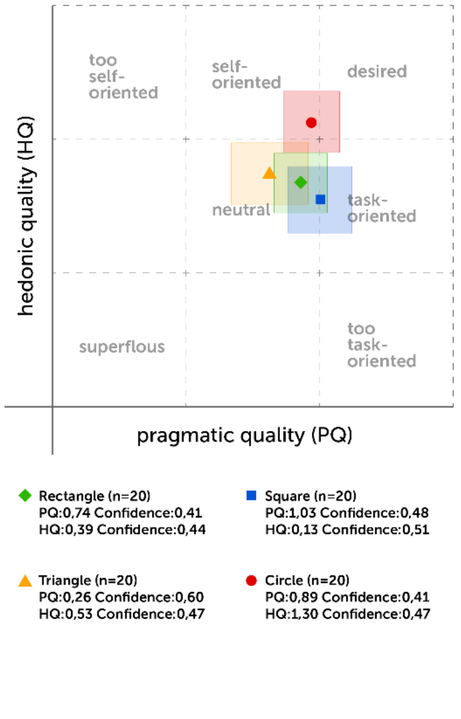

Figure 5: AttrakDiff results for shape stimulus group

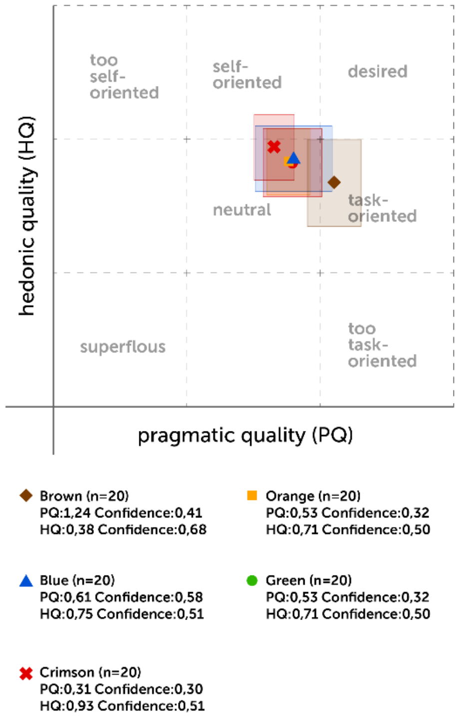

Figure 6: AttrakDiff results for colour stimulus group

In the shape stimuli group (Figure, there is significant difference between in the perceived hedonic quality of the circle-square and circle-rectangle, with higher score for circle sample in both cases (HQ = 1,30). Overall score puts the circle sample nearest to the "desired" character-region, as defined by AttrakDiff (Figure 5). This indicates that rounded shapes on visual design have higher overall preference compared to angular shapes, which is in line with existing research (Bar & Neta, 2006; Spence, 2012).
Results for the colour stimuli group are more clustered together compared to the ones for the shape group (Figure 6), with the significant difference being for the pragmatic quality rating between brown and crimson (PQ = 0,31) red sample (PQ = 1,24).
Although there are differences in scores between certain samples, all the samples in both evaluations have positive scores for both pragmatic and hedonic quality dimensions.

5. CONCLUSION

The results of this research indicate that implicit use of shape and colour on product packaging can have significant effect on attention when searching for specific taste properties but can also influence subjective perception of the overall pragmatic or hedonic qualities of the product. There was statistically significant difference in total fixation duration between designs with circular, square, and triangular patterns when participants searched for sweet and salty products. For sweet taste, most attention was on the product with circular pattern, while the participants focused on the design with triangular pattern when tasked with search for salty taste.

Although there was statistically significant difference between certain colour pairs, the influence of colour cues on visual search for product taste is not as clear. Brown colour gathered more attention compared to green and crimson for both bitter and sweet search tasks, although participants were more focused on the green packaging, as opposed to brown, when searching for sour taste property.

Results also indicate that change of shape cues in visual design impacts perceived hedonic quality of the product, with design featuring circular pattern having higher score than designs with square or rectangular cues. In the case of colour cues, only significant difference was in the higher pragmatic quality score for brown packaging compared to packaging in crimson red colour.

The results provide practical guidelines for designers, enabling them to adjust packaging design for desired taste properties, but also to consider how these changes can reflect on the perception of the overall pragmatic and hedonic quality of the product.

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EDUCATION

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EDUCATION AND ITS CHALLENGES IN POST COVID TIME

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Abstract: *Globalisation, has been challenged in the last two years by the emergence of the Corona virus. In particular, the events of the last two years have had a tremendous impact on the educational process throughout the world, as the learning process has taken a completely new turn; the young people, who have been deprived of much unconcern, have lost the most in terms of educational processes. Despite these facts, with a lot of effort, it has been possible to maintain the high level of education and knowledge transfer with the help of modern technologies (online learning). Even more, successful practises and thus real-time networking and education have been achieved.*

One of the results of the above work is also the bilateral cooperation between the Republic of Slovenia (University of Ljubljana) and the US state of Kansas (Wichita State University), which started in October 2021 and ended in January 2022. We created a project that involves students from both continents and gives them the opportunity to learn about cultural and linguistic differences. Multilingual communication is something to strive for, especially in the post-covid times. Slovenian students learned about US states and tried to represent them graphically in an appropriate way by imitating the design of letters or inscriptions. Following the same principle, Kansas students were also involved in the project, with the difference that they were able to collect and learn data about different European countries. The result of the bilateral cooperation was a world map that represents the state or country as the students see and perceive it. In designing the map, the students considered historical, sociological, and cultural aspects specific to a region. This laid the foundation for further collaboration and created a basis that can help educate and learn about cultural and linguistic differences in the world in the future. The first phase of the project is currently ongoing, but will be expanded in the coming years. The aim of the project is to create a graphic printout of all the countries in the world, displayed in what is called a typography world map. Our aim is to connect educational institutions from all over the world and thus contribute to the acceptance of cultural and linguistic differences.

Keywords: education, graphic design, language, typography, visualisation of information

1. INTRODUCTION

Until recently, it was common for universities around the world to mainly have classes in-person. It was almost unimaginable when, at the beginning of 2020, we suddenly had to interrupt the normal workflow and switch to various online platforms offering remote work. Many institutions adapted to the new situation without any problems, but they also identified some shortcomings for example inappropriate equipment, poor technical knowledge, adaptation of working environments, etc. (Ngo, 2021). The latter have finally settled in retrospect, and now many aspects that we were not aware of are coming to the fore, especially with regard to the social contacts that are important for young people.

After almost two years of mostly remote work, with breaks during which the situation in various parts of the world has improved somewhat, the study commitments could be performed in-person with a great caution. Still, it is hard to say that the occasional in-person meetings have contributed to more engaged work. In general, there was a sense of apathy and uncertainty (among both students and staff) as the media did not provide encouraging information about the improvement of the situation (Torres, Statti & Torres, 2022).

Despite the fact that everything happened very quickly, we found that people are very adaptable and can quickly transition to different situations and function well. An example of this is the use of online platforms for remote work (Kintova et al., 2022). It has been shown that some parts of the course (e.g. a seminar) can often be done even better because the whole group can see the product being commented on via the screen. In in-person discussions (especially with larger groups) often lead to students not being able to follow the comments and reflections (of course only if it is group work and not individual work).

Remote work can be of great help to educational staff when they are participating in training (or another form of work) in foreign institution (Tate & Warschauer, 2022; Suttiwan, 2022). Due to the distance (including the time difference), they cannot fulfil their obligations at the home institution (faculty) in real time. In the latter case, working through online platforms can be an excellent substitute for the study process and all its components expected from the educational institution.
In this way, we also carried out an international cooperation between the Republic of Slovenia (University of Ljubljana) and the US state of Kansas (Wichita State University) in a joint project entitled Typography World Map. Part of the students who participated in the project fulfilled all their obligations in seminars held exclusively by distance learning, while part of the students fulfilled their obligations in face-to-face meetings (Miller, Begović & Baumgartner, 2018; Mackare & Jansone, 2017).

2. METHODS

In the winter semester of the academic year 2021/2022, the slovenian master's students of the Creative Typography course individually developed various typographic solutions, which were linked to sets, presented in the course's seminar and linked in terms of content to the semester project Typography World Map. Thus, in 15 weeks, they were faced with the challenge of creating 10 tasks that helped them to select the appropriate features, shapes, colours to ensure that the results were used correctly in the final (semester) assignment.
As part of the semester assignment, students had to plan and design the letters needed to spell their chosen US state in English. The letters had to have the characteristics of accidental/decorative/display letters (letters with special shapes, for example: hollow, dotted, ornate, shaded, double or multiple strokes, stencilled...). They also had to research the representative features of the chosen state (cultural, historical, social, industrial etc.) and incorporate them into the designed letters. These were used to print the state without the borders that define it.
The students from the School of Art, Design and Creative Industries (Wichita State University, Kansas) with whom the first phase of the Typography World Map project took place, approached the work in a similar way. The difference was that the students from Wichita had to explore European countries.
At the beginning of the semester, the task was presented to the students from both Slovenia and Kansas. In order to make the assignment as objective as possible, the students were not allowed to freely choose the state/country for their assignment. They may have had an easier assignment because they knew a state or country better or other circumstances favoured them. Using lottery method, the students chose a number representing a particular state/country and thus randomly selected the state/country that was the topic of their semester assignment.
As part of the project, Slovenian students randomly selected the following states: *Alabama, Alaska, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Idaho, Kansas, Kentucky, Massachusetts, Minnesota, Missouri, Montana, Nebraska, Nevada, New Mexico, New York, Oklahoma, Oregon, South Carolina, Virginia, Washington, and Wisconsin.*
On the other hand, students from Kansas chose *Armenia, Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Ireland, Lichtenstein, Lithuania, Luxembourg, Monaco, Russia, Slovakia, Slovenia, Spain, Switzerland, and Turkey.*
In total, 27 of the 50 US states and 19 of the 49 European countries were selected. At this point we must point out that the whole of Europe was included in the project, not just the countries that are members of the European Union. In this way, we had a comparable number of countries on one continent or the other to choose from (50 US states and 49 countries in Europe).

2.1 Research and key components

Students immersed themselves in the research about the chosen state/country of their choice. This enabled them to research the cultural, social, linguistic, natural and other features or real events that are representative of US states and European countries.
Based on the research, the idea of each state/country was condensed into a keyword. *Table 1* shows the list of US states and European countries with their corresponding keywords, which were the main guide in creating the expression. To a greater extent, students relied on typical characteristics that were sufficiently objectively associated with the selected state/country.

Table 1: Keywords to describe states (US) and countries (Europe)

State – keyword	*Alabama – wood, Alaska – cold, Arizona – cactus, Arkansas – diamonds; California – coast; Colorado – landscape; Florida – water; Georgia – Martin Luther King; Hawaii – dispersion; Idaho – potato; Kansas – sunflower; Kentucky – Derby; Maryland – crab; Massachusetts – tea; Minnesota – lakes; Missouri – arc; Montana – tribes; Nebraska – meridian; Nevada – lights; New Mexico – adobe; New York City – chaos; Oklahoma – tornado; Oregon – diversity; South Carolina – golf courses; Virginia – love; Washington – grunge; Wisconsin – cheese.*
Country – keyword	*Armenia – carpets; Austria – form; Belgium – architecture; Bulgaria – Martenitsa; Croatia – landscape; Czechia – label; Denmark – music; Estonia – clothing; Ireland – mythology; Lichtenstein – principality; Lithuania – tradition; Luxembourg – cliffs; Monaco – casinos; Russia – script; Slovakia – folklore; Slovenia – nature; Spain – flamenco; Switzerland – gold; Turkey – patterns.*

2.2 Weekly assignments

In order for the project to produce adequate results, the students had weekly assignments to help them complete the semester assignment. So, they had 10 assignments to complete in 15 weeks. In *Table 2* we see the titles of the weekly tasks and their short descriptions.

Table 2: Weekly assignments and short descriptions

	Weekly assignment	Short description
1	Handwriting	Find the best approximation of your signature based on 20 repetitions. Digitise your signature. The result is a file (e.g., .otf) that you can install on your computer. Prepare an analysis of the data set based on the TypeCooker parameters.
2	Letters around us (Found type)	Compose a state name based on natural forms. Find motifs (in nature, in the urban environment...) that represent the letterforms of the state and compose them. It is not about composing objects and creating a record of the state. The natural shapes should represent the corresponding letters for the composition of the sentence.
3	Consistency in writing	Write down a state/capital. Write the word twenty times, making sure that the letters are as even as possible; that the length (width) of the word does not vary too much, that the letters are evenly connected, that the thickness of each letter varies as little as possible...
4	Representative colours	Identify the colour(s) of the state that best describe or define it. Select the colour(s) and use them to create a (handwritten) character. It is not necessary for the written word to be exact. What is important is the use of the colours and contrasts you create.
5	Modularity	Choose 4 elements to form the letters representing the state (lowercase only, uppercase only or a combination). Each element can be repeated for letters, but make sure that each letter contains at least two elements/modules.
6	Layers	Choose a colour and its variations. Create linear letters by superimposing the chosen colour to get the name of the state. The most important thing in this task is not the correct ratio of the letters or the correctness of the letters. The most important thing is that the overlapping layers make the printed word.
7	Purpose of letters	Find 4 words in different publications/websites that are related to or illustrate the concepts of information, identity, community and function. The words should differ in choice of typeface, font, size, colour, etc. Cut out or print the words and create a sample collage (A5) stating your findings next to each word.
8	Counterform	Draw the counterforms that will make up the name of the state. The counterforms can come from different groups of fonts (serif/sans serif, linear...). Try to coordinate the counterforms as much as possible so that the letters and the state can be derived from them.
9	Functionality and semantics	Research and find examples of typefaces (four for each category, eight in total) that have high functional and semantic value. The examples should be from everyday life and must be related to the state.
10	Combinations	Choose 3 typefaces and combine them accordingly. It is necessary to create a combination. Choose 3 fonts and combine them in an appropriate way. It is necessary to make a combination within a family and a combination between different families. Carry out an analysis and justify why it makes sense to combine certain fonts.

The weekly tasks could effectively contribute to the end result, which was actually the main part of the seminar. The step-by-step construction of the final product is a transparent representation of the production of elements that could be included in the created state/country files at the end of the project.

3. RESULTS

The results for a specific US state or European country are presented below. The typical features that emerged during the research are reflected in the motif selected and the colour used for each state/country.

3.1 United States of America

In the way shown in *Figure 1,* the Slovenian students imagined how they could illustrate and represent the US states. As mentioned earlier, 27 of the 50 US states are currently produced. This explains the empty spaces (white areas appearing where the rest of the states would otherwise be).

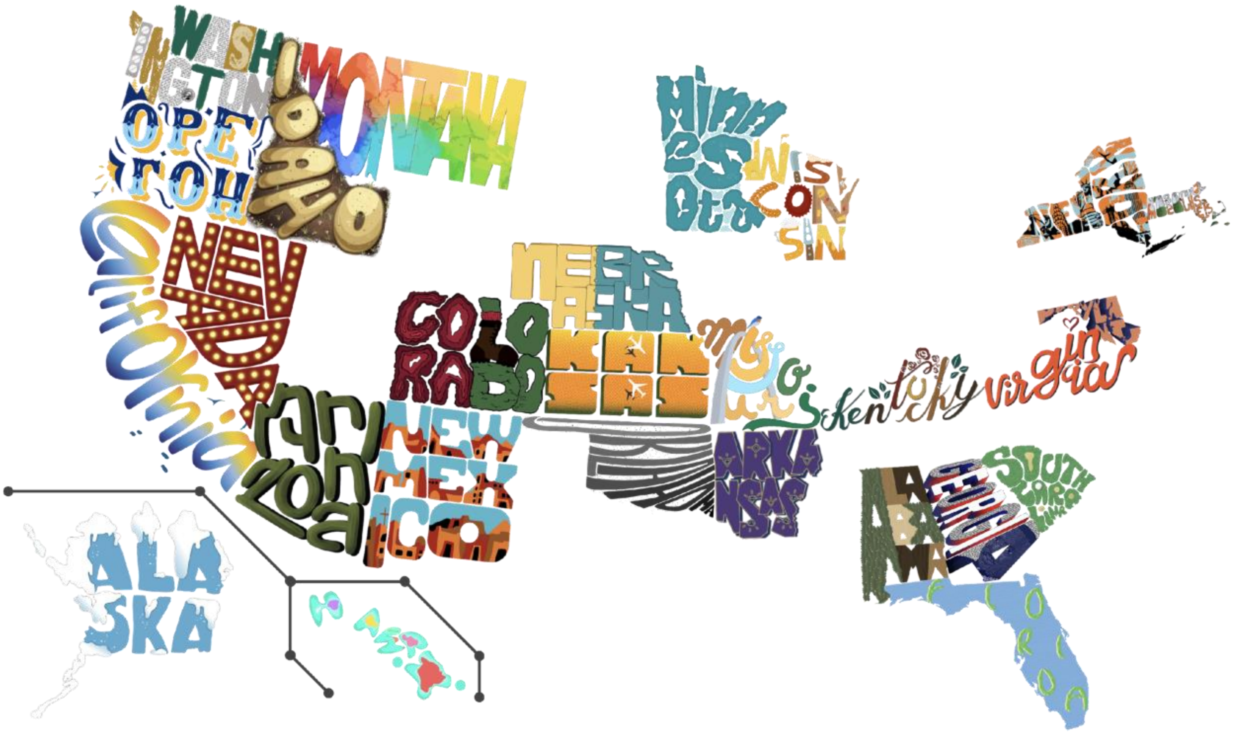

Figure 1: An overview of the US states from the perspective of Slovenian students

As can be seen in *Figure 1,* the US states can be clearly seen in reduced size as they cover a considerable area geographically. It is a little more complicated with the European countries, as they are much smaller. We will highlight the datasets of some US states and show which features are used in them.

The state of Hawaii consists of six main islands (the entire Hawaiian archipelago consists of 137 volcanic islands). For this reason, compiling the state's digital dataset was quite a challenge: how to capture all parts of Hawaii in one comprehensive unit? By creating a digital dataset and being able to represent it, the silhouette of the Hawaiian islands was somewhat simplified. In this way it was possible to cover a large part of the dislocated US state in the dataset. In *Figure 2* we see how the student approached the challenge of creating Hawaii. The key word for this state was dispersion, which is fairly obvious at first glance. Of particular interest is the fact that it was possible to represent the letter 'i' at the end of the word in the form of an interesting ligature, where the basic stroke of the lowercase i runs horizontally and the diacritical marks are arranged to the left and right of the horizontal stroke; all together representing two letters i.

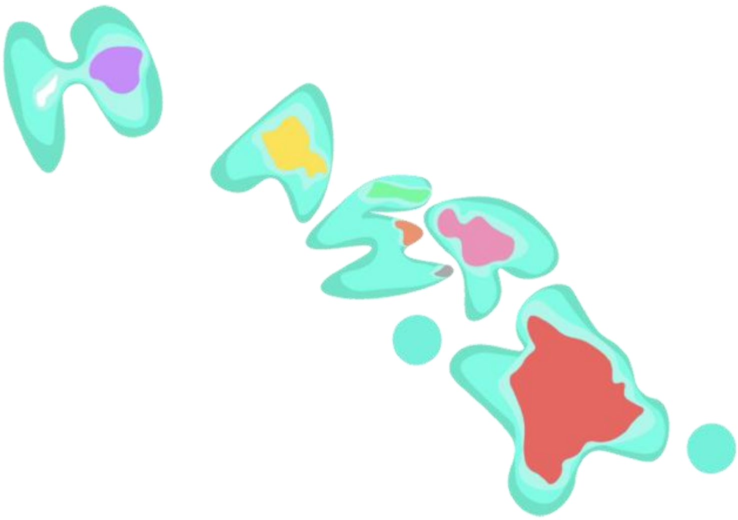

Figure 2: Motif of the US state of Hawaii

Figure 3: Motif of the US state of Massachusetts

The state of Massachusetts has a complex shape, which can be seen in *Figure 3.* The central motif used to create this state's dataset is a historical event called the Boston Tea Party. Motifs related to the events (tea, tea bag, tea cup, tea leaves) were created based on this. Besides the elements that appear, the choice of colours is also suggestive. The colours were chosen so that they can be associated with the culture of tea.

In the following, two states are presented which are not complicated in form, but nevertheless it was necessary to consider carefully which motifs and colours should be used to represent both.

Figure 4 shows the state of Kansas, which is known for its sunflowers and is also the name of the state: The Sunflower State. The rosette patterns in shades of orange, yellow and red represent sunflowers. The city of Wichita, the largest city in the state of Kansas, also holds the title of "Air Capital of the World" because much of the city's industry is based on aviation. The counters in the letters A are replaced by the silhouette of an aircraft. In this way, the Kansas state motif captures what makes it recognisable.

Figure 4: Motif of the US state of Kansas

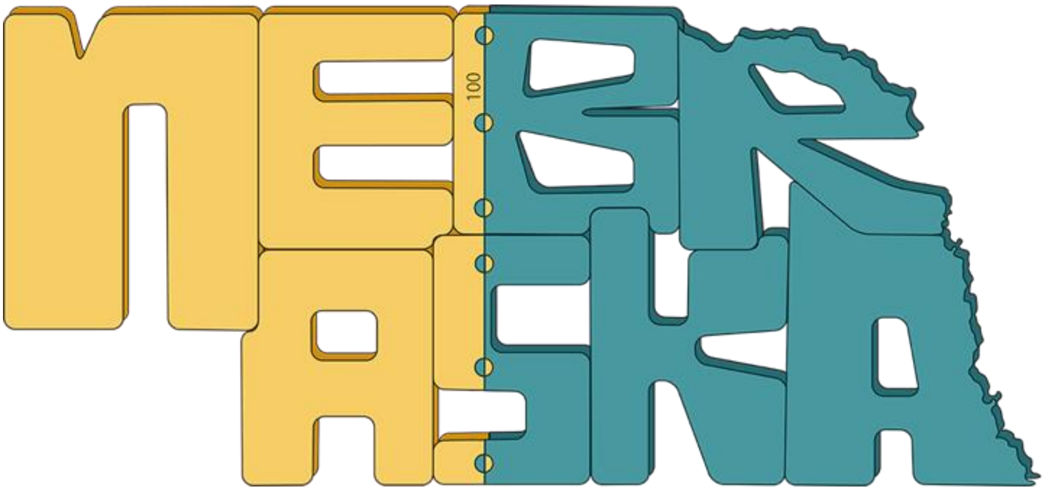

Figure 5: Motif of the US state of Nebraska

It was was quite a challenge to find motifs that could represent the state of Nebraska *(Figure 5)*. The state itself has no specific characteristics that make it immediately locatable. Nevertheless, thorough research yielded an interesting motif that was eventually used to represent the state. The 100th meridian runs through the state, which was the main idea for creating the motif, and naturally separates the lowland and high mountain regions of the state. During the research, it was also found that the colours that occur at the level of the state and also its individual parts are yellow and green. Thus, the yellow colour, which can be seen on the left side of *Figure 5*, represents the highland part of the state, while the green colour, which can be seen on the right side of *Figure 5*, represents the lowland part.

We have presented 4 cases that were very challenging because of their peculiarities. Nevertheless, we believe that the typical features of each state, as they occur in nature, have been adequately presented. In the next section we present how the students from Kansas researched and analysed the European countries.

3.2 Europe

In the similar fashion as Slovenian students, the students from Kansas also started the project. They chose 19 European countries *(Figure 6).* In contrast to the representation of the US states, some problems arise with the European countries, as the countries are inherently much smaller in land mass, which in turn leads to a lower visibility of the countries with smaller sizes. There is also a lot of empty space in this case, as more than half of the country datasets are still missing.

Figure 6: An overview of European countries from the perspective of Kansas students

Similar to the case of the US states, we will take a closer look at some examples. First, Belgium will be highlighted *(Figure 7).* The main point of reference for this country was its architecture, especially the arches characteristic of Art Nouveau. In the example we can see that the whole set looks quite organic because of the round shapes, and yet flowers have been added to the letters, representing poppies. This is a typical plant that can be found in almost all of Belgium. The shape of the country is quite complex (as with all European countries), but nevertheless the example shows that it was possible to keep the letters (with some simplifications) within the boundaries that make up Belgium.

Figure 7: Motif of the European country of Belgium

Figure 8: Motif of the European country Bulgaria

The next interesting example is Bulgaria *(Figure 8).* An Eastern European country with a rich culture presents quite a challenge when it comes to what is typical of that country. During the research, it turned out that the holiday Martenitsa, which illustrates the transition from the cold winter season to the warmer spring, is a good motif that is recognisable throughout Bulgaria. Characteristic of this holiday are knitted bracelets, usually rolled up in a red and white colour combination. And this was precisely the basis for the founding of the country within its borders.
As we have already mentioned, the complexity of forms in European countries is much greater than in US states. Nevertheless, there are also some countries in Europe that are not so complicated in terms of form. Such examples are the Czechia *(Figure 9)* and Lichtenstein *(Figure 10).*
The Czechia is famous for its rich history, which includes beer brewing. Many different labels were produced for beer advertising in the past and still today. It was the beer labels that represented the idea of the Czechia. In addition, there is the fact that in most Eastern European countries a socialist-communist regime ruled for a long time, which is also reflected on the processed plate. The colours typical of Slavic countries were an unavoidable element in the colour definition of the country. Added to this is the star, which appears in a counter of the letter e and was an important symbol in many countries of the Eastern Bloc.

Figure 9: Motif of the European country of Czechia

Figure 10: Motif of the European country of Lichtenstein

The Principality of Lichtenstein is one of the smallest countries in Europe. Nevertheless, it has a rich history and natural features that are recorded on the example of the land survey. The shiny elements, clearly give the impression of a princely state. Moreover, the country's landscape is very diverse, which is also reflected in the colours used. The colours blue and red stand for the border between the Alps and the Rhine valley. The letters are very ornate, which can be seen especially at the ends of the strokes. This is further evidence of the nobility that was important to the country in the past and still is today.

4. DISCUSSION

Based on the project, we find that modern online platforms, which we have adopted especially during the pandemic, can be excellent tools that allow working remotely. In particular, they are very welcome when it comes to projects that are considered transcontinental cooperation. Despite the considerable time difference of seven hours, it was possible to coordinate well the activities of the students from Slovenia and Kansas. It is true that this was a great challenge for the course instructors, as the work took place throughout the day, so that both groups of participating students could receive appropriate instructions and guidelines for their work.

From the digital motifs produced by the states/countries, we can see that the task was well posed and that there were no problems in understanding the tasks required of the participating students. The group of students was relatively large, which was known from the beginning of the project, and the aim was to involve as large group of students as possible in the collaboration. In this way it was possible to cover a larger number of states/countries (both in the US and Europe), which provides good starting points for further work.

The features that the students have included in their products show the diversity of the world and the enormous possibilities and potential that each continent or the states/countries that make it up have. It is true that modern culture has exposed us to some states/countries much more than others through the media, but perhaps this is what encouraged the students to research carefully before completing the assignments themselves.

Research work is an essential part of various (graphic) processes and is therefore very important to achieve excellent results. It is also interesting to note that the Slovenian students, whose assignments included the US states, learned about the individual states and realised that there is a great diversity among them.

We note that the Kansas students have also come to new conclusions. It is true that in Europe there is even more differentiation and definition according to the country of origin. The most important insight we have gained is that through their research they have found out some of the specificities of the countries that make up Europe and have effectively integrated them into their projects.

The smallness of the European countries was also something that was sometimes a little more difficult to explain (getting used to the size of the US states certainly has an influence on this). In addition to the small size, the shape of the European countries was also one of the biggest challenges in creating the datasets. The shapes of the European countries are generally different and quite complex. Therefore, when working on the shape of the countries, it was often necessary to simplify them considerably in order to implement them in this way: to create a dataset that has the shape of a country.

5. CONCLUSIONS

During the coronavirus outbreak, transcontinental cooperation faced major challenges. Travel restrictions made it almost impossible to conduct in-person international cooperation and visits, which are the basis for effective collaboration and finding appropriate solutions. Despite the difficulties, people quickly moved to online environments, which, at least to some extent, somewhat alleviated the day-to-day problems and made collaboration possible; with the help of cameras and appropriate programmes, of course.

Based on the relatively long duration of the global/collective online work (from 2020 for almost 2 years), we have found that some practises are successful and need to be maintained for the time when the situation normalises and international cooperation is possible, as we remember before 2020. And just the implementation of the pedagogical process of remote working has shown that this is possible and that it also makes the cooperation a little easier for the mentors.

Comparing the two processes we carried out during the project (i.e., face-to-face and online), it can be seen that both groups of students received clear and adequate instructions on how to carry out the project. The availability of the project mentors was at a high level throughout the collaboration, which was also reflected in the appropriate solutions expected at the end of the project.

We note that the transcontinental cooperation has been successful, which is an additional incentive for all involved to continue it and start new projects. The testing and implementation of the project fills us with great hope to continue the project and build cooperation on a global scale. The outcome of the project is quite challenging, as we want to create a Typography World Map, where each state/country of the world is represented by letters (shapes) and colours that contain the characteristics of that state/country of the world. An important aspect of the project is also that we want to represent the states/countries only with shapes without borders, which can often represent obstacles.

6. ACKNOWLEDGMENT

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THE AWARENESS OF ETHICAL DESIGN PRINCIPALES IN MEDIA DESIGN EDUCATION

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Abstract: *Designers today, through the creation of media content, do not only create a media construct, but they also participate in the creation of social values, norms, and common patterns of communication. When reading books, manuals and design instructions, a design practitioner often encounters the term "good design". If we take the "good design" concept of industrial designer Dieter Rams, then the term will be describing the product that is useful and understandable, innovative, aesthetic, unobtrusive, honest, long-lasting, thorough to the last detail, environmentally friendly, and involves as little design as possible. His principles of "good design" can be applied to the field of media design, applications, user interfaces and so on. Or, if we change the paradigm towards the ethics, is "good design" design which is not only aesthetically pleasing but also that strives to do good - to be socially responsible in order to improve the social environment? This approach is the basic of this article. The basis and starting point for the discussion was the article "Redefining design ethics" by Phil McCollam published in Design and Culture, 6: 3, 2014. The author argues that designers have a legal obligation to be aware of and to follow accessibility laws and standards, but also, more broadly, they have an ethical obligation to focus on the needs of the people who will use their designs, even when the law does not explicitly require it of them. Furthermore, he says that future professionals must be challenged to develop solutions that are human-centric. The research is based on a questionnaire and discussions with the students of graphic design. Therefore, the goal of this research is to explore the existence of awareness of the ethical and social role of design in contemporary society through individual awareness of students.*

Key words: ethical design, vocational ethics, citizen designer, media education

1. INTRODUCTION

Developing a definition of what is ethical is problematical because there is no one negotiated definition upon which to rely. The word itself is problematic, because people define it differently - some equate it with legality, some associate it with religion, some are guided by personal feelings in evaluating ethics. Many people are unclear about what is or is not ethical until they are asked to respond to actual case scenarios. Even then, not everyone will agree because the determination of what is ethical is socially constructed, and therefore varies from one discourse community to another and from one rhetorical situation to another. Ethical decision-making models grounded in ethical frameworks comprehend elements of moral philosophy such as utilitarianism, deontology, and virtue ethics. It has always been difficult to clearly define what good design is but determining what constitutes good design praxis is maybe burdened with lesser challenges (Boradkar, 2004). Good design therefore should extend beyond just form and function to those of society and culture. It should take into consideration the needs of many – users, employers, minorities, states, nations, future and past generations and all of this in spite of pressures of economy and profit. Value Sensitive Design (Friedman, 1996), Ontological Design (Fry, 1999, 2012), Transition and Pluriversal frameworks (Escobar, 2015; 2018; Irwin et al., 2015; Noel, 2020) all deal with the designing of values, rather than of artefacts, services, and systems. Design's aesthetic function has evolved into a tool to focus on people and technology (user-experience design); as a differentiation tool to support branding; as a business tool for fueling innovation; and finally as a cultural tool enabling transformation (Hernández et al., Cooper, 2018; Gardien & Gilsing, 2013). Ethical issues arise from gender, political and racial biases, to discrimination and profiling, from hidden exploitative labor to hidden environmental destruction (Luján Escalante et al., 2022). Luján Escalante et al. (2022) built Ethical, Legal and Social Implication (ELSI) guidance around a constellation of values that have been raised as important with the IsITEthical?Exchange Network. In their work they argue that an ethical framework should be unique for each project, co-designed by developers and practitioners. In his attempt to apply traditional approaches to ethics in the field of design, d'Anjou (2011) starts from ethical decision-making models also draw upon some sort of traditional moral philosophy such as utilitarianism, deontology, virtue ethics and then he proposes an Sartrean approach in which he emphasizes a total engagement and acceptance of both freedom and responsibility on the part of the individual involved in such process, and implies that it has to start over again for each individual case since there is no universal or objective truth; subjectivity is constitutive and intrinsic. His model is built upon five central tenets in Sartre's existentialism that form the core of his thought. They are: projectiveness, freedom, subjectivity of values, the subjectivity of experiences, and 'authenticity'. The model's emphasis is on the designer's awareness of his/her design freedom, design responsibility, prior design choices, existential projects, external and contextual demands, and the practical limitations of the design situation. For Sartrean ethics, freedom is the prevailing ethical value (d'Anjou, 2011). The model, which is heuristic and not absolute, is based on the core themes of Sartre's philosophy and ethics. In the design field, a more structured approach about ethics has been noticed in human computer interaction (HCI). For example, VSD (Value Sensitive Design) advocates organizing a process in which different stakeholders can express and negotiate their perspectives on these values in order to integrate these productively. VSD accounts for human values in the design process through an iterative tripartite design approach that examines conceptual, empirical and technical issues (Cummings, 2006). When applying the VSD approach, twelve specific human values have been determined to have ethical import that should be considered in the design process: human welfare, ownership and property, privacy, freedom from bias, universal usability, trust, autonomy, informed consent, accountability, calmness, identity, and environmental sustainability (Cummings, 2006). Although the VSD approach is one of the most revied one, some authors (Manders-Huits, 2009) emphasized its shortcomings: (1) it does not have a clear methodology for identifying stakeholders, (2) the integration of empirical methods with conceptual research within the methodology of VSD is obscure, (3) it runs the risk of committing the naturalistic fallacy when using empirical knowledge for implementing values in design, (4) the concept of values, as well as their realization, is left undetermined and (5) VSD lacks a complimentary or explicit ethical theory for dealing with value trade-offs (Manders-Huits, 2009). Stuhlfaut and Farrell (2009) made a very extensive study of the curriculum in the field of advertising that deals with ethics, law and the social dimension, and they observed that unlike the core courses, in this area there are great differences in the course names, their outcomes and goals, the literature used, the ways in which students are evaluated in this area. It is generally agreed that the primary objective for discussing ethical issues in class is to teach the students how to incorporate their values into the decision-making process (Menzel, 1997).

The purpose of this study was to assess the influence of ethics intervention within formal education on graphic and media design students' level of ethics awareness by asking them to rate their perceived importance towards 34 ethical issues. Despite the general consensus that ethics education is crucial to the development of an individual and a professional and that academia should take a proactive role, efforts made by the graphic design institutes in cultivating professional ethics are fragmented. For this investigation, teaching ethical issues about graphic design is defined as pedagogy related to the behavioral conduct of people in the design field and to their relationships with peers, clients, audiences, and greater society.

2. METHODS

2.1. Instrument

This study makes use of a questionnaire survey based on the Ethical Issues Rating Scale developed by DuFrene, Elliott-Howard, and Daniel (1990). The original instrument includes brief descriptions of 52 business issues that are designed to have ethical significance (Daniel et al., 1997) and respondents record their reaction to the items by indicating the degree to which they feel the issues are important. The instrument was developed for use on business students and professionals, but it is also applicable to a large extent in other professional fields. Daniel et al. (1997) propose use of the instrument for determining the ethical development of students over time, for example students could be administrated the instrument both before and after formal instruction in ethics. The instrument is one of the methods for quantifying students' ability to recognize the importance of different ethical issues with which they can meet in their professional environment. However, to ensure all issues are highly relevant to industry relevant in this research, a revised questionnaire with 54 issues (the 52 original issues plus three issues added by the researchers), was given to 20 professionals in design field. They were asked to answer either “yes” or “no” for each issue, a “yes” answer indicating that the issue is applicable to the industry and should be included. It is decided that if the percentage of professionals answering “yes” is less than 50%, the issue will be deleted. Using this dichotomous selection test, a total of 20 issues are excluded, with only 34 issues remaining (Table 1). The questionnaire, at the end, contained 34 ethical issues and the respondents were asked to indicate the perceived importance towards each issue in the design industry. Respondents were asked to indicate their perceived importance of each issue to the graphic design industry using a 5-point scale, ranging from “1” (extremely unimportant) to “5” (extremely important).

Table 1 : Used Issues in the questionnaire

1	Disposal of hazardous waste
2	Acceptance of bribes or gifts by employees
3	Sexual harassment on the job
4	Employees disclose corporate information or trade secrets
5	Theft by employees of company property
6	Remove a product from market due to potential health/safety risks
7	Communication to the public of sensitive information, e.g., bomb threats and product contamination
8	Pollution of air and water
9	Protection of natural resources
10	Export products that do not meet home country safety and/or quality standards
11	Honesty in the advertising and labeling of products or services
12	The issue of company loyalty versus public responsibility
13	Use of insider business information for personal profit
14	Employees provide fail-proof quality products and services
15	Communication by company to the media of true and complete information
16	Restrictions on legal actions against company by damaged or dissatisfied consumers
17	Fair and complete media coverage of business issues to consumers
18	Equal pay for comparable jobs
19	Use of computers for illegal purposes
20	Disregard home country trade sanctions in the sale of goods, services and technology to foreign countries
21	Protection of specified groups by equal employment laws
22	Hiring practices based on personal connection and favor
23	Employee abuse of company benefits, privileges, facilities, etc.
24	Use in foreign countries of advertising and promotional techniques that are illegal at home county
25	Making available to the market products or services that have the potential to save lives or reduce suffering, but which will likely be unprofitable
26	Removal or withholding of a product from the market due to potential health or safety risks
27	Use of electronic devices to monitor employee activity on the job
28	Provide free/discounted services to friends/relatives without company's knowledge
29	Illegal copying of registered software
30	Use of electronic tracking techniques to monitor computer use by employees
31	Use of low-paid foreign labor
32	Influence by business on the content of television program which they sponsor
33	Protection of minorities and underprivileged social groups
34	Copyright protection

The second section of the questionnaire collects demographic information of the respondents such as gender, age, area of study… data were collected, but not specifically analyzed, since the students in the sample are the same age, from the same year of study, so these data are not relevant for the interpretation of the results.

2.2 Sample

The questionnaire (DuFrene et al., 1990). was administrated to a cohort of graduate students (n= 120) enrolled in courses Communication of Graphic Design and Business Communication at Faculty of Graphic Design in Zagreb. This data was collected during regular and online class sessions and 100% of the returned questioners were usable.

2.3 Procedures

Since there is no course at the Faculty of Graphics Design that would offer students' knowledge and information from the field of ethics, the research could not be conducted in the proposed manner. According to the GRF curricula (ISVU, 2022), there is not a single course dedicated to ethics, but ethics appears fragmentarily in the content of several courses, and in teaching using case studies. Instead of the proposed use of the instrument, the research sample was divided into two groups that filled out the questionnaire - one group (n=67) filled out the questionnaire without any previous formal familiarization with ethical topics, while the other group (n=53), before filling out the questionnaire, was familiarized with the basic theories of ethics. This group of students, as presented in Table 2, was given information about basic ethics theories, they read the article "*Redefining design ethics*" by Phil McCollam published in Design and Culture, 6: 3, 2014., which deals with ethics in design and after that, they participated in a joint structured discussion on ethical dilemmas in design. Arfaoui et al. (2015) argue that programs in moral education with a dilemma discussion produce significant increases in moral development and that the magnitude of the increase in moral development is related to exposure to Kohlberg's stage theory of cognitive development. According to Rest (1986), interventions that occur over less than 3 weeks do not result in increases in moral development, whereas interventions of 3–12 weeks result in increases in moral development (Rest, 1986), so the ethics topics were processed in 4 weeks period.

Table 2: Adjusted framework approach for the delivery of ethics topics based on IFAC (2006)

Stage	Objective of stage	Focus of content
Stage 1	To develop ethical intelligence by attaining the necessary knowledge of ethical concepts and theories related to the designer's work	Traditional theories of ethics, virtues, and moral development
Stage 2	Sensitise learners to ethical issues and threats	Case study based on the article "Redefining design ethics" by Phil McCollam published in Design and Culture, 6: 3, 2014.
Stage 3	To integrate knowledge of ethics with sensitivity to develop competence in ethical judgment and decisions	Application of ethical theories, social responsibilities, code of professional conduct, and other ethical decision models to ethical dilemmas
Stage 4	Ethical Issues Rating Scale	Students' reaction to the ethical items by indicating the degree to which they feel the issues are important

3. RESULTS

3.1 Respondents' Profile

A total of 120 students enrolled in the courses *Graphic Design Communication* and *Business Communication* participated in the research. 64% of females and 36% of males were represented in the sample. More women than men are enrolled at the Faculty, so this ratio in the sample is expected and justified.

Table 3: Gender of the respondents

Gender	Group 1	Group 2	Total
F	47	30	77
M	20	23	43
Total	67	53	120

$$X^2(1, N = 10) = 2.3614, p = .124 \quad (1)$$

A chi-square test of independence was performed to examine the relationship between gender and belonging to group 1 or 2. The relationship between these variables was not significant, X^2 (1, N = 120) = 2.3614, p = .124 at p >.05 (Table 3).

3.2 Mean Scores of All Statements

Initial analyses of the collected data include a summary of means and standard deviations for the responses on all 34 ethical issues. The mean scores are used to reveal the central tendency measure of the degree of importance of the statements and the standard deviations to explain the dispersal of scores around them. The mean scores in the two groups (Table 4) are used to reveal the central tendency measure of the degree of importance of the statements and the standard deviations to explain the dispersal of scores around them. As presented, the lowest mean score in Group 1 is 2,21 and in Group 2 2,79. The highest average score in group 1 was 3,90 and in the Group 2, the highest average score was 4,34. In both groups, no statement was rated as completely unimportant (1), but none was also marked as extremely important (5). Although in individual cases there was an importance rating of 5, the measure of central tendency shows that in both groups, on average, all values are in the interval between 2 and 4.

Table 4: Mean scores of all issues

Group 1				Group 2			
N	Mean	Std. Deviation		N	Mean	Std. Deviation	
Issue1	67	3,04	,928	Issue1	53	3,45	,695
Issue2	67	3,51	,842	Issue2	53	3,26	,684
Issue3	67	3,73	,709	Issue3	53	4,04	,706
Issue4	67	2,90	,606	Issue4	53	3,30	,696
Issue5	67	2,97	,651	Issue5	53	3,11	,751
Issue6	67	3,90	,606	Issue6	53	3,91	,838
Issue7	67	3,87	,672	Issue7	53	3,62	,657
Issue8	67	3,63	,487	Issue8	53	3,85	,718
Issue9	67	3,60	,494	Issue9	53	3,85	,718
Issue10	67	3,28	,623	Issue10	53	3,34	,478
Issue11	67	3,84	,373	Issue11	53	4,15	,718
Issue12	67	3,85	,821	Issue12	53	4,13	,590
Issue13	67	2,84	,373	Issue13	53	3,75	,515
Issue14	67	3,37	,487	Issue14	53	3,74	,524
Issue15	67	3,54	,502	Issue15	53	3,74	,593
Issue16	67	2,66	,478	Issue16	53	3,28	,455
Issue17	67	3,21	,410	Issue17	53	3,72	,455
Issue18	67	3,52	,503	Issue18	53	3,57	,500
Issue19	67	3,64	,483	Issue19	53	3,62	,489
Issue20	67	3,22	,420	Issue20	53	3,66	,478
Issue21	67	2,21	,509	Issue21	53	2,49	,576
Issue22	67	3,28	,454	Issue22	53	3,32	,471
Issue23	67	2,82	,386	Issue23	53	2,72	,455
Issue24	67	3,43	,499	Issue24	53	3,51	,505
Issue25	67	2,72	,486	Issue25	53	3,49	,505
Issue26	67	3,78	,420	Issue26	53	3,49	,505
Issue27	67	3,09	,484	Issue27	53	3,26	,593
Issue28	67	2,54	,502	Issue28	53	3,04	,678
Issue29	67	3,60	,494	Issue29	53	4,04	,759
Issue30	67	3,00	,550	Issue30	53	3,25	,434
Issue31	67	2,28	,454	Issue31	53	3,23	,609
Issue32	67	3,27	,447	Issue32	53	3,66	,478
Issue33	67	3,18	,737	Issue33	53	3,79	,689
Issue34	67	3,76	,430	Issue34	53	4,34	,478

3.3 Mann-Whitney test

To test the differences between two groups, Man-Whitney test was preformed for 34 issues. The test showed that the difference was statistically significant in 20 issues. The data for all variables is presented in Table 5. When we look at the Mean rank score, we can see that the there is a tendency in a Group 2 (group with educational intervention) towards higher ranking of ethical issues. The exceptions are two issues – "Communication to the public of sensitive information, e.g., bomb threats and product contamination" and "Removal or withholding of a product from the market due to potential health or safety risks". First issue, "Disposal of hazardous waste", according to Mann-Whitney test was highly rated in Group 2, U(N(G1)=67 (Mdn= 3), N(G2)=53 (Mdn=03))=1309, z=-2,694, p <.01. All following issue were also graded higher with statistical relevance in the Group 2: "Sexual harassment on the job", U(N(G1)=67 (Mdn=4), N(G2)=53(Mdn=4))=1380, z=-2,274, p <.05, "Employees disclose corporate information or trade secrets", U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=3))=1206,5, z=-3,331, p <.001, "Honesty in the advertising and labeling of products or services" U(N(G1)=67 (Mdn=4), N(G2)=53(Mdn=4))=1315, z=-2,943, p <.001, "Use of insider business information for personal profit" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))=420, z=-3,644, p <.001, "Employees provide fail-proof quality products and services" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))= 1173,5, z=-3,644 p <.001, "Restrictions on legal actions against company by damaged or dissatisfied consumers" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=3))= 836, z=-6,057, p <.001, "Fair and complete media coverage of business issues to consumers" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))= 873,500, z=-5,554, p <.001, "Disregard home country trade sanctions in the sale of goods, services and technology to foreign countries" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))= 1000,5, z=-4,796, p <.001, "Protection of specified groups by equal employment laws" U(N(G1)=67 (Mdn=2), N(G2)=53(Mdn=3))= 1300,5, z=-2,901, p <.001, "Making available to the market products or services that have the potential to save lives or reduce suffering, but which will likely be unprofitable" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=3))= 661, z=-6,761, p <.001, "Provide free/discounted services to friends/relatives without company's knowledge" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=3))= 1088,5, z=-4,067, p <.001, "Illegal copying of registered software" U(N(G1)=67 (Mdn=4), N(G2)=53(Mdn=4))= 1209 z=-3,320, p <.001, "Use of electronic tracking techniques to monitor computer use by employees" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=3))= 1405 z=-2,504, p <.001, "Use of low-paid foreign labor" U(N(G1)=67 (Mdn=2), N(G2)=53(Mdn=3))= 509,5 z=-4,273, p <.001, "Influence by business on the content of television program which they sponsor" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))= 1080 z=-4,273, p <.001, "Protection of minorities and underprivileged social groups" U(N(G1)=67 (Mdn=3), N(G2)=53(Mdn=4))= 1075,5, z=-3,994, p <.001, "Copyright protection" U(N(G1)=67 (Mdn=4), N(G2)=53(Mdn=4))= 892,5, z=-5,897, p <.001. On the 14 remaining issues, the Mann-Whitney test showed that there were no statistically significant differences between the groups.

Table 5 (part 1): Mann-Whitney test results

	Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Issue1	Group1	67	53,54	3587,00	1309,000	-2,694	0,007**
	Group2	53	69,30	3673,00			
Issue2	Group1	67	64,67	4333,00	1496,000	-1,614	0,107
	Group2	53	55,23	2927,00			
Issue3	Group1	67	54,60	3658,00	1380,000	-2,274	0,023*
	Group2	53	67,96	3602,00			
Issue4	Group1	67	52,01	3484,50	1206,500	-3,331	0,001**
	Group2	53	71,24	3775,50			
Issue5	Group1	67	57,56	3856,50	1578,500	-1,140	0,254
	Group2	53	64,22	3403,50			

Table 5 (part 2): Mann-Whitney test results

Issue6	Group1	67	60,73	4069,00	1760,000	-0,089	0,929
	Group2	53	60,21	3191,00			
Issue7	Group1	67	65,96	4419,00	1410,000	-2,137	0,033*
	Group2	53	53,60	2841,00			
Issue8	Group1	67	56,48	3784,00	1506,000	-1,613	0,107
	Group2	53	65,58	3476,00			
Issue9	Group1	67	55,84	3741,00	1463,000	-1,861	0,063
	Group2	53	66,40	3519,00			
Issue10	Group1	67	59,82	4008,00	1730,000	-0,278	0,781
	Group2	53	61,36	3252,00			
Issue11	Group1	67	53,63	3593,00	1315,000	-2,943	0,003**
	Group2	53	69,19	3667,00			
Issue12	Group1	67	55,96	3749,50	1471,500	-1,811	0,070
	Group2	53	66,24	3510,50			
Issue13	Group1	67	40,27	2698,00	420,000	-8,189	0,000**
	Group2	53	86,08	4562,00			
Issue14	Group1	67	51,51	3451,50	1173,500	-3,644	0,000**
	Group2	53	71,86	3808,50			
Issue15	Group1	67	56,16	3763,00	1485,000	-1,763	0,078
	Group2	53	65,98	3497,00			
Issue16	Group1	67	46,48	3114,00	836,000	-6,057	0,000**
	Group2	53	78,23	4146,00			
Issue17	Group1	67	47,04	3151,50	873,500	-5,554	0,000**
	Group2	53	77,52	4108,50			
Issue18	Group1	67	59,34	3976,00	1698,000	-0,475	0,635
	Group2	53	61,96	3284,00			
Issue19	Group1	67	61,01	4087,50	1741,500	-0,215	0,830
	Group2	53	59,86	3172,50			
Issue20	Group1	67	48,93	3278,50	1000,500	-4,796	0,000**
	Group2	53	75,12	3981,50			
Issue21	Group1	67	53,41	3578,50	1300,500	-2,901	0,004**
	Group2	53	69,46	3681,50			
Issue22	Group1	67	59,51	3987,50	1709,500	-0,439	0,660
	Group2	53	61,75	3272,50			
Issue23	Group1	67	63,25	4238,00	1591,000	-1,348	0,178
	Group2	53	57,02	3022,00			
Issue24	Group1	67	58,47	3917,50	1639,500	-0,832	0,406
	Group2	53	63,07	3342,50			
Issue25	Group1	67	43,87	2939,00	661,000	-6,761	0,000**
	Group2	53	81,53	4321,00			
Issue26	Group1	67	68,07	4560,50	1268,500	-3,243	0,001**
	Group2	53	50,93	2699,50			

Table 5 (part 3): Mann-Whitney test results

Issue27	Group1	67	56,22	3766,50	1488,500	-1,858	0,063
	Group2	53	65,92	3493,50			
Issue28	Group1	67	50,25	3366,50	1088,500	-4,067	0,000**
	Group2	53	73,46	3893,50			
Issue29	Group1	67	52,04	3487,00	1209,000	-3,320	0,001**
	Group2	53	71,19	3773,00			
Issue30	Group1	67	54,97	3683,00	1405,000	-2,504	0,012*
	Group2	53	67,49	3577,00			
Issue31	Group1	67	41,60	2787,50	509,500	-7,305	0,000**
	Group2	53	84,39	4472,50			
Issue32	Group1	67	50,12	3358,00	1080,000	-4,273	0,000**
	Group2	53	73,62	3902,00			
Issue33	Group1	67	50,05	3353,50	1075,500	-3,994	0,000**
	Group2	53	73,71	3906,50			
Issue34	Group1	67	47,32	3170,50	892,500	-5,897	0,000**
	Group2	53	77,16	4089,50			

In this study, it is stated in the questionnaire that the more important the students rate an issue, the more important the topic to be for their profession. Respondents were also given the same instructions on how to fill out the questionnaire.

4. DISCUSSION

As the instrument used in this study was originally designed for students of business studies, there is a visible difference in the students' evaluation of the categories that are closer to them, i.e. that they can more easily connect with the application in their profession. They consider these categories to be more important, which indicates that the results would be clearer using a questionnaire fully adapted to the application in the corresponding business area. In this research, 34 issues were used and in 20 of them there was a significant change in valuation of topic importance. The results indicate that the intervention in education can have an impact in the field of ethics, more precisely, in raising awareness of the importance of ethical issues and decisions in professional life. The teaching of ethical issues is critical to a design education because the subject increase students' understanding of the field, raise their awareness of broader effects beyond the promotion of products and services, and inform students of their responsibilities as professionals. Applied ethics is a branch of ethics that focuses on general ethical principles and analytical approaches upon a particular discipline (Epstein, 1989). According to Epstein, the analyses can be divided into four levels. The first level involves the macro ethics pertaining to the norms and values of the total political-economic system, the second level is the intermediate ethics that focuses on the conduct of groups of business firms while the third level relates to the conduct of specific firms. For the final level of analysis, it focuses on individual ethics that deals with the conduct of individual persons. Given that ethics is really a combination of factors on several levels, it is not possible to effect on changes at all levels with such a simple education intervention, but it is possible to encourage an individual to think about the importance of ethics in professional life, and then perhaps, consequently, to apply ethical principles in personal action in a professional environment.

5. CONCLUSIONS

There is currently a big "ethical turn" in tech innovation, and the media is following cases related to social media, autonomous systems, facial recognition, bio cams and sensors, health apps, track and trace, and algorithmic political manipulation (Badawy et al., 2018). Because there is big potential for deception, conscious or unconscious, through graphic design, graphic designers should develop an ethical sense and apply it to their design. In this context, the training of teachers must also be considered in addition to the training of students. Educators must adopt a leading role in training the new generation of designers who will incorporate ethical decisions consciously and reflexively in their practices. We cannot generalize ethical principles in design, trying to follow step-by-step predefined rules is almost impossible, because contexts change, people change and the technology changes. The design should try to direct changes in an ethical and human-centered direction. This research could potentially be expanded by analyzing and comparing ethics curricula in the European area with the aim of establishing common and mutually comparable foundations in education in professional ethics in the field of design and media design. By reviewing the literature, it was determined that, unlike education in some other fields, in the field of design education in the European area, there are no studies systematically dealing with this topic.

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DIDACTIC METHODS FOR ACHIEVING IMPROVED CREATIVITY IN TEACHING GRAPHIC DESIGN IN SECONDARY SCHOOL FORMAL EDUCATION

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Abstract: *In teaching and learning graphic design in a secondary vocational school, we mainly use digital tools for both teaching and learning. According to the curriculum, students in the 2nd and 4th years learn to design various printed and animated content. The work is very creative and students need to be able to visualize their ideas in an appropriate way and with appropriate tools, which is a challenging and complex process. For the teachers, it is a challenge to give instructions for a specific task and to evaluate it, and for the students, it is a challenge how to solve it in the most successful way. With the rapid development of technology and the unstoppable updating of programs, problems arise because students must constantly familiarize themselves with new programs and the variety of new digital tools and techniques, while thinking about how to conceptualize and visualize a particular idea in accordance with the task at hand. As a result, they are unable to focus on their own creativity as they have to constantly learn how to use digital tools that enable them to create a design product. The goal of the research is to create measurable and verifiable data that will help apply an appropriate didactic method to achieve optimal results when teaching graphic design. When teaching the subject matter in the practical classes of graphic design, teachers mainly use 3 didactic methods: Demonstration methods, text methods and video methods (Figure 1). In the research, we determined which didactic method is the most effective in achieving a certain learning goal according to the set task. The methodology included experimental work and interviewing students. In the experimental part, students solved tasks using the method of all three didactic methods and then completed a questionnaire. The survey was completed by 56 students (2nd and 4th year students). Students rated each didactic method on a 5-point Likert scale. The results obtained were statistically analysed using IBM SPSS Statistics. The results of the analysis provide an interesting insight into the creative process of the students in relation to the learning methods. The results of the study show that the choice of an appropriate didactic method or a combination of didactic methods is important both for a student's successful and creative implementation of a design task and for the effective teaching of graphic design.*

Key words: graphic design, high school, formal education, didactic methods, creativity, digital learning tools

1. INTRODUCTION

In graphic design classes, students mainly use digital tools while acquiring knowledge in high school. It is this digital technology that is leading to major changes in the way students communicate and relate to each other, as well as the way they learn (Bates, 2019).

In his work, Teaching in a Digital Age, Bates points out that society requires educators to develop different types of knowledge and skills needed by students in the digital age. To develop these knowledge and skills, educators must establish clear learning outcomes and select teaching methods that support the development of these knowledge and skills.

All of this requires practice and feedback. On the other hand, students should be given ample opportunity to practice these skills. This requires a move away from the traditional model of information delivery and toward more learner-centred teaching and new assessment methods that measure both skills and content mastery (Bates, 2019).

Today's generation of students are "digital natives" (Prensky, 2001), meaning they use digital devices for learning and entertainment. As being "native speakers" of the digital language of computers, video games, and the Internet, they generally have no problems using complex technological devices.

Therefore, it is necessary to change the way of learning and the implementation of certain formal education requirements in parallel with the development of technology, especially in classes where we use digital tools and computer graphics. (Nurannisaa et al., 2020).

Learning graphic design is based on knowledge of computer graphics, which is the basic technology and infrastructure of all programs whose function is visual design, drawing and creation (Gabrijelčič Tomc, Kočevar & Iskra, 2021).
The teaching of computer graphics is also based on the experiential learning model. According to this model, teaching and learning are inseparable; theory and practice are organically linked. Experiential teaching requires students to connect theory with extracurricular practice, to learn as much as possible about the theory and application of computer graphics software, to explore their own thoughts and feelings from different perspectives, and finally to creatively design specific content (Fleischmann, 2013).
In graphic design teaching, in addition to experiential teaching, we can also talk about problem-based teaching and research-based teaching. These are two forms in which students focus on exploring and solving a particular problem, whether fictional, theoretical, or practical (Grmek & Krečič, 2011).
The study, which involved 33 students, was conducted in the first year of a computer graphics school for visual communication design in China. The research used Adobe Illustrator software to create 2D and 3D designs. The results of the study show that students have no problems with accessing and using complex technologies; information related to content knowledge in learning computer graphics was stored through the Internet. The challenge is to guide students so that the information they receive meets their learning needs. In addition, the study showed that students are more interested in the design process than in computer-aided design techniques and software. This is due to the presence of various online tutorials that facilitate them to learn and explore the technical use of computer software (Nurannisaa, 2020). Graphic design as digital media art is a combination of multimedia technology and artistic design. It is based on the technical means of information and digitization in multimedia technology and combines the concept and method of artistic design (Bonsu, Chisin & Cronjé, 2020).
Given the digital world in which education is increasingly embedded, there is much talk about creativity, which is closely linked not only to the world of art and product design, but also to science, engineering, innovative thinking, and problem solving. There is an increasing demand for creative people in the labour market (Ambrose, 2017).
Education, knowledge and creativity are gradually becoming the driving force of new social, cultural and educational structures. In 2019, data were collected from a sample of 3519 Hong Kong Chinese students aged 11 to 15 from 16 schools. Using the data, this study examined the sources, values, and limitations of fostering creativity in young learners in formal education. The results show that there is a lack of awareness among teachers and parents about the importance and developmental benefits of creativity. Students should be given more opportunities to express their creativity within and outside of the school environment. The majority of students in this study felt that the most important component of the value of a creative education is to train creative minds for the future. Questions are raised about how to bring the arts and sciences closer together. The study also showed that students value learning about the arts that could guide their creativity as an educational experience. Students' creativity should be as important as passing a test or exam (Wai-Chung, 2020).
When teaching with digital learning tools, it is important to promote appropriate cognitive processing in learners without overloading their cognitive systems. This can be achieved by mastering essential processing and promoting generative processing (Dumont, Istance & Benavides, 2010). The cognitive theory of multimedia learning is based on the construction of knowledge within which learners actively construct mental representations to make sense of their experiences. When teaching with modern digital tools, it is the method and not the medium that matters (Mayer, 2021).
The method of teaching is the subject of didactics, an independent scientific discipline within educational science that deals with questions of education, learning, and teaching. Didactic or teaching methods are scientifically and practically tested ways of communication between teachers and learners, classified according to the source of information, purpose, function and dominant processes (Grmek & Krečič, 2011).
Our research aimed to determine which teaching method helps students complete a task more efficiently and which method makes students more creative, more satisfied with the final product, and more successful in mastering a particular computer program. In this study, we looked more closely at the effects of the three basic learning methods and how they are combined. These teaching methods include:
The text-based method is one of the document-based teaching methods. A prerequisite for its use is the ability to read functionally - reading comprehension and mental processing of information. It is important for the teacher to check in various ways whether the students have adequately understood the text in relation to the set objectives, which requires the integration of this teaching method with other methods, e.g. the practical method, the interview method... (Glossary of Education Terminology, 2008-2009).

In didactics, the teaching method of demonstration is defined as a way of working in the classroom in which the teacher (or students) demonstrates static objects (pictures, models, drawings, etc.) or dynamic phenomena and activities that can be practical (motor activities and practical tasks), sensory and expressive (speaking, reading, writing, painting, singing, dramatic expression, etc.) and intellectual. (Glossary of Education and Training Terms, 2008-2009).
The video method is a video explanation that follows the principles of the explanation method. The asynchronous video interpretation method naturally follows different principles than the synchronous application of this method. The video may include "real" video footage or screen recordings in the interpretation. Typically, video interpreting involves a combination of all the above methods (Pesek, Lipovec & Zmazek, 2020). All methods are associated with the explanatory method or the Socratic method, which has traditionally been one of the most widely used and also relatively effective teaching methods in various fields (Overholser, 2018).
The purpose of the present study was to investigate the factors and teaching methods that influence students' creativity and effective task performance in graphic design classes in formal education. Above all, the goal of the research is to find optimal teaching methods for teaching graphic design in practical education based on measurable and verifiable statistical data. And to do so in such a way that students achieve their learning goals, become more creative, and at the same time are satisfied with their own work.
Figure 1 depicts the interweaving of learning methods at different levels necessary to implement a creative task in the practical teaching of graphic design in formal education.

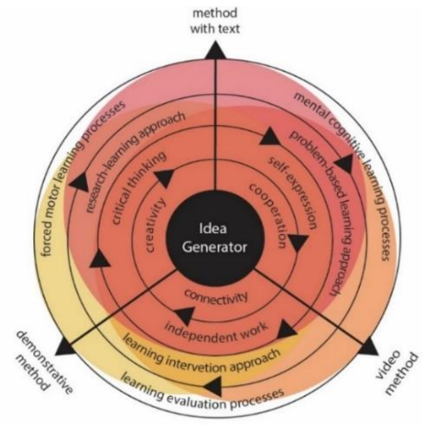


Figure 1: Demonstration of didactic methods that intertwine with each other and thus influence the visualization of the idea. Summarized from Didaktika by Blažić et al., 2003

We set three hypotheses:
H1: In terms of learning methods, the combined learning method, namely demonstration and video, is the one that makes it easiest for students to work and visualise their own ideas.
H2: We hypothesise that there is a difference in the popularity of learning methods between lower- and upper-year students (2nd and 4th year) in terms of the popularity of learning methods.
H3: We assume that students prefer to follow the instructions for the task on their mobile phone.

2. EXPERIMENTAL PART

2.1 Research sample

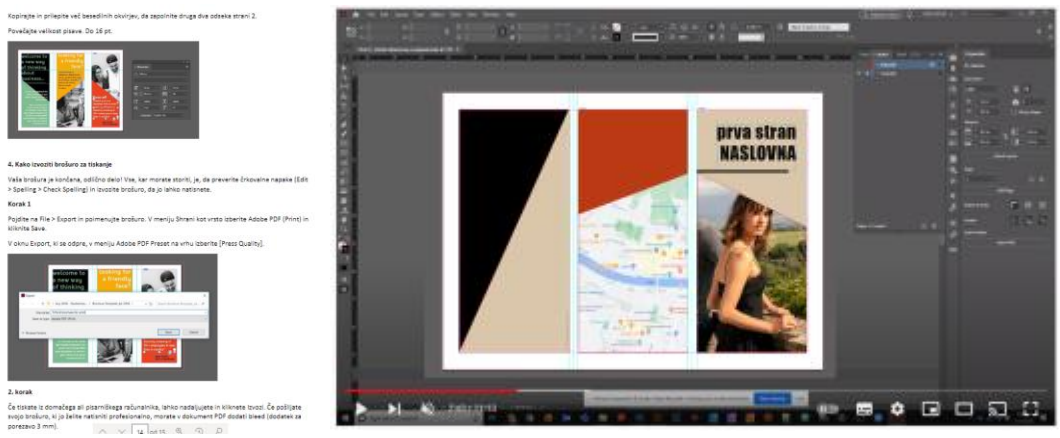
56 students participated in the study; 30 2nd year students (aged 15-16 years) and 26 4th year students (aged 17-18 years). The students participated in the study voluntarily.

2.2 Data collection procedure

Data were collected within 15 school hours. The survey was conducted during a practical graphic design lesson as part of a regular lesson.
The research included: lesson preparation, content preparation, tasks modelled on different teaching methods, questionnaires, teacher observation, and analysis of results. The teaching material was taught

using demonstration, video and text teaching methods. We also used combinations of teaching methods such as the demonstration method, the video method, and the text method. For the study, we selected the areas where new learning materials are introduced that are consistent with the curriculum, in both the 2nd and 4th years:

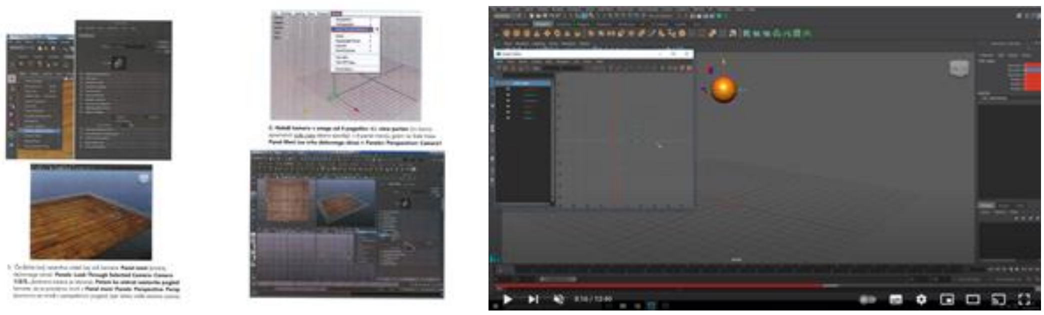
- In the 2nd year, students are introduced to design and learn to design single and multi-page printed materials such as posters, brochures, magazines, books, newspapers, calendars, etc.
For this purpose, they learn how to use InDesign, a programme for designing printed materials. Since the programme is new to them, they learn it gradually.
Figure 1 shows an example of written instructions and a video for this task.



Learning goals: design a classic advertising flyer in Adobe InDesign and Adobe Photoshop; tri-fold.
Informative goals: know the design and technical standards of text layout for different media, ...
(KZ Graphic Design, 2020)

Figure 1: An example of written instructions and a video of the task and learning goals for the 2nd year task

- In the 4th year, students learn about animation. Animation creation is a project work. They learn the new programmes Adobe Animate, Adobe Premiere and Mayo to create 3D animations. The assignments are very complex and require the use of new skills, processes, and tools. Figure 2 shows the instructions for the assignment and the learning objectives for the assignment.



Learning objectives: create a simple 3D animation in Maya; bounce a colored ball
Informative objectives: knowledge of animation and the basic creative principles of animation editing (primary editing, time sequence, spatial relationships, contextual relationships, contrasts of shapes and forms) ... Knows the technical basics of animation and the moving image. (KZ Graphic Design, 2020)

Figure 2: An example of written instructions and a video of the task and learning goals for the 4th year task

Students work on these assignments in the computer lab, where they have their own computer and computer programmes in their own Adobe Cloud.

Teachers introduce each assignment, show examples of, for example, a flyer or animation using projection, and then guide students step-by-step through the process of creating the flyer or animation. In addition, students who are absent from class or cannot do it all are given the opportunity to work on the assignment independently without the teacher's presence and support. For this purpose, they have written texts or videos ready to solve the task.
Students use digital technology to create products, using tools and processes such as Adobe InDesign and Photoshop for 2D tasks and Autodesk Maya for 3D modelling and animation.
Figure 3 shows the layout of the classroom where the practical lessons take place.

Figure 3: Computer layout in the classroom

2.3 Exploratory instrumentarium

The study used a survey and an observation protocol.
The survey was used to determine the popularity of the selected methods in the classroom.
The anonymous focus group survey was conducted using the online tool 1ka and sent via email. Students completed the online survey after school from 5/10/2022 to 5/20/2022.

The online survey included:
- Part 1 of the survey: students completed demographic information.
- Part 2 of the survey: students answered questions about where they get inspiration to create a product/practical task and how they relax when creating a product/practical task, and completed two questionnaires consisting of four statements with the option to add a second statement. Each statement was rated by participants on a 4-point Likert scale (1 - never; 2 - rarely; 3 - often; 4 - always).
- Part 3 of the survey: students responded to five sets of questions, each of which represented a specific teaching method or combination of teaching methods based on their previous experience working in a practical graphic design course; three examples are provided: When I follow the teacher's demonstration of the procedure for designing a task and I create it myself on the fly, ...
The statements in the questionnaire were the same in each set; each statement was rated by the participants on a 5-point Likert scale (1 - never; 2 - rarely, 3 - often; 4 - always; 5 - completely true).

The observation protocol was used to monitor the effectiveness of the chosen methods by the teacher instructing the students.

2.4 Research methods

A quantitative method of educational research was used for the study.
Statistical analysis of the results was carried out in IBM SPSS statistics and 1ka data analysis.
The transfer of the empirical data into SPSS allowed us to perform the statistical analysis. We analysed the characteristics of the variables and presented them in tables and graphs (figures) along with frequencies, arithmetic means, and standard deviations.
Cronbach's alpha (Table 1) was used to evaluate the reliability of the measurement or the internal consistency of the measurement scale. The test of Cronbach's alpha evaluates the reliability of a measurement (Cronbach, 1989). From the table, it can be seen that the Cronbach's Alpha test of the reliability of a measurement shows that the internal consistency of the factors is adequate, since the value of the Cronbach's Alpha test for all factors combined is greater than 0.70.

Table 1: Reliability statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
,968	,972	7*

*7 sets of all factors (Q4, Q5, Q7, Q9, Q11, Q13, Q15)

A Mann-Whintey (M-W) test was used to test for differences between 2nd and 4th year.

3. RESULTS

3.1 Analysis of the research with students

Assessing the popularity of learning methods

Descriptive statistics for each learning method were compiled and compared. Table 2 shows the groups of responses according to the selected factors. The results obtained with the Likert scale were summed for each group, the arithmetic mean was calculated, and the percentage was determined. One hundred percent means a value of 5, a value of 2.5 means 50 percent, and the remaining calculations were performed analogously.

Table 2: Results of the descriptive statistics "Teaching methods"; Q7 (demonstration method), Q9 (video method), Q11 (text method), Q13 (combined method with demonstration and video method), Q15 (combined method with demonstration and text method)

	Q7*		Q9*		Q11*		Q13*		Q15*	
	M	SD	M	SD	M	SD	M	SD	M	SD
I design the assignment without problems	3,3	0,9	3,5	0,8	**2,9**	1,0	**3,8**	0,8	3,5	1,0
I get the job done quickly	3,0	0,9	3,4	0,9	**2,8**	1,0	**3,7**	0,9	3,3	1,0
I have more possibilities to visualise my own ideas	3,4	0,8	3,4	0,9	**3,0**	1,0	**3,9**	0,8	3,6	1,0
I can easily visualise the idea	3,2	1,0	3,2	0,9	3,1	1,0	**3,8**	0,8	3,5	0,9
I have a better understanding of computer software, procedures and tools	3,6	1,0	3,9	0,7	3,1	0,9	**4,0**	0,8	3,6	0,9
I am happy to design the assignment	**3,6**	0,7	3,4	0,8	3,3	0,8	3,5	0,9	3,5	0,9
I feel stressed and insecure	2,6	1,0	2,7	1,0	**3,0**	1,3	**2,3**	1,0	2,4	1,0
I am struggling to follow the instructions	2,4	0,9	2,4	0,8	**2,7**	1,1	**2,0**	0,7	2,2	0,8
I am not creative	2,4	1,1	2,2	0,9	**2,5**	1,1	**2,1**	0,9	2,1	0,9
I am not satisfied with the finished product	**2,8**	1,2	2,7	1,0	2,6	1,1	**2,3**	1,2	2,4	1,0
other	I need additional help, I am satisfied with the final product, I am not meeting my expectations (Q7, Q9, Q11, Q13, Q15); the instructions confuse me(Q11)									

Q7* When I follow the teacher's demonstration of the process for designing a task and create it myself,
Q9* When I help myself to design the task by watching a video of the workflow, using the tools,
Q11* When I use written instructions and workflows to help me design the task,
Q13* When I follow the teacher's demonstration of the process of creating the task and later help myself with written instructions/procedures,
Q15* When I follow the teacher's demonstration of the process for creating the assignment and later help myself with the video instructions/procedures
***Links that are statistically significant are shown in bold**

Analysis of the age difference between the students

In addition, we were interested in whether students' responses differed depending on whether they were commuters or not with respect to each variable describing the visual characteristics of each mobile self-learning application. The results are presented in Table 9.

Table 3: Summary of Mann-Whintey (M-W) test results between 2nd and 4th year students on the popularity of teaching methods (Q7, Q9 and Q11)

Q7*, Q9*, Q11		**Q7**		**Q9**		**Q11**	
		M-W test		**M-W test**		**M-W test**	
		$\chi 2/P$	$\bar{R}$	$\chi 2/P$	$\bar{R}$	$\chi 2/P$	$\bar{R}$
I design the assignment without problems	2nd year	319,000/	26,00	250.500/	23.64	319,500/	26,02
	4th year	0,583	28,21	0.064	31.06	0,596	28,19
I get the job done quickly	2nd year	307,000/	25,59	226.000/	22.79	272,500/	24,40
	4th year	0,435	28,71	0.022	32.08	0,162	30,15
I have more possibilities to visualise my own ideas	2nd year	319,500/	26,02	312.000/	25.76	341,500/	26,78
	4th year	0,589	28,19	0.502	28.50	0,905	27,27
I can easily visualise the idea	2nd year	346,500/	26,94	237.000/	**23.17**	279,000/	24,62
	4th year	0,978	27,06	**0.037**	**31.63**	0,205	29,88
I have a better understanding of computer software, procedures and tools	2nd year	332,500/	27,53	288.000/	24.93	282,000	24,72
	4th year	0,773	26,35	0.234	29.50	/0,219	29,75
I am happy to design the assignment	2nd year	347,000/	26,97	218.000/	22.52	293,500/	25,12
	4th year	0,985	27,04	**0.014**	32.42	0,306	29,27
I feel stressed and insecure	2nd year	317,000/	28,07	337.500/	26.64	333,500/	26,50
	4th year	0,567	25,71	0.846	27.44	0,791	27,60
I am struggling to follow the instructions	2nd year	345,500/	27,09	303.000/	25.45	259,000/	23,93
	4th year	0,962	26,90	0.398	28.88	0,104	30,17
I am not creative	2nd year	292,500/	25,09	339.500/	26.71	240,000/	**23,28**
	4th year	0,307	29,31	0.874	27.35	**0,048**	**31,50**
I am not satisfied with the finished product	2nd year	335,000/	26,55	284.500/	29.19	342,000/	26,79
	4th year	0,812	27,54	0.239	24.35	0,912	27,25
other	2nd year	259,500/	23,95	212.000	22.31	221,000/	22,62
	4th year	0,060	30,69	/0.006	32.67	0,010	32,29

Q7* When I follow the teacher's demonstration of the process for designing a task and create it myself,
Q9* When I help myself to design the task by watching a video of the workflow, using the tools,
Q11* When I use written instructions and workflows to help me design the task,
***Links that are statistically significant are shown in bold**

Table 4: Summary of Mann-Whintey (M-W) test results between 2nd and 4th year students on the popularity of teaching methods (Q13 and Q15)

Q13*, Q15*		**Q13**		**Q15**	
		M-W test		**M-W test**	
		$\chi 2/P$	$\bar{R}$	$\chi 2/P$	$\bar{R}$
I design the assignment without problems	2nd year	298,000/	25,28	284,000/	24,79
	4th year	0,357	29,08	0,236	29,67
I get the job done quickly	2nd year	315,500/	25,88	275,000/	24,48
	4th year	0,550	28,35	0,180	30,04
I have more possibilities to visualise my own ideas	2nd year	280,000/	24,66	264,500/	24,12
	4th year	0,210	29,83	0,123	30,48
I can easily visualise the idea	2nd year	291,000/	25,03	267,500/	24,22
	4th year	0,290	29,38	0,133	30,35
I have a better understanding of computer software, procedures and tools	2nd year	294,500/	25,16	282,000/	24,72
	4th year	0,322	29,23	0,223	29,75
I am happy to design the assignment	2nd year	247,500/	23,53	271,000/	24,34
	4th year	0,056	31,19	0,156	30,21
I feel stressed and insecure	2nd year	251,000/	**23,66**	249,000/	**23,59**
	4th year	**0,075**	**31,04**	**0,071**	**31,13**
I am struggling to follow the instructions	2nd year	208,000/	**22,17**	231,000/	**22,97**
	4th year	**0,009**	**32,83**	**0,030**	**31,88**
I am not creative	2nd year	278,500/	24,60	309,500/	25,67
	4th year	0,198	29,90	0,478	28,60
I am not satisfied with the finished product	2nd year	306,000/	25,55	304,500/	25,50
	4th year	0,435	28,75	0,428	28,81
other	2nd year	205,000/	22,07	223,500/	22,71
	4th year	0,004	32,96	0,016	32,19

Q13* When I follow the teacher's demonstration of the process of creating the task and later help myself with written instructions/procedures, Q15* When I follow the teacher's demonstration of the process for creating the assignment and later help myself with the video instructions/procedures

***Links that are statistically significant are shown in bold**

Monitoring the task instructions by medium

Figure 5 shows that most students follow the instructions for the practical task on the computer.

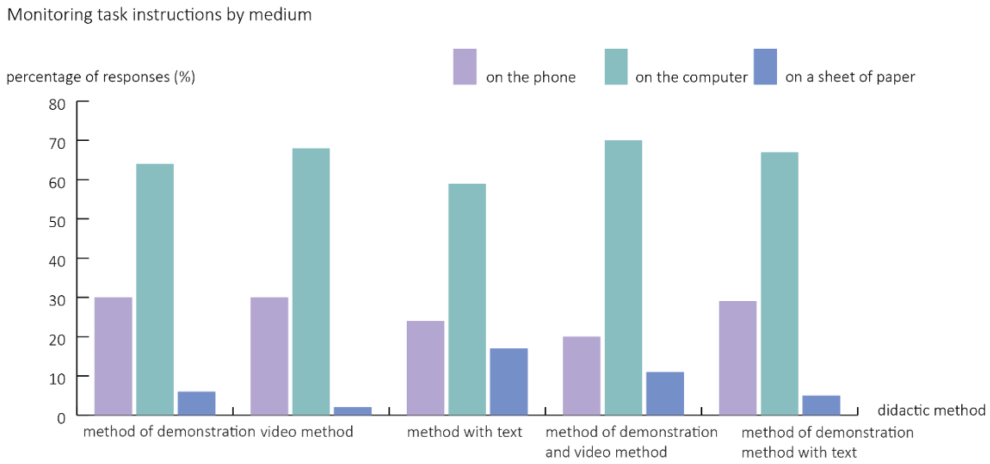


Figure 5: Monitoring task instructions by medium

3.2 Analysis of the observation protocol

2nd year assignment: design a classic advertising flyer in Adobe InDesign and Adobe Photoshop; tri-folded. The most representative results were selected. Figures 6, 7, and 8 show the students' products created using the video method, the text method, and the demonstration method.

Figure 6: Student product; video method

Figure 7: Student product; text method

Figure 8: Student product; demonstration method

Task in 4th year: create a simple 3D animation in Maya; bounce a coloured ball. The most representative results were selected. Figure 9 shows the students' products created with the video method, the text method and the demonstration method.

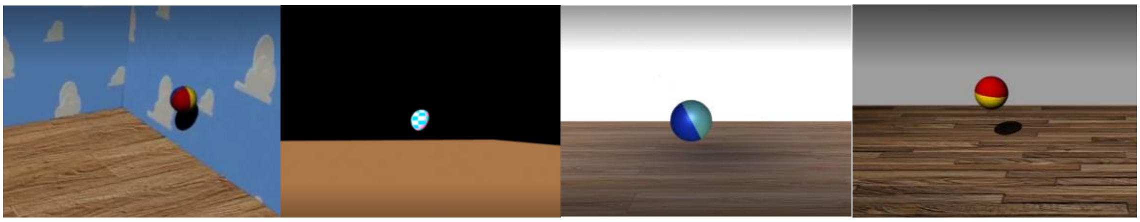


Figure 9: Student products; combination of demonstration, text and video methods

Students' mood while creating according to the teaching method?

Students have condensed 5 school hours with 5-minute breaks, so after the 4th school hour their concentration and motivation to work drops dramatically. In 2nd grade, only 6 students listen to music while working on a practical task, while in 4th grade, 8 students are working on a hands-on task at the beginning of 4th grade. Students who complete the task early and are satisfied with it help other students who are behind on the task and do not understand the process, tools, etc.

Quality of products in terms of teaching method?

The highest rated products are those created with the help of a teacher and using the demonstration method. These products are technically and esthetically sophisticated and show the development of the student's own style. In the video method, they create the task faster but with lower quality. In the text-based method, they do not read the instructions carefully and are therefore too sloppy and consequently unmotivated to work, as their sloppiness makes it difficult for them to match the technique of the learning materials with the visualization of their own ideas.

Speed of the task in relation to the teaching method?

Within the allotted time (10 school hours), students work on the product as quickly as possible using the demonstration method. Those who are more engaged watch a video that helps them with the technological processes and work with the software to visualize their own ideas.

4. DISCUSSION

In Table 2, we present the 5 factors of "learning method," which includes 11 variables that we used to assess the popularity of each method. The surveyed students indicate that they use a teaching method with demonstration, which they supplement with a video method: they solve the practical task without problems ($M = 3.8$; $SD = 0.8$); they solve the task the fastest ($M = 3.7$; $SD = 0.9$); they visualize their idea easily ($M = 3.8$; $SD = 0.8$); they have more opportunities to visualize their own idea ($M = 3.9$; $SD = 0.8$); they understand the computer program, procedures and tools more easily ($M = 4.0$; $SD = 0.8$). However, they find the most enjoyment in creating a task when the teacher demonstrates the process ($M = 3.6$; $SD = 0.7$), and they are also most satisfied with the final product when this process of instruction is used ($M = 2.8$; $SD = 1.2$). Students have the most difficulty when the teacher gives instructions for the task in written form; 1 student reported being confused by the written instructions. In general, students like the text method the least.
The results show that there are no differences between Year 2 and Year 4 students in the way they work with the demonstration method (Q7). A statistically significant difference is found when working with the video method (Q9), as Year 4 students ($\bar{R} = 31.63$) are, on average, happier to design the task and better at visualizing their idea than Year 2 students. A statistically significant difference is also found when working with the text method (Q11); Year 4 students ($\bar{R} = 31.50$) are on average less creative than Year 2 students ($\bar{R} = 23.28$) when following written instructions to complete the task.
There is also a statistically significant difference in the way they work with the combined video and demonstration method (Q13); Year 4 students are on average more stressed ($\bar{R} = 32.83$), feel more insecure and find it more difficult to follow the instructions to work on the task than Year 2 students ($\bar{R} =

22.17) when they design the task in such a way that the teacher demonstrates the process of working on the task and then gives the instructions in the form of a video. The same is true for the way students receive the material in a combined demonstration and text method (Q15); Year 4 students ($\bar{R}$ = 31.13, $\bar{R}$ = 31.88) are on average more stressed, feel more uncertain, and find it more difficult to follow the instructions to solve the task than Year 2 students ($\bar{R}$ = 31.13, $\bar{R}$ = 31.88, $\bar{R}$ = 31.88). They are more stressed ($\bar{R}$ = 23.59, $\bar{R}$ = 22.97) when they do the task in such a way that the teacher demonstrates the process of the task and then gives written instructions.

We have confirmed hypothesis 1 that students find the combined teaching method of demonstration and video easiest to work with and visualize their own ideas. However, they are most satisfied and happy with their product when they follow the teacher's demonstration of the task, as they need the teacher's support in the form of discussion and further clarification of the task. Also, based on the final products, we can see that students were most creative when they designed the task following the teacher's demonstration and with the help of the video.

We also confirmed hypothesis 2 that there was a statistical difference between the 2nd and 4th grade students.

However, hypothesis 3 was rejected because students chose to follow the instructions for the task by computer rather than by cell phone, as hypothesized.

5. CONCLUSION

Compared to other creative disciplines such as fine arts and architecture, graphic design is a young profession. Formal education in this field should follow the trend of technological development and consequently the current stylistic trends. Educators face a challenging task as they need to provide students in formal education with appropriate training that fosters their creative potential and appropriate use of digital learning tools while meeting the established formal learning objectives.

In our study, we found that the teaching method of demonstration combined with the video method is a very effective method to help students achieve their learning objectives in practical graphic design classes. This combination of teaching methods demonstrates that students learn most effectively when they have to build their own knowledge structures and mental models. We also found that there is a statistical difference between age groups in the popularity of each learning method. It is also important to note that students prefer to follow instructions on the computer rather than on the cell phone.

Mayer (Mayer, p. 168) states that lesson planning should not only involve the delivery of information but should present that information in a way that encourages learners to engage in appropriate cognitive processing, which can certainly be usefully applied to the teaching of graphic design in formal education.

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PARAGRAPH DEVELOPMENT IN SCIENTIFIC AND TECHNICAL WRITING

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Abstract: *A paragraph is a grouping of sentences, a way of carving them up into connected sets so as to reduce the diversity of their thoughts to manageable proportions. Normally readers will expect a paragraph to have a single focus and one role since it is defined as a group of sentences developing a single idea, concept, thought, and topic. Overlong paragraphs, with too many sentences in them, have numerous drawbacks. The text becomes under organized and difficult to follow. However, paragraphs should not be too short. If paragraphs are reduced to just one or two sentences, then they cease to have this organizing rationale and become heteronymous cogs, turning as the argument progresses but not doing any useful work. For English-speaking readers, short paragraphs in technical writing will also make the text look disconnected, fragmented, and uncertain. A paragraph's pattern is important in making an argument look coherent and well organized because it is a unit of thought. In general, a paragraph should make one point, or one component part of a single broader point. Where a paragraph handles miscellaneous unconnected points, as it is sometimes necessary to round out an argument, this role should be explicitly signaled to readers because they will not expect it. The relationship between the ideas in an EST (English for Science and Technology) paragraph and between the items of information and the core generalization is expressed by several techniques. Sometimes the nature of the material the writer has available determines the applied technique, but at other times, the writer makes his own decisions as to the best way of presenting the relationships between his ideas. In the first case, we are dealing with natural techniques, and in the second, with logical techniques, and they are not mutually exclusive.*

Key words: paragraph development, English for Science and Technology, natural techniques, logical techniques.

1. INTRODUCTION

A paragraph is a unit of thought. In English writing, much more than in many other languages, the pattern of paragraphs is a very critical element in making an argument look coherent and well organized. In general, a paragraph should make one point, or one component part of a single broader point. Where a paragraph handles miscellaneous unconnected points, as is sometimes necessary to round out an argument, this role should be explicitly signaled to readers because they will not expect it (Jones, 2007). Normally, readers will expect a paragraph to have a single focus and one role. Overlong paragraphs, with too many sentences in them, have numerous drawbacks. The text becomes disorganized and difficult to follow (Bahtia, 1998). But paragraphs should not become too short either. A paragraph is not a sentence. It is a grouping of sentences, a way of carving them up into connected sets so as to reduce the diversity of the thoughts to manageable proportions. If paragraphs are reduced to just one or two sentences, then they cease to have this organizing rationale and become heteronymous cogs, turning as the argument progresses but not doing any useful work. For English-speaking readers, short paragraphs in academic work will also make the work look disconnected, fragmented, and uncertain (Hartley, Sotto & Fox, 2004). The author will appear to be casting around for what to say, starting to make points but then not properly developing them.

The optimal length for paragraphs varies a great deal from one kind of writing to another. Professional academic work is always configured for printing as books or journal articles. Here, the printed page typically holds around 500 words. The ideal length for paragraphs is one that divides each page several times. A good starting point is at around 150 words. But paragraph lengths of between 100 and 200 words are perfectly acceptable.

The paragraph, as the basic concept in scientific and technical writing, consists of a *core generalization* followed by supporting information that develops this generalization to the extent the author feels is necessary (Murray & Moore, 2006). This supporting information can be made up of other generalizations on various levels of abstraction or details, or a mixture of the two. However, whether the paragraph is deductive (proceeding from core to support) or inductive (proceeding from support to core) or is a mixture of these two, the same rhetorical elements are found in the development of the paragraph

(Jordan, 2005). The same principles also apply to the larger units of communication: the subsection, the section, and the entire text.

1.1 The concept of conceptual/physical paragraph correspondence

A paragraph is typically defined as a group of sentences that develop a single idea (concept, thought, and topic) and are distinguished from other paragraphs on a page of text by spacing and/or indentation; thus, *conceptual and physical paragraphs* can be discussed. (Chandler, 1995).

The conceptual paragraph can be redefined as a group of organizationally (rhetorically) related concepts which develop a given core generalization in such a way as to form a coherent and complete unit of discourse. This conceptual paragraph is the basic unit of discourse in EST (English for Science and Technology) writing. If the writer develops his core generalization in one physical paragraph, then the physical and conceptual paragraphs are the same and there is a one-to-one correspondence between them. If, on the other hand, the information in the conceptual paragraph is presented in two or more physical paragraphs (which is most often the case when the core generalization is divisible into parts), then there is one-to-more-than-one correspondence (Brooks & Warren, 1992). When more than one *physical paragraph* is used to develop the core generalization of the conceptual paragraph, each physical paragraph usually has its own "sub-core". Thus, each has a lower level generalization which, while supporting the major generalization, at the same time provides the subject for the particular group of sentences making up the physical paragraph (Elbow, 2000).

2. PARAGRAPH DEVELOPMENT RHETORICAL TECHNIQUES

The relationships between the ideas in an EST (English for Science and Technology) paragraph and between the items of information and the core generalization are expressed by several techniques. Sometimes the nature of the material the writer has available determines the technique (or techniques) he will use; at other times, the writer makes his own decisions as to the best way of presenting the relationships between his ideas. In the first case, we are dealing with *natural techniques*; in the second, we are dealing with *logical techniques* (Day & Gastel, 2006). For example, if the writer has some material that requires a chronology, he will present it by using *time order.* This type of material may be historical or it may be a process description, thus requiring events to take place one after another in a given series. Or the writer may have to present the physical structure of something—for example, a machine, a building, or an electrical circuit. In this case, his material will require him to show the physical relationships of the parts to one another in terms of their relative positions. Then, he will have to use the technique of *spatial order***.** Again, if he is faced with a process description or any discussion that employs a step-by-step development in which the various phases of operation are functionally related, he will need to use *cause and effect* to show how one activity affects one or more following activities. These three techniques: time, space, and cause and effect, are called the *natural orders* because the nature of the material determines the choice the writer should make. It should be noted that they are not mutually exclusive. All of them can be employed in a given paragraph (Herbert, 2008). However, one will usually dominate.

If, on the other hand, the material is of such a nature that the writer has freedom of choice, then other factors enter into the technique(s) he will use. For example, if he wishes to inform his reader by relating something the reader knows to the subject under discussion, then the writer can choose the technique of *comparison, contrast***,** or *analogy*. If he wishes to exemplify, he can choose the technique of *example,* or present his explanation in a detailed example, usually called an *illustration by words.* If he chooses to relate his discussion to a visual aid, he is then using the technique of *illustration.* Or he may deliberately choose to present his information in causal terms, even though the nature of the material does not demand it. In this case, he is using the technique of *cause and effect*. These techniques chosen by the writer are called *logical techniques.* Again, they are not mutually exclusive.

The important factor in relation to reading comprehension is for the reader to become aware of the core generalization of the paragraph. That is:

1. What does the paragraph refer to?
2. What subject is being discussed?
3. What is the paragraph's purpose?

The reader should also be aware of the nature of the core, whether it is a single statement or one that has two or more parts (Herbert, 2008). If the latter, the reader should be alerted to the possibility that more than one physical paragraph will make up the total paragraph — the conceptual paragraph — that is developing the core generalization. Having determined the core generalization, the reader should be aware of the technique or techniques the writer is using to develop the information that supports the core. These techniques are usually marked by words—as a rule, adverbs or prepositions.

2.1 Time order

There are two types of *time* development of a paragraph (Hayes, 2006).

Time chronology, in which the writer shows events taking place one after the other in clock or calendar time; that is, the writer traces the development of something through history or over a shorter period of elapsed time. In this type of development, the terms that indicate the time pattern are usually dates (calendar time) or hours, minutes, etc. (clock time). In some paragraphs, a time period (the 18th century, for example) will be set and the events being described will fall within that period. In these cases, the key words such as *first, second,* etc. are used.

Time process, the second type of time development in the paragraph, is concerned with the steps in a procedure or process. The term "process" can be defined as a series of two or more steps in which each step but the first is related to the preceding step; that is, a definite order of activity should be followed. Terms indicating time processes are often *first, second*, etc. or *now, then, after,* etc. The time process, by the very nature of the material, is usually combined with *cause and effect* in that one step will be the cause, with its effect being the following step.

2.2 Spatial Order

The order of the components in a descriptive essay should correspond to their spatial locations or other relevant factors. The perspective and perception of details by the reader are influenced by the structural sequence of descriptive paragraphs. Place is emphasized, while time is disregarded. It is the rhetorical technique the writer uses when he wants to show the reader how objects are related spatially to one another. It is especially common in giving physical descriptions (Hayes, 2006).

Common *spatial order* words are: *in, out, up, down, above, below* (any adverb of place or position); *first, second, last, next, following...* Besides, there is a common use of appropriate verbs to describe the spatial order of certain procedures.

2.3 Cause and effect

Information in a text is frequently organized using the cause-and-effect model. Cause and effect essays give the explanations for why something occurred or its results. Cause-and-effect text structures are frequently utilized in persuasive and explanatory writing styles (Hayes, 2006). When a writer provides explanations for why something occurred, they are describing what created an effect (reasons are causes, and the thing that happens is the effect). Additionally, when a writer discusses the outcomes of an activity, they are discussing the impacts of a cause (since outcomes are effects and causes are things that happen). Because cause-and-effect text structures are so ubiquitous, it's likely that we have written a paragraph with one without realizing it.

It is used to show a causal relationship between things or ideas, etc. It is very common in technical writing. It is indicated by the terms: *because, thus, hence, therefore, so that, such that, due to, as, since, as a result of ...*

2.4 Examples

Examples are used to give the reader a specific case (or a general one) of the generalization represented by the core idea. This rhetorical technique is denoted by terms *such as, as can be seen, as an example...*

A representative is something that exemplifies the entire group. The knowledge the audience already possess is used to help them learn something they do not know. Creative and captivating examples illustrate the points (Hayes, 2006).

2.5 Visual illustration

Words and illustrations can be combined in various different ways. Good readers can envision what they are reading in their minds. When reading technical writing, drawings can aid readers in picturing the settings, and events that take place. In addition to assisting readers in visualizing what the text is describing, illustrations can also aid in word comprehension. In addition, the illustrator's choice of medium can help convey an appropriate tone for the text.

It is used when the writer wants to make his point clear by referring the reader to a picture, a graph or any other visual aid. This is often used as a kind of example. Terms which indicate this technique are: *as figure n indicates (shows, illustrates, explains) as can be seen in figure n ....; see figure n....*

2.6 Verbal illustration

A good visual illustration is not an excuse for a poor presentation. And often, a concept is too abstract to be represented visually. So, this is when we use *verbal illustrations*. An example used by a speaker to evoke in the listener a vivid mental picture that best conveys the speaker's message is known as a verbal illustration (Graham, 2006). It is used when the writer wants to give the reader a very specific, detailed example. Terms which indicate this rhetorical technique are: *an illustration is, by way of illustration...*

2.7 Comparison and contrast

This structure emphasizes the similarities between things, happenings, or people through comparison and the differences between things or happenings through contrast. This format is typically used in technical writing. Writing in this format gives the author the opportunity to cite specific instances that support their point of view, which could be biased. A Venn diagram is a popular graphic organizer for students to use to separate and arrange their ideas (Graham, 2006). When comparing, writers that use this pattern may use words like *alike*, *similarly*, or both. Writers may employ contrastive words like *opposite, however, or while*.

They are used to make a difficult concept easier to grasp by comparing or contrasting it to something already known to the reader; or they are used to state the opposite of what might be expected from a preceding statement. Terms that indicate these techniques are: *in comparison, in contrast, on the other hand, however, although, nevertheless, but, in spite of ...*

2.8 Order of importance

It is a rhetorical technique used when a series of supporting details should be put in some order. This order can be from the least to the most important, or more commonly in technical writing, from the most to the least important. Common terms that indicate this technique are: *first, second, most important, least important, last, in the order of importance ...*

The writer or speaker assigns ideas or actions a ranking in accordance with a hierarchy of values. Information can be arranged from most important to least important or from least important to most important when adopting the order of importance pattern of organization. Both text structures would be regarded as having equal relevance (Hayes, 2006).

2.9 Details

It is customary in technical writing to give specifics, details, and concise descriptions or explanations of unknown concepts. Even if the audience is comprised of experts, if we use a specific phrase or detail that is not frequently used, it should be defined clearly.

Details are used when simple supporting statements for the core idea of the paragraph are needed, often in descending order of importance. Details can be presented in *cause and effect*, *comparison or contrast*, *time*, *space*, and other rhetorical techniques. A common type of detail is statistical data (Hayes, 2006).

2.10 Analogy

It is a rhetorical technique used when the writer wants to make a comparison of things which are basically not alike. Comparison compares things that are basically similar, but analogy compares things that are basically dissimilar. Terms indicating this rhetorical technique are: *by way of analogy, analogically, by analogy...*

Analogies have two types: correspondences and inferences. The first type of analogy is a relationship between two otherwise unrelated items. If we want to compare a notion to another one that our audience is familiar with, a structure, connection, or purpose that is comparable to the concept we are defining should be considered. Analogies are used especially when we are unable to come up with any common examples of the topic since it is so strange.
The second kind of analogy assumes that if two objects are similar in some ways, then they must also be similar in other ways. For instance, we can argue that if raising tuition at institutions in our country made it more difficult for foreign students to attend, raising tuition at private colleges would have a similar effect (Graham, 2006).

3. CONCLUSION

The technical paragraph in its simplest and most common form begins with or has near the beginning a core idea—a generalization that tells the reader what the paragraph is about. Then this core is developed by one or a combination of the methods given above. By the writer's using the key terms listed, the reader is told what type (or types) of development is being used, and therefore the reader can understand the information given to him more quickly and more clearly. Which types of development are chosen by the writer should be determined by the writer's analysis of the problem.

(1) Which type (or types) best expresses this core for the purpose for which the paragraph is written, and
(2) Which type (or types) is best suited to a specific reader (or group of readers)? A reader with little background knowledge needs a simpler presentation than a more knowledgeable reader.

A technical paragraph basically makes some kind of statement, and then it proves that statement or provides the reader with further information in some way. Also, it is a unit of organization for the material that makes up the entire piece of writing.

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GAMIFICATION AND SERIOUS GAMES METHODOLOGIES IN EDUCATION

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Abstract: *Gamification as a concept was defined for the first time two decades ago, as the use of game elements in a non-game context. Specific game elements like points, challenges, badges and leaderboard are incorporated in the learning process in order to increase motivation, engagement, and satisfaction to students. On the other hand, serious games are interactive video games that have a defined purpose of learning and practicing skills rather than entertainment. Serious games aim to improve problem solving skills, critical thinking and learn specific knowledge through playing video games that are software that have specific learning oriented purpose. The first purpose of this paper is to compare and contrast different aspects of gamification and serious games in the education domain, in order to identify appropriate applicable environments for these two approaches. Another purpose is to identify models and frameworks to apply gamification and serious games that are more effective to increase motivation and engagement to students. The final purpose is to identify in which courses these approaches are more applicable and help to improve the learning process by increasing creativity, motivation, engagement and problem solving skills. Methodology of this research is realized by analyzing different research papers in conferences proceedings and journals in the last two decades for concepts of game based learning, gamification in education and serious games evolved over the years. Also questionnaires are conducted for academic staff of Albania universities to measure perception and identify challenges and strategies of incorporating these approaches in the learning process. We conducted qualitative and quantitative research analysis in order to achieve results to fulfill the purposes of this research in all the aspects. This research represents conclusions and recommendation related approaches to evolve gamification and serious games methodologies in the education system in Albania. The paper aims to suggest practices and some of the most appropriate and effective models to apply gamification and serious games during the learning process.*

Key words: Serious Games, Gamification, Engagement, Motivation, Learning Process

1. INTRODUCTION

In the last years, researchers as well as different industries have increasingly expanded their focus and interest from pragmatic issues of human-computer interaction, to include aspects like user-experience, emotion, satisfaction and motivation (Deterding, 2011). One of the methods that comprise this concept is called "Gamification": the use of game design elements in non-game contexts (Deterding et al., 2011). The purpose of gamification methodology is to drive user engagement, and motivate users to engage an application or service by making it 'fun' and joyful to use. Gamification, in other words, is extracting different game elements like points, challenges, badges, and leaderboard to a non-game context like education, business, and marketing. Gamification is used in a variety of contexts and scenarios, but this paper aims to demonstrate the importance in the educational environment. Existing reviews on gamification literature have indicated that education and learning are the most common contexts for empirical research of gamification (Koivisto & Hamari, 2014). By incorporating game elements in the learning process we aim to increase motivation, however we need to pay attention to the integration of tasks and exercises within the game design (Von Ahn & Dabbish, 2008). The other methodology that comprises the human-computer interaction, that include user-experience and motivation are serious games. In the past decades, the fast development of the tech industry, together with rapid development of the serious games industry, has become an important method to incorporate in technology in order to receive better results. Different from gamification that use and extract specific game elements in a non-game context, serious games are referred to entertaining tools with a purpose of education, where players cultivate their knowledge and practice their skills through overcoming numerous hindrances during gaming (Juan et al., 2017). Players' performances are scored during the gaming process and in case players overcome a hindrance, they will obtain some awards, such as points, advancement and power to classify in leaderboard. The most important reason for the effectiveness of serious games in the education domain is their influence on learners' mood, motivation and engagement. Gaming plays an important role in mood formation such as happiness, surprise, sadness, and anger (Van der Wal et al., 2016). Effective serious games attempt to form a positive mood in order to motivate and engage players to continue the play process, leading to increased interest in gameplay through learning and doing specific tasks and exercises that have a specific learning purpose, as well as better academic performances. This research study, therefore, aims to find out the main features of successful serious games and gamification methodology and put forward constructive suggestions for designers and education institutions via reviewing significant works in the recent decade. We attempt to answer the following research questions: (1) What are the main purposes and differences between serious games and gamification methodology in education? (2) What are the positive and negative findings in use of serious games in education (3) What are the positive and negative findings in use of gamification methodology in education? (4) In which courses is more effective to apply gamification and serious games methodology? (5) What is the perspective of mentors and students in Albanian universities towards incorporating gamification and serious games in the learning process? This study makes an empirical and theoretical contribution to retailing literature by expanding the knowledge on application of these methodologies in education domain.

2. RESEARCH METHODS

In order to answer research questions, we obtained 697 results including 617 articles, 45 reviews, and 35 proceeding papers by searching "Web of Science" (involving four databases, i.e., CCR-EXPANDED, SSCI, ESCI) with the subject "gamification" AND/OR "gamified learning" AND/OR "serious games" AND/OR "education" AND/OR "learning".

The quality of publications was assessed by a three point criterion: (1) quality of research framework for answering research questions. The quality is classified into "high" if the study is conducted through a rigid research methodology including qualitative and quantitative research, The quality is considered "medium" if the study is carried out through a medium rigid research design through an experimental research; the quality is reduced to "low" if the study is weakly designed research, like self-reported evidence; (2) appropriate research methodology applied; (3) reliability of findings. Each of the selected publications was scored based on the above criteria and reviewed by researchers. The papers with high quality that fulfill research criteria were selected in this study.

However, we conducted a questionnaire for students and professors in Albanian Universities. The purpose of this questionnaire is to give an answer related to the two last research questions (1) courses that are effective to apply gamification methodology; (2) perspective of mentors and students towards incorporating gamification and serious games in the learning process. The survey was conducted online through google form for two weeks from 5th June to 19th June. We collected 207 results for that period of time.

3. FINDINGS

All the selected papers were reviewed and rigidly analyzed, whose results for the research questions were shown below:

3.1 Main purposes and differences between gamification and serious games

Gamification essentially is use of game elements in a non-game context, is a set of activities included in this case in learning environment with the purpose to solve problems by applying the features of games like points, challenges, levels, and leaderboard to increase engagement, motivation and satisfaction to learner's. In the other hand, serious games have the primary purpose to commit knowledge and technical skills. Entertainment is not the objective of serious games. The main difference between these two methodologies is that gamification is just an extra layer that is applied in the non-game context in order to motivate and engage learners, otherwise serious games are real game designed for a specific knowledge or technical skills learning purpose.

3.2 Positive and negative findings of applying serious games in education

The findings in serious games for learning most of them have positive results and support this approach to apply in the education system. However, there are few findings with negative results. Serious games could facilitate and improve learners' understanding of scientific conceptions due to the improved performances on science and the prolonged retention of science knowledge (Zhonggen, 2019). Gaming immersion and concentrating was also positively correlated with performance of science learning (Cheng et al., 2017). Serious games prove effective in enhancing cognitive abilities and effect, as well as pleasant and motivated mood, in general learning cases. Through analyzing 24 empirical studies, serious games were found to be helpful for learners to obtain cognitive abilities, and increase satisfaction of learning (R. L. Lamb, 2018). Education based on technology, such as serious games, improved learners' academic achievements and encouraged their participation in learning activities. Educational or serious games can act as effective tools to improve teaching in the sciences (Cheng et al., 2017). Serious game-based learning proved significantly more effective than non-game-based learning. Learners were engaged in serious games significantly longer than the non-game-based learning. In the former learning approach, learners and teachers were significantly more motivated, engaged, and satisfied compared with the latter. It was empirically evidenced that learners who learn through playing serious games were scored significantly higher than those who did not learn through gameplay although significant differences in knowledge exams were not revealed (Roozeboom, Visschedijk & Oprins 2017). Some negative results were found especially in terms of the correlations between mental workload and learning effect. The nature of serious games negatively influenced the relationship between mental workload and learning effect (Cowley et al., 2013). In case the serious game makes the mental workload heavier, the learning effect tends to be negatively influenced (P.Wouters, 2013). In order to summarize these findings and enhance the readability of the paper, positive and negative findings are summarized in Table 1.

Table 1: Summary of, positive and negative findings of serious games

Items	Findings
Positive findings	● Facilitate learner's understanding of scientific concepts (Cheng et al., 2017) ● increase satisfaction and motivation during the learning process (Zhonggen, 2019) ● provide flexible and dynamic learning (Garneli, Giannakos & Chorianopoulos, 2017) ● facilitate socio-cultural learning in terms of cognitive and motivational effects and team cooperation (Wouters et al., 2013) ● obtain cognitive skills ● increase positive affect of learning and improve teaching in the sciences (Lamb, 2018)
Negative findings	● no improvement in-depth and detail-oriented learning ● Some serious games framework aggravated the mental workload and decrease learning performance (Cowley, Heikura & Ravaja, 2013)

3.3 Positive and negative findings of applying gamification in education

The findings in implementing gamification approach for learning, most of them have positive results and are implemented in the learning process, however there are few downside related gamification. Gamification helps students gain motivation towards studying, and because of the positive feedback they get pushed forwards and become more stimulated to learn. Gamification can constitute a powerful boost to determine them to learn more in a pleasant and satisfied environment. Based on research, it is revealed that a gamified learning environment is positively correlated with a student's grades and performance in the learning process (Grangeia et al., 2019). Furthermore, gamification is a low-cost tool and easy to incorporate in existing learning environments with high effective performance (Majuri, Koivisto, & Hamari, 2018). Some negative results were found especially in terms of effectiveness in the long-term. Gamification resulted that the effectiveness towards the learners' decrease when applied for long-term because game elements, rewards, do not provide long term satisfaction (Rodrigues, Pereira & Toda, 2022). However, results revealed that gamification does not increase the performance to the learners that are not performance oriented. In order to summarize these findings and enhance the readability of the paper, positive and negative findings are summarized in Table 2.

Table 2: Summary of influent factors, positive and negative findings of gamification

Items	Findings
Positive findings	● Increase learning activities in a gamified environment, positive correlation between student's grades and gamified learning process (Grangeia et al., 2019) ● Game elements can support different motivational types; potential to counter the downward trend in students' autonomous motivation; personal characteristics mediate between gamification and motivation (Van Roy, 2018) ● User types react differently to gamification mechanics; gamification is valuable for designing smart technologies to design, boost, and maintain users' engagement (Leclercq, Poncin & Hammedi, 2017) ● Gamification is a low-cost tool to implement and high-effective in education domain (Majuri, Koivisto, & Hamari, 2018)
Negative findings	● Less effective in the long term application because rewards do not provide long term satisfaction (Rodrigues, Pereira & Toda, 2022) ● Increase performance only to a limited target group, for learners that are performance oriented

3.4 Courses that is more effective to apply gamification and serious games methodology

Based on the responses collected in the questionnaire we concluded that "Applied Sciences" are the most appropriate courses to implement gamification and serious games methodology. As shown in the chart below, 128 of the students and mentors responded that applied science like computer science, engineering and architecture are the most effective courses to apply these gamified technologies.

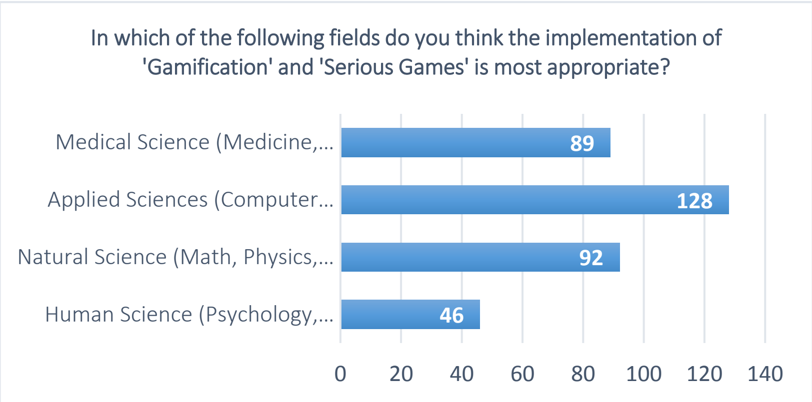

Figure 1: Courses that are more effective to apply gamification and serious games methodology

3.5 Perspective of professors and students in Albanian universities towards incorporating gamification and serious games in the learning process

Based on the results of the survey we concluded about the perception of students and mentors towards incorporating these gamified methods in learning process. We concluded that 79 of 207 students and mentors response agree that serious games and gamification could improve performance of students related academic achievement. Most students and mentors think that gamification is more appropriate to incorporate in the education system than serious games. The pie chart shows that 65% of responses agree for gamification and 35% of responses agree for serious games. On the other hand, the perception of responders related to the effectiveness of these methodologies to implement in education shows that 54% responds agree for serious games and 46% of them for gamification. Based on the results we can conclude that gamification is more appropriate and easy to implement in the education domain, however serious games are more effective in the long term to keep learners engaged and motivated.

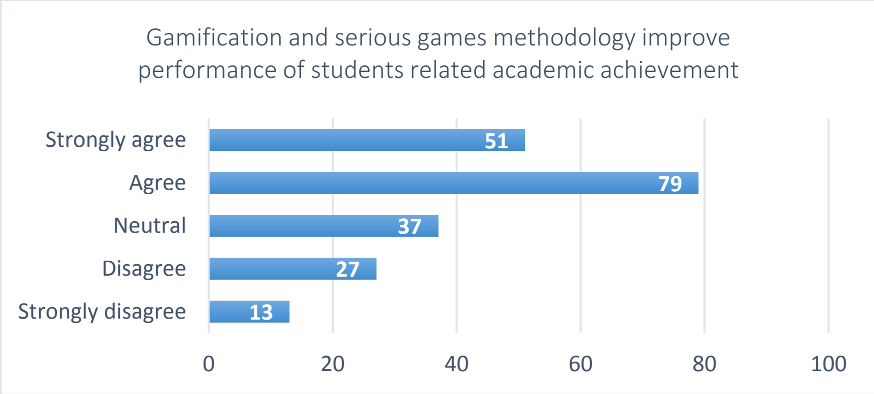

Figure 2: Perspective of mentors and students towards gamified methods in academic achievement

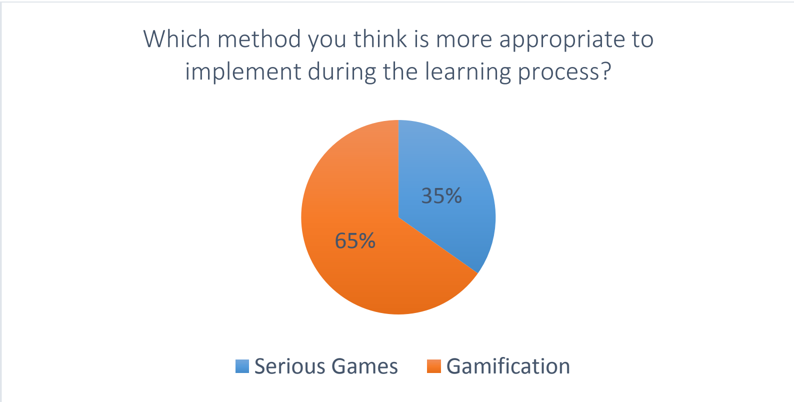

Figure 3: The most appropriate methods to implement in learning process

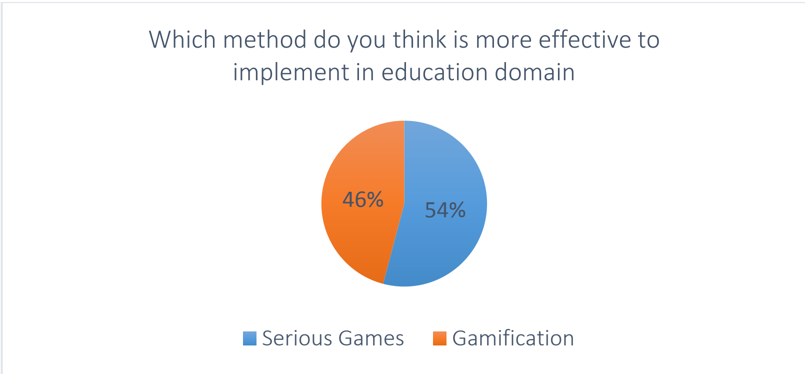

Figure 4: The most effective gamified method to apply in education domain

4. CONCLUSIONS

Gamification and serious games are educational innovations that have proved to have a positive effect in the education domain. Researchers often advocate that gamification and serious game's impact is positive due to its novelty, gamified environment, rewards and that it consequently vanishes as the novelty passes. Gamification and serious games have different concepts and purposes (Grangeia et al., 2019). Gamification is just an extra layer that is applied in the non-game context in order to motivate and engage learners, otherwise serious games are real games designed for a specific knowledge or technical skills learning purpose. Based on our research we reveal that both these methods in general have positive effectiveness in the education domain. Furthermore, this research concluded that gamification is more appropriate and easy to implement in the learning process, while serious games are more effective for long term motivation and engagement to learners'. Prospective students and mentors encouraged implementing these methodologies in the learning domain. Ultimately, our conclusion is that gamification and serious games impact positively on students' engagement, motivation, and facilitate the learning process.

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AN INTERACTIVE PHILOSOPHICAL VISION FOR TEXTBOOK DESIGN TO INCREASE INFORMATION VALUE

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Abstract: *This research aims to improve the visual design of information in primary school education by improving the structural and graphic design of the textbook through paper engineering of pop up interactive book based teaching material. The goal of the research is also to find a solution for textbook design that combines the benefits of an electronic book and an ordinary book by displaying images in three dimensions and content in an interactive manner to simplify and facilitate the information. The difficulty for primary school students to understand some curricula through ordinary textbooks is a research problem. In this study, we used a field study with a focus group discussion to achieve our goal, and we chose an informal ordinary book as the primary source, its title (into the crater of doom) and transforming its structure design into a pop-up book to present to primary school students and get their feedback on the method to design the pop-up book to use as an aid means of simplifying information for students, interacting with the book, and presenting the information in an interesting manner. The results of a discussion group with 33 primary school teachers divided into three groups revealed that 92% of them agreed that the design of the ordinary textbook should be updated. By presenting the researcher's pop-up book, all of them prefer to use the pop-up book as an aid in improving students' cognitive and intellectual skills. Furthermore, the results of the discussion groups with the students, a total of 35 students divided into three groups, revealed that all of them preferred to use the pop-up book in all textbooks, particularly science and social studies for 4th grade primary students.*

As well as making recommendations to the Ministry of Education on their performance regarding the positive impact on students of using pop-up books designed by the researcher as an aid means to students in schools and homes.

Key words: Popup book, paper engineering, Ergonomics, Structural design, intellectual skills.

1. INTRODUCTION

Interactive design is a design method that allows children to participate in it personally with the use of different forms of book design, the design of a children's book may have many different ways of presentation (Song, 2021). Interactivity is like games, It is a way that children prefer. Children are easily distracted during the learning process, and the interactive design is more suitable for children (Yan, 2019), they are more active in the process of reading and learning, and are more able to learn actively through the process of interacting with books. Currently, digital displays are used in education, but with elementary school kids, the function of the textbook must be enhanced and an attempt made to improve it to suit the students. Therefore, it is necessary to updated the design of the ordinary textbook, particularly with the increasing of smart phones in reading educational content, is a major challenge that has led to shed light on the revival of textbook use. To accomplish this, the graphic design and structural design of the textbook must be updated, taking into account the selection of a standard book size that is appropriate for children of the target age, the use of appropriate colors, whether for text or backgrounds, the use of appropriate font sizes with an interest in clarifying information in the form of 3d images, and the search for solutions for students' interaction with the textbook.

Pop-ups or movable books are three-dimensional books containing pieces of paper that appear or move when the book is opened and fully folded when the book is closed (Conrado et al., 2014). The ones that can make pop-ups appear are various methods of cutting and folding, as well as on the hidden mechanisms behind and under the page. Pop-up books are included in the characteristics of a three-dimensional learning media, therefore, pop-up book included a unique and interesting learning media to help students understand the material that had been taught (Ahmadi & Khasanah, 2018).

1.1 Interactive Design in Children's Books

order to develop age-appropriate content to be used for both the printed pop-up book and the interactive pop-up book, I started by looking at the work of children's authors and artists, including Eric Carle, Sandra Boynton, Emma Quay, Anna Walker, and Eric Hill. There is still a certain difference between interactive design and traditional ordinary printing books. It is different from traditional books in terms of material, structure, and content presentation. It breaks the expression form of flat books and introduces new design methods. This makes this kind of books look "different" from other books (Song, 2021). Books are added with toys, or some foldable cards, etc., so they can attract children's attention and be more acceptable to them. There are also various forms of interactive books. It's flipping form and content presentation can also produce different effects with different design methods and opening methods, which greatly enriches children's visual enjoyment experience. Children can learn knowledge in a more realistic and visual way, and have fun in the learning process.

1.1.1 Pop-up books

Pop-up book mean a book with pages that rise when opened to simulate a three-dimensional form, as shown figure 1. Figuring out the paper mechanics necessary to convert a 2D sheet of paper into a full 3D structure is quite a technical process, and one that will need to be done by a professional designers. They'll know what cuts will need to be placed where, how each piece will need to fit together, and which markings to use in the artwork to indicate this all to a production team (PrintNinja, 2022). Because pop-up books are so unique in their manufacturing, they come with some particular production requirements. Interior Paper Must be sturdy enough to support the pop-up structures, Because of how complex and labor-intensive these projects are to manufacture, the minimum order quantity is 500 units.

Figure 1: Pop-up book

1.1.2 Characteristics of Children's pop-up books

The success of pop-up books within the word of infant literature seems to suggest that they were designed specifically for children. However, in their beginning, these books were aimed at reaching adult audiences. Originally, the purpose of the pop-up book was as a type of pedagogical resource. As such, these books made it easier to understand and explain theories. It wasn't until the 18th century when the same technique extended into the world of entertainment literature, especially for children (youaremom, 2022).

In the whole childhood, children's unintentional attention has reached a high level of development and occupies a dominant position. Intuitive stimuli or sudden changes in stimuli will cause children's unintentional attention. As everyone knows, children generally have the nature of playing. The love of play here refers to the love of doing things and discovering some novel things. Interactivity is just in line with this feature, which is not only in line with children's psychological characteristics, but also can increase the interactivity of books. This is a very appropriate thing (Yan, 2019).

1.2 Ergonomics Principles in Book Design

The principles of ergonomics ensures that the design complement the consumer ability strengths for and strives to minimize the effort and limitations while using the product rather than forcing them to adapt. Ergonomics is widely implemented in different industries effecting the creative sector. Many designers believe ergonomics is only considered in product design. However, designers in different fields such as graphic and interactive design are required to consider ergonomics in their design projects. For example, the interactive designers should consider the user experience research as an essential stage in designing mobile applications, user interfaces, and book design (Elmansy, 2015).

1.2.1 Children's Book Sizes

Book size, also known as trim size, is the actual book dimensions. Book size is measured in length by height. A trim Size in inches 8.5 x 11 (would be a portrait orientation, while) 11 x 8.5 would be a landscape orientation. Book size measures the interior of a book, also known as the book block. For a paperback book, the book cover size will be the same as the trim size. For hardcover book, the book cover size will be larger than the trim size to accommodate for the hardcover case that wraps around the book block. The hardcover will typically add extra .125 to the top, bottom, and right side of a closed book (Vitale, 2020).
The best portrait children's book sizes in inches: (7 x 10), (7.5 x 9.25), (8 x 10), and (8.5 x 11).
The best square children's book sizes in inches: (8 x 8), (8.5 x 8.5), (9 x 9), (10 x 10).
The best landscape children's book sizes in inches: (10 x 8), (11 x 8.5).

1.2.2 Readability

The ultimate purpose of book design is to learn and read a good book is not complicated. Human beings should find its concise expression in a variety of design methods. At this age, children's cognitive level is still relatively limited. They may not be able to fully understand things that are too complex. Only simple and easy method is the best (Song, 2021). In the process of reading books, students aged 10 to 12. Accuracy of reading was measured by the average of error that students made when reading the text, while reading speed was determined by the time it took students to read the text. Therefore, font sizes 14 and 16 point are readable for readers aged 10 to 12 and over (Abubaker & Joun, 2021).

2. METHODS

The research method that used in this research is a research and development (R&D) method that can be interpreted as a scientific way to research, design, and produce, this section of the study summaries the tools and materials used to implement the research idea. When developing the initial mocks for the printed pop-up book, I started by looking at the work of David A. Carter and Robert Sabuda, two well-known pop-up book artists. Both artists' work helped to shape my decisions when it came to building pop-up book functionality that enhanced the story. Initially, a structural design proposal based on paper geometry with the same graphic design for the book (into the crater of doom) shown figure 2.

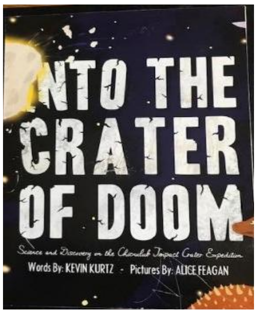

Figure 2: The cover of the book into the crater of doom

Preliminary research revealed that the textbook's design requires development in terms of graphic and structural design, and the researcher focused on practical application of structural design through the use of paper engineering in displaying images in a pop-up style. a book was chosen in the crater of death, To learn more about the mass extinction that introduces children to the asteroid impact 66 million years ago that caused the extinction of dinosaurs and many other species. This book was chosen because it requires imagination and understanding through the use of three-dimensional images.

With the same graphic design, the structural design of the internal book pages was changed. First, a prototype of 250g Canson paper was created, and the pop-up images shown in Figure 3 were created using paper engineering. The background, text, and images were then printed while keeping the same cover to create the pop-up book shown in Figure 4. Following that, the proposed book was presented to the students, as shown in Figure 5, and their reactions were recorded as shown in Figure 6.

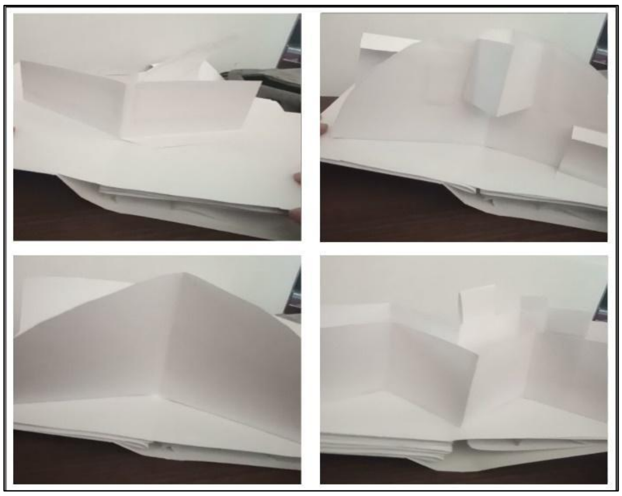

Figure 3: The suggested pop-up book's initial prototype

Figure 4: The suggested pop-up book

Figure 5: Student feedback on the suggested book and compare it to other books

Figure 6: Students' opinions on the suggested book that appears are positive

The ordinary structural book design was developed in order to measure the effect of the structural design of the book on students' comprehension, and it evaluated through a focused group discussion of teachers and students At the Egyptian International School, 33 primary school teachers participated in a focused group discussion, They were divided into three groups and a series of questions were given to them to gauge how well students understood the topics included in the book, how well they accepted the book's structural design, and how well the pop-up book's structural design affected their understanding of the subject. Additionally, through a focus group discussion with 35 primary school students who were separated into three groups with the assistance of the responsible teachers. Before they read the content, they were shown the pop-up book the researcher had suggested in order to get their thoughts on it and gauge how well they understood the topic.

3. RESULTS

According to the researcher's observations of the focused discussion with the fourth primary stage students after presenting the proposed book design with the pop-up images, it was discovered that most of the students interacted with the book and understood what the book contained through the three dimensional images that were designed through the paper engineering, they see that it is a successful way to understand the topics and that this The method is interesting and fun. One of the students commented that the size of the textbook and its dimensions are very large and inconvenient to use, and that there are some Subjects in which the font size very large and others are small, so the size of the font in all Subjects should be fixed to be suitable for reading, shown table 1.

Table 1 (part 1): An overview of the opinions of teachers and students on the pop-up book design as an aide schoolbook

Primary school teachers' questions	*Responses, refer to Number (percentage %)*	
Do you notice that the majority of students refuse to use the schoolbook?	**YES,** 25 (75.75%)	**NO,** 8 (24.24%)
	Most teachers believe that the majority of students refuse to use the schoolbook.	
Do you think the ordinary schoolbook's design should be updated?	**Strongly agree,** 31 (93.93%)	**Agree,** 2 (6.06%)
	Most teachers Strongly agree that the ordinary schoolbook's design should be updated.	
Do you believe that using pictures in a textbook helps students understand the text more effectively?	**YES,** 33 (100%)	
	Everyone agreed that using images in textbooks is extremely effective.	
What are the challenges that primary school students face of designing a textbook?	- Most teachers believe it is uninteresting for students. - Others think the text must be as interesting as the images. - Some books are quite large and heavy. - Some books are lack imagination & lack interactivity. - There is no idea in the design of the book. - Students are dissatisfied with book design. - The schoolbook's lack of color.	
Have you heard of a popup book?	**YES,** 33 (100%)	
Is it preferable, in your opinion, to use a pop-up book as an aide book with a schoolbook?	**YES,** 33 (100%)	
	Everyone strongly agree that the pop-up book system should be used as a textbook or a specific book, especially for topics that are difficult for students to understand or imagine.	

Table 1 (part 2): An overview of the opinions of teachers and students on the pop-up book design as an aide schoolbook

By displaying the proposal of the pop-up book figure 7 to a group of fourth year primary school students, Would you prefer to use the popup book style as a structural design for the textbook?  *Figure 7: The proposal's structure design book with pop-up*	Everyone strongly agreed that using Popup images in textbooks and using pop-up books as an aid in some textbooks was a good idea. By scanning the QR code shown figure 3 , you can watch a video of students' opinions about the pop-up book *Figure 3: Students' opinions about the proposal Pop Up book*
What entices the student to use the suggested book?	3D image display method and their understanding of the subject through the use of pop-up images prior to reading the text. By scanning the QR code shown figure 4, you can watch a video of One of the students' opinions about the Popup book & Compare it to ordinary books. *Figure 4: One of the students' opinions about the Popup book*
According to students, Is the popup book design improves cognitive and intellectual skills?	Everyone strongly agreed that the popup book design improves cognitive and intellectual skills, on other hand The use of popup books improves content knowledge of the subject and improves the retention of knowledge

Table 1 (part 3): An overview of the opinions of teachers and students on the pop-up book design as an aide schoolbook

Is the Pop-up book design making the subject more interesting and enjoyable to learn?	Everyone agreed that the popup book design makes the subject more interesting and enjoyable to learn, and it also improves self-directed learning on the topic. By scanning the QR code shown figure 5, you can watch a video of students' opinions about their thoughts on the pop-up book feedback. *Figure 5: Students' opinions about their thoughts on the pop-up book*
Is the Pop-up book design improves Eye tracking and interactive?	Everyone agreed that the pop-up book design improves eye tracking and instructiveness, as well as promoting student interaction with one another. It also aids in memory improvement.
At the end of the focus group meeting, teachers and students were asked the same question: What are the curricula that require the use of the pop-up method from their perspective?	- Science and social studies were mentioned by the majority of students and teachers. - Retelling detailed stories in a sequential manner, science topics (characteristics of various organisms), and social studies topics (intercultural themes). - In the opinion of one of the teachers, it will be most useful for explaining scientific objectives. It will make the concept almost tangible, giving students more hands-on experience.

Following the great responses to the printed interactive book the researcher presented the project idea to second-year students at Higher Institute of Applied Arts, Department of Printing, Publishing and Packaging, in book design course to create graphic designs and apply interactive methods and pop-up images in the design of the science and social studies book to solve the problem of curriculum difficulty on the students, as shown in Figure 8, then presenting it to those responsible and interested.

Figure 8: Samples of the covers book and pop-up inside pages for social studies and science.

4. DISCUSSION

Based on the result of the interview, the design of the children's textbook must conform to the characteristics of children at this age and children's nature. Children's books should not only maintain the readability of ordinary books, but also have innovative forms, so as to highlight the distinctive characteristics. For example, in order to meet the characteristics of children's love of play, books can be designed into various folding methods, which will greatly enhance children's interest in reading and learning, and make children love learning more. In line with the characteristics of less literacy and easy reading, it is necessary to use pictures to convey language, put more pictures and fewer words as much as possible, and use bright colors and Pop up picture forms to stimulate children's brain, and enhance memory, which is also helpful for children's learning. By changing the forms of books, children can participate in the interaction. This interactivity is a process that allows children to use their brains, eyes, hands and other aspects to experience comprehensively. In the whole reading process, this method can make children more focused. This approach was successful in creating positive reactions from the focused group discussion of students and teachers by using interactive methods in suggested book design to overcome the boredom of using the ordinary book, among the beneficial outcomes of the usage of interactivity in the design of a children's book, as shown in Table 2.

Table 2: interactivity in the design of ordinary book versus suggested book

Significance of Interactive children's book Design	Suggested book	Ordinary book
Design Breaks the Single Mode of Book Design	√	×
Design in Line with the Characteristics of Children	√	×
Improving Children's Self-learning and Practical Ability	√	×
Promoting the All-round Development of Children	√	×
Expression of interactive characteristics	**Suggested book**	**Ordinary book**
Visual Interactive Experience	√	×
Tactile Interactive Experience	√	×
Inner-page Folding Experience	√	×
Flipping Experience	√	×
Game Interactive Experience	√	×

5. CONCLUSIONS

As a final result, the researcher can conclude the importance of Interactive Design in Children's Books, especially in schoolbooks. Book content and interactive form become more colorful, powerful and interesting. It allows children to participate and interact with books, which not only improves children's practical ability and learning efficiency, but also improves children's autonomous learning ability.

As a result, the role of academic institutions in solving societal problems is represented in this research through innovative ideas for designing the textbook to be more interactive with students and to simplify difficult-to-understand information through pop-up images and interactive methods in the book. To activate the role of academic institutions in solving societal problems, the researcher focused on designing a textbook for the primary stage after conducting preliminary studies to learn about the problems that students faced in the primary stage, the majority of which were in science and social studies for the fourth primary stage. In focus group discussion, the researcher presented the notion of an interactive printed book to students and teachers, this led in really good comments. By conducting usability testing throughout the creative process of the printed pop-up book, I found that it helped produce constructive feedback, which helped to inform the content of the written story.

For the fourth primary stage, it is recommended to use pop-up images and interactive techniques in the science and social studies textbooks. It is also recommended to lower the size of the book to suit students.

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VIDEO GAMES AS A LEARNING TOOL - POTENTIAL APPLICATIONS IN THE GRAPHIC ENGINEERING AND DESIGN STUDIES

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Abstract: *Throughout this research, evidence has been accumulating on the positive impact of educational games (serious games) on students' learning and achievement and the impact of non-educational games on different psycho-physical traits. Today's dynamic way of life and almost innate familiarity with technology opens many new possibilities for teaching and can facilitate a better understanding of specific topics. There are numerous applications of video games for educational purposes. This paper aims to give insight into these researches and propose potential applications in a Graphic engineering and design studies. There is not much literature describing and discussing applications of video games in this field of study, and only simulations for specific graphics-related processes are commercially available. Significant findings in various applications of video games are listed and discussed. Some game design guides for implementing video game technology as an educational tool in the field of Graphic engineering and design are proposed.*

Keywords: video games, education, gamification, edutainment

1. INTRODUCTION

Throughout history, games have been meant to enrich leisure time and provide a sense of advancement and fulfilment by following specific rules and overcoming obstacles. Play, on the other hand, is usually not bounded by externally imposed rules and is more casual, creative, and liberating. However, that does not mean participating in a game cannot be playful. Our educational system is, by analogy to games, also founded on a different set of rules meant to be obeyed. By following these rules and overcoming various obstacles throughout studies, students acquire specific achievements after which they should be prepared for the challenges of the real world. Suppose the educational system is looked at in this way. In that case, educators can be found to be in the position to tailor their "mini-systems" to be similar to games or even to incorporate different kinds of games for better understanding, engagement, and learning. Guided by this premise, over the last three decades, there have been discussions about the influence of gaming on learning in students of various ages. Games are also studied as a tool for adult professional education and training.

There are various definitions and debates of what the game is. According to some scientists (Dempsey et al., 1996; Malone, 1981), a game is defined as “usually a contest of physical or mental skills and strengths, requiring the participant(s) to follow a specific set of rules in order to attain a goal.” Prensky (2001) defined a game as organized play, including six critical structural elements: rules, goals and objectives, outcomes and feedback, conflict/competition/challenge/opposition, interaction, and representation or story. What differentiates a game from a simulation is that it usually involves competition and is not necessarily a strict replica of reality. Rogers (2014), in his book “Level Up - The Guide to Great Video Game Design”, cites a few definitions of game proposed in academic circles: “a game needs to be a closed formal system that subjectively represents a subset of reality”; where “players are in conflict with each other.” Suits (1978) wrote that “playing a game is a voluntary effort to overcome unnecessary obstacles”, but ultimately Rogers gave his definition of a game: “a game is an activity that requires at least one player, has rules, has a win and/or lose conditions”. To answer a question what the video game is Roger said that: “a video game is a game that is played on a video screen”.

To give these definitions of a video game a little bit of “soul”, Crawford (1984) stated that: “The computer game is an art form because it presents its audience with fantasy experiences that stimulate emotion.” and that games are “intrinsically participatory in nature” which gives players “not the experience itself but the conditions and rules under which the audience will create its own individualized experience.”

For purposes of this study, games can also be defined as “a voluntary activity structured by rules, with a defined outcome (e.g., winning/losing) or other quantifiable feedback (e.g., points) that facilitates reliable comparisons of in-player performances” (Klopfer, Osterweil, & Salen, 2009).
One cannot discuss games, not to mention what the fun is. The fun does not refer only to something amusing or simply the result of a leisure time activity. In his book “Flow: The Psychology of Optimal Experience,” Csikszentmihalyi (2008) talks about the state in which we dive when doing something interesting to us or when we make something interesting even if it does not look like fun in the beginning. He called this state the “flow” state in which even assembly workers can find themselves if they establish hourly goals and try to beat their best times. Young et al. (2012) stated that if work can be fun, the game can also be work (e.g., professional sports).
This paper aims to give insight into research done in the field of implementing games for educational purposes and what are some of the advantages and disadvantages of using games in education in the last decades. After this initial part of the study, suggestions about potential applications in Graphic engineering and design studies are discussed.

2. LITERATURE REVIEW

In this section of the paper, research that unveils valuable theoretical information for explaining some basic terminology used in studies about gaming for educational purposes is gathered and reviewed. One of the common misconceptions is that simulation and games, or even more often, simulation and simulation games, are synonyms. To understand how to implement games in the university curriculum, educators should also be aware of how games are related to learning process and the upsides and downsides of this approach in education.

2.1 Simulations and simulation games. Serious games.

Simulation can be defined as a “representation of reality or some known process/phenomenon “(Deshpande & Huang, 2011). It is a mathematical or algorithmic model with an appropriate set of constraints that allows predictive system analysis (Ochoa, 1969).
A simulation game, on the other hand, is a simulation with elements such as score, performance rating, conflict, and payoff, but which still simulates an actual world situation for decision-making or alternate evaluation (Deshpande & Huang, 2011). Simulations and simulation games allow the player to experience some process and engage in it without the risk of expensive mistakes. If a simulation involves competition (players with themselves or other players), it can be considered a simulation game. However, if the focus of a simulation involves only the completion of an event, it cannot be considered a game (Ke, 2009).
A serious game is a term coined by Abt (1987) in his book “Serious Games”, and it can be defined as games whose primary purpose is education rather than entertainment. They are designed to teach academic content and skills to students playing them (Mayer, 2014).
Serious games are, to this day, successfully applied in healthcare, education, military, defence, ecology, etc. for teaching, training, raising awareness, changing attitudes and behaviours purposes and their target audiences include all ages (Daoudi et al., 2021). They are applied in primary, secondary and higher education in different disciplines such as computer architecture (Tlili et al., 2015; Hsu & Lin, 2016), mathematics (Ke, 2014; Chadli et al., 2019), science (Shute et al., 2016; Yang et al., 2021), computational thinking and programming concepts (Giannakoulas & Xinogalos, 2018; Theodoropoulos & Lepouras, 2020), history and language learning (Liu & Chu, 2010; Suh et al., 2010; Yang et al., 2010), and it is considered as alternative to traditional. Investigations of serious games have grown in the past 20 years, and today it represents an established academic field, as seen in Figure 1 (Gómez & Suárez, 2021).

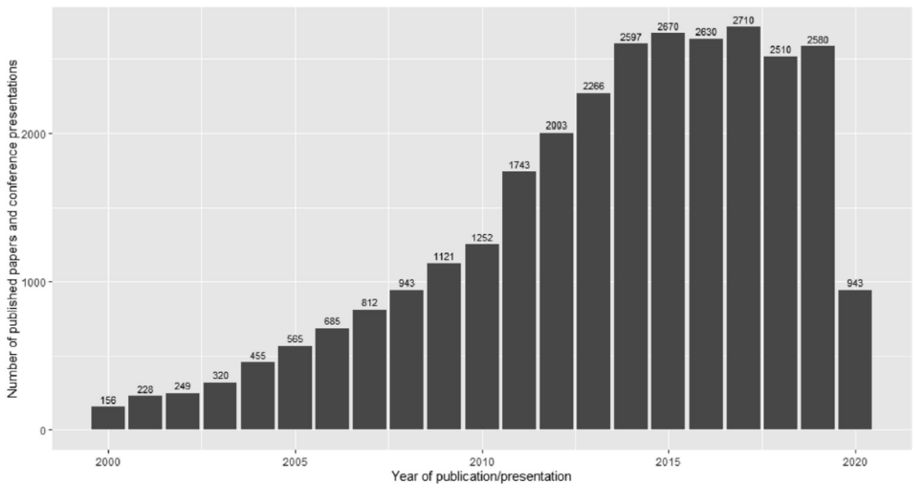

Figure 1: Number of research papers on serious games from year 2000 to 2020 according to Gómez & Suárez (2021)

2.2 Game-based learning

In the work of Piaget (1951), play and imitation are considered two crucial functions in a child's intellectual development process: play as an assimilation strategy and imitation as an accommodation strategy. Play is an important mediator for learning and socializing throughout life (Csikszentmihalyi, 1990; Provost, 1990). As a mediator of play, computer games should be looked at as an integral part of children learning and social lives.

Simulation games and problem-based learning represent experiential learning, collaborative, active, and learner-centric approaches (Deshpande & Huang, 2011). Both approaches include some assessment. In problem-based learning, self-assessment is conducted at the end of the problem or the learning cycle. The simulation game has a scoring system that indicates one's performance.

In game-based learning, students can be motivated to maximize their scores by trying alternative strategies and learning something new from the literature. Games can also be offered online, where advanced graphics and multimedia may be used to capture students' attention. In addition, help for the problems encountered in the game could be found online without waiting for the instructor to address the problem.

2.3 Advantages of using game in educational purposes

Using simulation games with authentic and situational problem-solving and instant feedback provide players with a realistic framework for experimentation and situational understanding and can act as essential primers for active learning (Laurel, 1991; Gee, 2003). In their study, Hitchcock (2000) concluded that computer-based simulation/gaming instruction increased motivation, attention, and learning retention. Motivation established through gaming can lead to engaged classroom culture (Barab et al., 2005)

Playing computer video games is more effective in facilitating third-graders' average learning outcome than text-based computer-assisted instructions (Chuang & Chen, 2009). Game-based learning in higher education can teach and reinforce skills necessary for future jobs, such as collaboration, problem-solving, and communication (Federation of American Scientists, 2006). In addition, game-based learning can motivate students by providing challenges, rapid feedback, and adapting to students' needs and interests (Council, 2011).

In the mobile game-based learning world, some efforts, such as Kahoot! application can yield promising results in engaging students in the learning process (Clark, Kirschner, & Sweller, 2012).

2.4 Disadvantages of using game in educational purposes

According to some research, the implementation of games is much more difficult in larger class sizes because they need additional space (Brown, 2018; Strickland & Kaylor, 2016; Graham & Richardson, 2008). Also, embarrassment or unwillingness to speak up and answer questions can arise (Boctor, 2019; Graham & Richardson, 2008). Also, some students that are not competitive can perceive competition in games as threatening (Blakely et al., 2008).

Some of the mentioned disadvantages of using games in the curriculum found in the literature are that there is an additional cost for supplies. Also, preparations for the class can be time-consuming for the faculty, and additional presence at the faculty may be needed (Kinder & Kurz, 2018; Strickland & Kaylor, 2016), as well as the amount of content needed to be covered (Boctor, 2019).

2.5 Approaches in using games in education

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. Klopfer and colleagues (2009) pointed out that while "the first group embraces games and abandons school, the second group often embraces school to the detriment of anything that looks like real gaming." 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.

3. FINDINGS

This section of the paper will cover findings about the implementation of simulations in the field of Graphic engineering and design. After investigating selected literature, the next section will present the potential application of simulation gaming in the education process.

3.1 Using simulations in the field of Graphic engineering and design

Research papers and solutions regarding simulations and games in teaching graphic arts and printing are scarce. However, there are solutions for simulating some of the printing processes found during the research phase, such as Sinapse print simulators (Sinapseprint, 2017) and PrintSIM simulators (Printsim, 2022).

Sinapse print simulators represent interactive software that simulates the running of a printing press. They reproduce various printing conditions and problems that can be used for training, skills assessment, performance enhancement, and process analysis. Simulation can also familiarize other staff with the printing process, improve teamwork and increase process efficiency. Simulators are available for major printing processes such as flexography, sheetfed offset, gravure, heatset and coldset web offset (Sinapseprint, 2017).

One other simulation system is PrintSim. It was developed in 1987, combining knowledge of processes and know-how on teaching and course materials of partners from different parts of Europe (Printsim, 2022). PrintSim is an open, flexible simulation and multimedia system for learning printing processes, special situations, sequences, and modern automation systems. PostPressSIM is a computer-aided training system for bookbinding, finishing, and mailing which utilizes multimedia and three-dimensional virtual reality factory simulations. PrintSIM also provides a Course Generator that allows a teacher to write instructions for the trainee to use the system interactively without the teacher's supervision. PrintSIM also provides a database of questions and trainees' answers to help assess their work (Launonen, 1998).

According to Launonen (1998), the PrintSim, with its simulation and multimedia, has been very useful with good user feedback. Furthermore, courses enabled by incorporating PrintSim into training activities have indicated that multimedia and simulation are suitable for self-learning either as a private user or business company in the printing industry.

Saikumar et al. (2020) stated that knowledge gained by using simulations in the industry field minimizes risks and decreases costs, time, and energy for implementing a control system. These simulations can also be used in the academic setting to promote understanding processes. In the work of Saikumar et el. (2020), the authors designed and simulated the automatic pad printing machine using CATIA software for 3D modelling and Automation studio for animation and simulation in a virtual environment. The virtual model is used for virtual commissioning.

These examples can be categorized as simulations, but not as simulation games due to the lack of some of the essential elements of the games, such as rules, goals and objectives, conflict/competition, win/lose conditions, representation, or story. One can argue that in these simulations, there are specific “rules” for running a printing press or that there are objectives, such as successfully running the machines. However, conflicts/competition or win/lose conditions are vaguely defined. Concerning representation, usually in these simulations, there are only some kind of user interface and rarely the exact 3D model of the observed printing machine, which can be observed in real-time, rotate around and interact with it. Moreover, there is no storyline besides strict theoretical explanations of the machines and systems.

4. DISCUSSION

For simulation to become a simulation game, all of the previously investigated elements of a game and approaches to implementing games in education must be considered carefully. The primary purpose of this process is to provide students with a realistic representation of the machines in the field of graphic arts. Also, to provide them with an immersive and enjoyable experience while exploring and participating in the game to increase engagement and ultimately equip them with practical skills and theoretical knowledge that will remain longer in their memory.

4.1 Possible solutions for using simulation games in the field of Graphic engineering and design curriculum

Using real printing machines in learning and training for special situations is very expensive (material and labour costs as well as the operating expenses of the press) and often impossible due to the risk of causing damage to the press. Purchasing a printing machine for training is a significant investment for most companies and schools. Even if resources are allocated for buying a printing machine, problems with available space for its installation can arise. Instead of using real machines, simulations can be used to train professional people in occupations where a human error would cost considerably or even be dangerous for their lives. Simulations provide risk-free education and practical knowledge for the trainee. It is possible to construct expert systems for complicated processes with many variables, such as in the printing industry. The purchasing costs of the simulation system are much lower than the costs of the corresponding printing press line, and usually, one system can serve several purposes or printing presses (Launonen, 1998).

In the article “Simulation software for training in the graphic arts,” Launonen (1998) stated that new educational technologies are important to the graphic arts industry. However, getting new students into a vocational school is hard, and companies have difficulties recruiting new employees to their printing and finishing departments. These challenges are present due to the low work status, the night jobs in newspaper presses, and the lack of skilled craftsmen. They claimed that multi-skilled craftsmen would be needed in the printing industry in the future because of the wide variety of products and production machine types.

After years of experience in the education of graphic engineers and designers, there is still a great need for students’ practical work on different machines in the printing industry because of the abovementioned issues. However, also there is a need for students’ active participation in the learning process. The cognitive principles of educational technology should support metacognition and self-regulation or, in other words, reflective thinking rather than replacing students’ thinking. Simulations should encourage problem-solving skills, and they should activate the user.

Technologies such as modern game engines (Unreal Engine, Unity, etc.), virtual reality, and augmented reality can help develop new simulations and interactions with otherwise expensive printing machines often unavailable to students. To acquire practical skills in the graphic arts industry, students need to have a chance to see and interact with printing systems and get familiar with the processes. Besides company visits which are very useful for getting a glimpse into the industry workflow, they cannot see all of the machines and systems that the curriculum includes, and they do not have the opportunity to try and work on the ones they saw. With the simulations, this can be overcome.

By introducing the “game” component into simulations, as seen from the literature discussed in this paper, students can interact on a whole new level, expanding the possibilities of their learning process and engaging them even more. Using modern game engines to make simulation games enables educators and students to build an immersive world of a printing house with machines from the graphic industry, which can help the learning process. Real-time graphics enable players of the simulation game to see exact replicas of the machines and provide interaction through coding, which provides immediate feedback. Students could explore, interact, and learn about these systems more engagingly. By using some scoring system or even a currency, students can learn how to operate and run the whole system and observe what implications it will have on their virtual economy. Every student can run their virtual print shop, follow how their virtual businesses advance, and later compare the results of the virtual printing game. In such a way, they can get as close as possible to practical experience, which is often hard to achieve in the real world.

Simulation games can also be created in the same game engines for future use in VR (virtual reality) or offer mixed reality experiences by employing AR (augmented reality). In this way, an even more immersive experience could be achieved to get the education as close as possible to one gained in real-world situations.

One more critical aspect of learning is learning by doing. By learning to work in modern game engines, students better understand the world they are building. By collaborating with other students and educators, they can build essential skills for future work in the industry (Kafai, 2015). This suggestion of making games for a better learning experience can be achieved by incorporating students' academic thesis and combining them in joint projects to build more complex virtual worlds and simulation games. A thesis done on subjects with different topics (3D modelling, game design, programming, and animation) can be combined in collaborative work. Even students' thesis from different departments can be used in a collaborative research project with the same ultimate goal - to build a better learning experience.

In Daoudi's (2022) work, the author suggests that a prerequisite to creating effective game-based educational systems is that researchers from different disciplines, such as computer science, educational science, psychology, and cognitive ergonomics, should work together. Also, collaboration between researchers, game designers/developers, and educators should be achieved to identify the best game usage to improve learners' achievements.

5. CONCLUSION AND FURTHER RESEARCH

Throughout reviewed literature, evidence has been accumulating on the positive impact of educational games (serious games) on students' learning and achievement and the impact of non-educational games on different psycho-physical traits. Today's dynamic way of life and almost innate familiarity with technology opens many new possibilities for teaching and can facilitate a better understanding of specific topics. There are numerous applications of video games for educational purposes. This paper aims to give insight into these researches and propose potential applications in Graphic engineering and design studies. There is not much literature describing and discussing applications of video games in Graphic engineering and design studies, and only simulations for specific graphics-related processes are commercially available. Significant findings in various applications of video games are listed and discussed.

From the statements mentioned above, it can be seen that to incorporate simulation gaming into the curriculum of Graphic engineering and design studies, knowledge and expertise from different disciplines should be combined. Artistic as well as technical skills are needed to accomplish this goal. Artistic skills include concept art, 3D modelling (in Autodesk 3D Max, Inventor, CATIA, etc.), and building virtual environments such as print shops where virtual machines would be located (Unreal Engine, Unity, etc.). Technical skills are also needed to get precise animations of the system and printing parameters which can be modified during the pre-printing, printing, and post-printing processes to get a representative simulation game. Industry experts should also be involved in this process to ensure that the functionality of the simulation game provides realistic feedback to the students. Finally, educators and game designers should ensure that all the necessary information is provided and delivered during the game. That simulation has game elements that provide a fun experience, realistic immersion in the game world, and challenges that students need to overcome to finish the game. Developers could provide a proper system for evaluating and assessing student progression.

This paper should be used to get familiar with the work done in applying games for educational purposes and as a starting point in implementing technologies from the gaming industry, such as game engines and virtual headsets in the Graphic engineering and design curriculum. After the basic principles and approaches reviewed in this paper, further research should be done to propose detailed guidelines and best practices on incorporating game elements in simulation and combining knowledge from different branches of engineering and the art industry.

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SUSTAINABLE APPROACH TO BOOK DESIGNING CONCEPTS IN BINDERY SECTOR: AN OVERVIEW

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Abstract: *Nowadays, graphic arts bindery sector has shown growing environmental awareness in reaching the targets regarding economic, social, environmental, and technological aspects. Croatian bindery small entrepreneurship sector provides a piece of work done for clients in a sheetfed offset lithographic printing manufacturing which isn't involved in any manner in bindery manufacturing. On top of that, sustainable bindery concepts are strictly related to effective printed resources usage, in which the generated waste is reduced through numerous binding manufacturing activities. In binding sector, designing concepts help achieve less negative environmental impact. Sustainable awareness is beginning from practical work, from preparing plans and a modelling shape, in which the process of designing the three-dimensional book presents its proposed structure on a printed original scale. Bindery eco-efficiency concepts cope with manufacturing service activities, in which the printed paper sheets (or outputs) together with binding raw materials move in a specific direction through the machine operations (cutting, folding, gathering, binding, trimming, joining and surface finishing), which are predictable in edition binding. This study provides a comprehensive overview on how a new approach in book designing might contribute to reducing "non-hazardous" printed or/and bound paper output residuals which gradually appear in a specific way during book binding process. What's more, it offers "eco-friendly book binding", which has "the best book in class" value. This eco-efficient bound production is monitored as well as the indices of graphic arts materials are followed up throughout the working procedures under standardized circumstances. These innovative creative thinking might bring up sustainable engineering solutions or frameworks in which "the business as usual" shifts towards "the eco-friendly business". Eco-labelled printed paper sheets, from Croatian markets, are a sustainable choice which encourages responsible business and leads to zero pollution and circular economy. However, scientists have been worried about the fact that many manufacturing sectors rely on using adhesives with non-renewable resources, which are harmful to humans. Present published literature gives a general overview on the existing advanced adhesives which have less harmful impact on environment, but at the same time have promising performances.*

Key words: bindery concepts, book designing, sustainable eco-engineering solutions

1. INTRODUCTION

European INTERGRAF association supports the graphic sectors competitiveness and recommends environmental indicators which should be included in the calculation of a greenhouse gas emissions-GGE (carbon footprints) of graphic arts products or services (INTERGRAF Activity Report, 2021; INTERGRAF recommendations on CO_2 emissions, 2021). Nowadays, printing industry suppliers sell different types of consumable graphic art materials (paper, toners, inks, adhesives, etc.) globally. The majority of printing arts sectors, in Croatia, consists of small-sized enterprises in need of a simple environment model which is easily applicable at entrepreneurial activities. Hence, the models for calculating carbon footprints need to be accepted through the international approach that is easy to use for entrepreneurs. The general specific indicators enable the entrepreneurs to follow carbon footprints models; to manage the internal environmental graphic arts work and to show and communicate environmental improvements. The awareness of environmental issues within the core industry and their consumers should make a deference between mean value and "value best in class". Hence, the focus of each company is to reduce the waste and carbon footprints energy, which are linked to cost saving and economical profitability enhancement.

The printing paper production and printing process include emissions of volatile organic compounds (VOCs) and hazardous chemical waste, which are identified as an environment load of importance. Hence, it is important to replace them with eco-friendly chemicals whenever possible. The printing methods of lithographic offset and digital printing are worth mentioning because paper-ink interactions show reduced environment load only if the engineering design process is more sustainable, in which waste has reduced impact on environment. It means that sustainable "green" designing of graphic arts products calls upon to use education and knowledge to apply solutions which are sustainable. Hence, it is

vital to think about the life cycle of a printed book product that fulfils more than its basic purpose. New options, which are a great alternative to bookbinding consumable materials (papers and adhesives) offer recycled papers and modified eco-friendly adhesives. Eco-book designing is presented as a technological and material response to practice which helps to improve impact on the environment. Joel Towers said, "sustainable work may mean the use of short-run production methodologies, print-on-demand publications, the specification of recycled papers and non-toxic inks, or the development of end products specifically engineered for reuse within artificial or biological nutrient cycle…" (Towers, 2008).
Sustainable development for the future, in which graphic arts production chain generates less carbon footprints and hazardous waste is complicated for Croatian entrepreneurs. Therefore, "new green" business systems require tailoring work procedures and tools which are strictly used in order to improve the environmental efficiency. So, the individual creative thinking and practical skills combined together, should put creative "green" graphic arts working environment on higher level. In "green business environment" the project context becomes more understandable (Enhroth, 2001), and therefore individuals within a group can create and develop appropriate concepts which are called eco-strategy (Design for environment or Environmental management systems). Furthermore, business operational activities, which refer to superiority in functionality, bring together the key elements (leadership, business culture quality, management system, solution delivery), in which each person can generate greater organization value.
Sustainable book designing is achieved by reducing graphic arts materials consumption and waste (less papers, less adhesives). It is important to implement the knowledge of sustainable designing into practice, convincing clients that organic products have lower impact on the environment. Hence, a contemplated functional bound book designing purpose should be taken into consideration in order to reduce waste. The main material which books designers use is paper, paper industry is the third biggest polluter in the world. Therefore, it is important to use the most eco-friendly papers, possible for book designing. Certified white printing and writing paper labels (FSC, SFI, PCF) help the sustainable forest management without harmful chemical (chlorine-free) waste (Bolanča Mirković et al., 2019; Twin Rivers, 2013). In that way everyone supports the highest social and environmental standards in the global market (Vidmar, 2019). Previously mentioned lithographic offset printing method doesn't used petroleum-based inks anymore because the vegetable-based inks are more sustainable and better quality (Aydemir et al., 2018; Bolanča Mirković et al., 2012). So, green materials have long-term economic significance because they can easily decompose and be recycled. Generally, new solutions provide both long shelf-life and biodegradability of graphic arts products, in which case, waste is minimized and the impact environmental is reduced. On the other hand, multiplied graphic arts job obtains maximum efficiency only if different designing products are set correctly. Another way to ensure sustainable environment impact is to minimize transporting and shipping distances. Croatian vendors in graphic arts industry have environmental certifications, who can`t influence on reduction of carbon footprints because they only distribute products or services from franchisor who established the brand trademarks onto global market. Finally, the maximum shelf-life of graphic arts product is even more sustainable because it reduces the energy which we need to recycle the consumable raw materials. The main benefit of sustainable product designing is global coalition of stakeholders (designers, educators, researchers, engineers, leaders, workers, consumers, vendors) who work together to create positive environmental and social impact (INTERGRAF activity report, 2021). Working together they create awareness, share ideas, and promote sustainable graphic arts solutions. The conclusion is "if you can`t describe the process of production, you won`t be able to put it into practices", each activity or group of activities transform inputs by adding values and providing outputs to internal or external stakeholders. Because of that, Croatian small-sized enterprises attempt to create the unique framework of environment management system that helps them to structure environmental indicators, in which they are going to attain better environment performance and put more focus on products and services. In graphic arts industry, the framework has its own specifics which are related to information and knowledge of current production circumstances and is easy to use although is based on scientific data.

2. SUSTAINABLE ENGINEERING DESIGN PROCESS

Manufacturing technologies, reducing the environmental impact of materials and the management of natural resources are very important. If the production of goods or services are unsustainable environment problems appears. A new focus on sustainable development requires innovative creative thinking (Figure 1). "Business as usual" shifts towards changing our mind, the way we exploit natural resources and enhance a current and future potential to satisfy human needs and aspirations (Koltun, 2010).

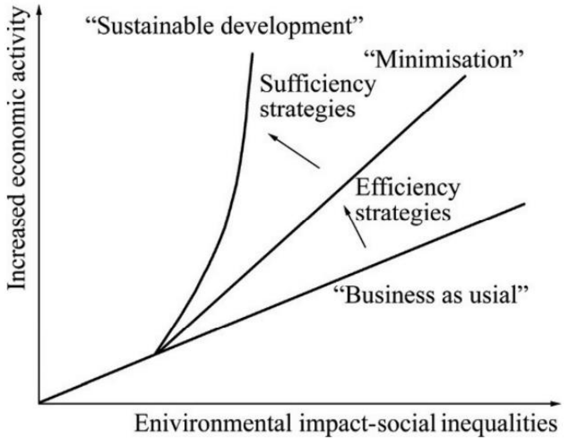

Figure 1: Developing path towards sustainability

Furthermore, practical sustainability is considered regards to collecting data and metrics which will catch three sustainable aspects (cleaner raw materials production, cleaner goods/services production, clean work environment) in which the resources and energy are used in cost-efficient way, producing small amounts of waste and footprints using renewable resources (Figure 2). As previously mentioned, technological solutions bring up sustainable working procedures to minimize the ratio of environmental impact (Koltun, 2010).

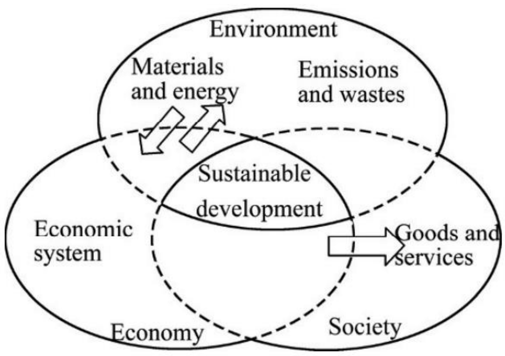

Figure 2: Practical sustainable development model

These industry-specific tools give environmental information on important aspects of engineering and designing (producing and recycling). A checklist is the most common tool which is used by Croatian entrepreneurs when designing and manufacturing printed products or services. The focus of environmental efforts should be kept, the beginning of engineered product designing to the very end, when the product reaches its useful life. Hence, the created environment management system is set up according to entrepreneurs' environment targets, which deals with the total environment impact of manufactured products.

2.1 Designing for Environment (DfE) – Applications of general rules to manufacturing

Design for environment method is accepted the 1990s. It is material indices method in which eco-indicators for sustainable engineering design show specific energy consumption for various materials and specific manufactured products. The Method-DfE is the simple, functional form which takes in consideration into all negative aspects of graphic arts materials have on the environment. Engineering design is oriented towards the environment, the design process must function from its initial structure parts to the final graphic arts product. The process of creating lists of requirements, the process of searching for solutions, evaluating, and selecting solutions to the stage of designed engineering which give new integral approach to developing sustainable product or services. Functions such safety, usability, durability, reliability and cost are noticed as topics into created DfE lists. Furthermore, the environmentally friendly structural graphic arts materials require more analyses of the potential effects of basic phenomena and processes in machines (friction, adhesion, wetting, etc.), consumption raw-materials toxicity, price availability, process-related processing capability and susceptibility to material recycling. This design strategy ensures sustainable development of specific resources for:

- recycling and compatibility,
- minimizing variety materials in the product or its components,
- recovering energy sources,
- minimizing resources in production and transport phases,
- applying structural techniques and materials technologies,
- minimizing total materials volume,
- providing light materials and components,
- minimizing material waste and number of components,
- ensuring cleaner production processes.

After all these demands have been met, DfE method ensures harmless input and output for the environment without hazardous substances. In that way the easy removal of concentrated toxic components is ensured. Finally, this method minimizes consumption of resources during operation, reduces power in partial separated systems, prevents the waste of materials by the users, ensures durability of products and components, ensures product repairing and upgrading, ensures easy cleaning methods and reusability and marks materials with reutilization protocols. This simplified method is a powerful tool that is used internally. However, some logical steps of the analysis can`t be scientifically derived. It is important that DfE method develops various types of ecolabelling schemes for products. That “eco -labelled criteria” strictly improves a products environmental performance which are tailored from created lists. The conclusion is that product development process itself focuses first on creating concepts and making prototypes and finally testing and evaluating various components, products, and business concepts. Hence, these sustainable environment concepts are raised as a result of engineered designing activities.

3. CONTEMPORARY BINDING METHODS

European Publisher Federation (2021) has presented reports from the national book publishing associations for the year 2019. (Table 1), in which 29 national associations are presented. The book revenue of the EU in 2019 was approx. € 22.4 billion with total market value of € 36-38 billion. About 605 thousand new book titles were issued by publishers which is small increase compared to 2018. Digital publishing (in different formats) has been increasing significantly through print-on demand services and the surge in self-publish titles. This report included the entire book value chain including authors, booksellers, printers, designers, etc. Furthermore, the e-book market has shown signs of stagnation for the last 5 years, whereas audio book sales exploded in 2019.

Table 1: European Book Publishing Statistics

	2019	2018	2017	2016	2015
Publishers' revenue from sales of books (€ 22.4 billion)	22.4	22	22.2	22.3	22.3
Educational (school) books	19.3%	19.8%	21.2%	21%	19.9%
Academic/Professional books	18.0%	18.9%	18.5%	18.7%	19.5%
Consumer (trade) books	49.4%	48.4%	47.4%	47.2%	48.4%
Children's books	13.3%	12.9%	12.9%	13.0%	12.2%
Sales by area					
Sales in the domestic market	79.0%	77.9%	78.0%	77.8%	77.1%
Exports	21.0%	21.1%	22.0%	22.1%	22.9%
Sales by distribution channels*					
Sales in bookstores and specialized stores	50.3%	-	-	-	-
Sales in supermarkets and other stores	12.1%	-	-	-	-
Online sales	23.0%	-	-	-	-
Direct sales (incl. libraries and book clubs)	14.6%	-	-	-	-
Number of titles published in period					
New titles	605.000	585.000	610.000	590.000	575.000
Number of persons in full-time employment in book publishing	130.000	130.000	130.000	125.000	125.000
*This section has been reviewed and its data, not comparable to those of previous years, will need time to become more reliable					

Conducted American research for the publishing industry during the COVID-19 crises showed that the industry moves forward slowly, and books are being printed, distributed and purchased. Sales are up for children`s and young adult's books in hardcover and paperback formats. Children are entertained while learning. Book publishing in America changed in digital form of book production, Amazon company increased its market share all over the world showing its winning strategies which is often executed online. Public and academic libraries look for e-books, and therefore publishers must treat bookselling as digital option being first and physical being the last option (Guren et al., 2021). INTERGRAF Economic Reports–Evaluation of the European graphic industry (2000-2023) showed printed product dynamics requirements, in which edition binding products (books, magazines, newspapers, catalogues, advertising, commercial) become less engaging in mass printing production. Hence, the printing processes (sheetfed offset litho, heat set/cold set web offset litho, letterpress) are in decline. Meanwhile, digital printing processes are in the increase as a result of printing on demand services (Reynaud, 2019). Despite extensive advance in electronic communication, in which an e-book takes the first place on the scale, the traditional book still stays unique. That is the most efficient information storage tool, which is guarded in libraries or home shelves. Bookbinding style selection mostly depends on book end usage and the book purpose needs to be categorized in understandable manner to explain its function. Distinguishing binding styles and their activities are very important. In bookbinding, it is important to be able to put together series different graphic arts substrates (blanked and printed fine papers, adhesives, thread, strings, rings, cloth, leathers, etc.). Edition binding style relates to mass-manufacturing, in which book copies are produced at once including certain book edition. Nowadays, edition books have been printed and bounded in short runs on-demand through suitable planning of bindery services. From a marketing viewpoint, paperback editions are more common than hardcovers. For double lower price paperbacks bindery production can be realized, with bulky paper that carries out satisfying book durability. More desirable hardcover editions are fully printed colours on coated papers including thread-sewing and hardcover case in bindery manufacturing. Last but not least, the most expensive edition (bibles, monographies, cookbook, children book) enters a leather-lined flexible binding style with rounded corners and gold stamps. Novelty approaches in bindery process services need to realize customer expectations and create new sustainable binding solutions. Solid book compactness and its easy handling should arise from a well-chosen book designing concept. What's more, planning book concepts in bindery sector should permanently follow new trends of graphic arts raw materials improvements. In those circumstances, the novelty graphic arts engineering solutions would lead to higher environmental awareness. Thus, book engineering has been guided to judge values, limitations and possibilities to improve book performances in accordance with ISO 16763:2016 Graphic technology: Post Press Requirements for bound products and ISO/DTR 19305: Graphic Technology-Framework for TC 130 standards. In addition, specific requirements of graphic products quality, bound book tolerance and intermediate components are listed in the documents (ISO 16763:2016 and ISO/DTR 19305) including

Standards for paper and board, ISO 534 and ISO 536. Converting processes of printed paper sheets or blank paper substrates into end-products are accomplished in binding method, which needs to ensure good bound book performance and appearance as well as desirable endurance for various high-grade papers, from rough to smooth paper surfaces. In addition, declining of paper grain direction disables the correct execution of book construction. The paper grain needs to be lead from top to bottom edge of book, preferentially parallel to binding edge, along bound pages (signatures) of book block. Efficiency of edition binding processes arises as a results of correct imposition signatures designing, in printing sector. Then, the book residuals (printed sheets, signatures, book block, semi-finished book and covers) are included into process stages more than once, which shifts waste disposal to reusing printed book residuals. In addition, graphic arts substrates in bindery manufacturing rely mostly on semi-finished printed products (high-grade papers) which come from printing sector. This kind of paper belong to European Standard grade list EN 643, Group 3: High Grades. It is important to emphasize that semi-finished printed products (bulky, uncoated, coated paper) will have negative impact on the environment if offset inks contain non-renewable resources, which directly decreases eco-efficiency for bindery sector (Bolanča Mirković et al., 2019).

The book designing logically starts in bindery. From binding specification, the best possible folding solutions first must be recommended that build up book block. After that the optimal printed paper sheets dimension should be determined. Finally, the correct imposition of signatures should be created and presented through 3D dimensional book model. That engineering approach achieves reducing printed paper residuals of signatures/covers, which gradually appear throughout binding manufacturing. This unique approach in book designing is appropriate for different binding method solutions in that way bindery eco-efficiency will be realized if everyone in graphic arts production follows references which are presented in the international standardized framework. A sustainable concept in designing book construction searches for innovative solutions in advanced paper substrates, adhesives, printing substrates (leather, cloth, plastics, etc.) for various converting processes as well as their options of waste recycling and recovering. Nowadays, the usage EU Eco-labelled grade papers and modified eco-friendly adhesives should provide a more reliable recycling process of printed and bound-book residuals, which are generated in large quantities as technological waste during the edition binding manufacturing. Such advanced materials should make crucial improvement in function optimizing, as well as create advanced acceptable end-of-life solutions (Vukoje et al., 2022). In addition, generated technological waste during edition bookbinding, might be neglected only if the advanced materials (EU Labelled paper, eco-friendly adhesive) with their engineered properties increase the productive capacity, which enables small-sized enterprises to develop in a short period of time. One can conclude that intention of book designing starts primarily in bindery sector, long before its existence in graphic arts pre-press or printing sector. Standardized concept approach means a conversion of printed paper sheets into book products by the desired results are achieved. The usability and durability of a book relate to performance and its functional effectiveness which graphic arts engineer (producers) and clients with stakeholder supports together. Different approaches in designing of book construction outside the given graphic technology framework, might show shortcomings at the very beginning of book production. On the other hand, innovative version of book designing might contribute to the improvement of existing standardized production processes. Accordingly, sustainable eco-paperbacks would have an advantage in global market if eco-labelled printed high-grade papers and the novel bio-based adhesives considerable improve production efficiency, especially if eco-friendly adhesives show compatibility with different substrates which are applied in bindery sector.

3.1 Sustainability in Bindery: Engineered Design Concepts

Full-service bindery sector is the backbone of the printing sector in which binding equipment allows transforming printed outputs into soft cover books (paperbacks). From cutting, folding, gathering, binding to trimming, where the services are handled to ensure efficiency binding procedures with three adhesive options. In perfect bound method (Figure 3), the pages and cover are glued together at book spine using a strong flexible synthetic polymer adhesive (EVA/PUR hot melt). The other 3-sides of a book are then trimmed and given clean "perfect" edges. This bindery method permits about approx. 5 to 50 mm book thickness and demands greater inside book margin (extra white space) because the pages are not only harder to open but also limited by book length. Acceptable binding units are the signatures that consist of minimum of 4 pages to maximum 32 pages or single leaf, regardless of what kind paper is used. PUR adhesive offers superior adhesion in comparison EVA hot melt. A perfect bound book is lightweight and flexible, its laminated soft cover ensures the paperback usability and durability. Furthermore, the perfect bound method is more cost effective than hardcovers, which allows consumers to create high quality printed products on a budget. On other hand, hardback books are bound with stiff material like cardboard that is covered with cloth or leather. Hardcover binding method gives a more durable solid bound book. It is more expensive than paperbacks, uses high grade wood-free "fine papers" marks and its quality corelates to book intention. The average shelf life of paperbacks is much shorter than hardcovers. Therefore, the book life span strictly depends on its physical conditions. High grade wood-free bulky paper, which contains more than 10% mechanical pulp, is mostly represented in belle letter paperbacks mass production. The digital electrophotographic printed books on-demand and printed books in lithographic offset technique in mass production are commonly used around the world. EU standard of high-grade papers is more undesirable due to significantly polluted environment. These are blanched solutions of alkaline chemical pulping processes, in which wood component lignin, on virgin cellulose fibres, is dissolved. Nowadays, unfavourable pulping processes are replaced by more sustainable ones, in which pulping processes spend significantly less energy and water and show reduced carbon footprints. These processes use recycled consumed papers, in which virgin cellulose fibres are added. These sustainable certified raw materials paper FSC®, PEFC™ and "Blue Angle seals" are selected as eco-labelled papers. As such, they need to be used as much as possible in bookbinding mass-production and on-demand. From ecological point of view, these environmentally friendly-books production on recycled eco-labelled fine papers provides sustainable forestry management on the global market, in which fine papers are manufactured from responsible wood sources that are 100% traceable (Sustainability in Publishing, 2021; Bolanča Mirković et al., 2019).

Paperback edition books are widely represented in bindery sector because they play an important role in contemporary education and find their riders more easily. It explains why publishers release a large number of paperbacks at once to bring the cost per bound book unit down. However, lots of them don't get sold, and end up in recycled paper for other uses. The lower negative environment impact can be avoided though sustainable reading in digital environment (e-reader devices) which has lower carbon footprint and chose sustainable printed book solutions (Dasović et al., 2015; Gašparić et al., 2018).

The publishers print books on-demand (Figure 5) and printed when a customer places and order and the publisher supply chain start book manufacturing with reduced waste. These efforts of "green" processes and supply chains produce significantly less cost and carbon footprints per book than traditional lithographic offset printing processes. Working to incorporate more recycled materials (eco-labelled papers) into supply chains is vitally important for reducing consumption of the graphic arts materials; electrophotographic toner, electricity and overall carbon footprints which are required in books manufacturing. In that way, publishers give a customer a choice of what to read and how to read in a more sustainable way. Commercial perfect binding system provides a wide variety of binding capabilities in large production runs (Figure 4). Office bookbinding systems, on the other hand, generally involve manual intervention and provide relatively few binding capabilities but it is significantly less expensive to set up and operate than commercial, even for short on-demand production of only a few books. That system has limitations in handling of certain paper weights and sizes and its maximum paper format 320x460 mm. Such book is limited by book trim sizes, binding types, and certain shape of binding units (single leaves, signatures), (Figure 5), (Cobene et al., 2003).

Nowadays, eco-labelled papers are popular and widely used, while non-toxic (eco-friendly) adhesives are still being explored. Both are used in eco-friendly book manufacturing and overall reduction in used graphic arts materials. Digital commercial electrophotography "laser" printing increase in market share; its strong potential for the future is ensured by dry toner that enables 4-color production onto uncoated and coated fine papers including eco-labelled papers. Furthermore, it is more sustainable in comparation to lithographic sheet-fed offset printing technique (Vukoje et al., 2022) because "laser" digital prints are usually well deink-able (Vukoje et al., 2018; Sönmez et al., 2018).

Thermal adhesive is a major pollutant in book productions due to hazardous VOCs emissions during its application on book blocks (Figure 6). New strategies for eco-friendly gluing are non-toxic adhesives for perfect binding method. The wide range of thermal adhesives are developed for modern (edition) bookbinding. These synthetic polymer adhesives are100% solid thermal materials that are applied in a melted state. Such spine adhesive is applied on each single leaf in a book block of paperback, as well as on the spine tread-sewn book block of paperback that consists of signatures as binding units (Figure 4). Polyethylene vinyl acetate (EVA) is a base of hot melt adhesive which is currently uses in commercial and on-demand (edition) binding manufacturing. That one-shot adhesive for paperbacks is preferable in binding principle like milling (with signatures as binding units) and notches (with single leaves as binding units), (Figure 4, Figure 5). Thus, thermoplastic EVA hot melt adhesive shows very fast setting speed, gives the distinct advantages of being extremely high tack with widest possible range of uncoated high-grade papers and eco-labelled papers. Thermosetting polyurethane reactive (PUR) hotmelt adhesive, on the other hand, in presence of moisture, enables crosslinks and forms a tough skin which resists re-melting, giving high resistance degree far beyond EVA hot melt adhesive. In contrast to eco-labelled widest range of papers substrate, the synthetic PUR hot melt adhesives are not recyclable; they are elastic and are fully incorporated into book spine and some become an integral part of paper stock fibres. Luckily, elastic PUR hot melt adhesive is preferred with widest range of high-grade papers only in commercial perfect binding systems and long production runs of books manufacturing. The largest pollutant in bindery sector is paper sheet residuals which arise during the trimming process. Like electrophotographic dry toner in digital printing, PUR hot-melt adhesive is considered difficult to remove during recycling process. Hence, it is particularly important to approach designing book constructions in a way which should be more sustainable and corelate to optimal edges size of trimming (Clark, 1994).

As previously mentioned, sustainable engineered design concepts involve specific knowledge, skills, and experience in choosing binding style solutions which should be in accordance with book block and cover construction. Books shelf-life defines the choice of paper substrate, adhesives, and add-on bindery supplements. The rule is that a cheap book should be bound economically; the converting styles and book decorations should be consistent with book purposes and matched with graphic arts materials; and the book should have preferable, durable, and usable binding construction. Contemporary binding styles and methods need to be continuously up to date with new environment strategies and goals which should be realized through implementation of advanced "eco-friendly" graphic arts materials, which directly contribute to eco-efficiency in binding production. Thus, moving from traditional book productions towards circular economy is crucial, bindery sector must improve waste and materials management, and the issue related to the problem in synthetic polymer (PUR, EVA hot melt adhesives) waste accumulation can be minimized (Vukoje et al., 2021).

Note 1: The rectangles present inputs and outputs in post press.	Note 2: The rhomboids present processes in post press.	Checklist for DfE method in post press.
A: printed paper sheet-fed processing (book block, cover) EN643/G3 B: signature (folded printed sheet) C: book block D: semi-bound book product E: bound book product	0: cutting: knife principle I: folding "right-angle" principle + I^1 pressing II: gathering signatures into "multi-layer" block III: perfect binding method: joining block and cover IV: 3-sided trimming ISO 12637-4:2008	Potentially hazardous waste: 5 Smiles Hard recycling waste: 4 Smiles Partially recycling waste: 3 Smiles Recycling waste: 2 Smiles Neglecting waste: 1 Smiles ISO 16759:2013

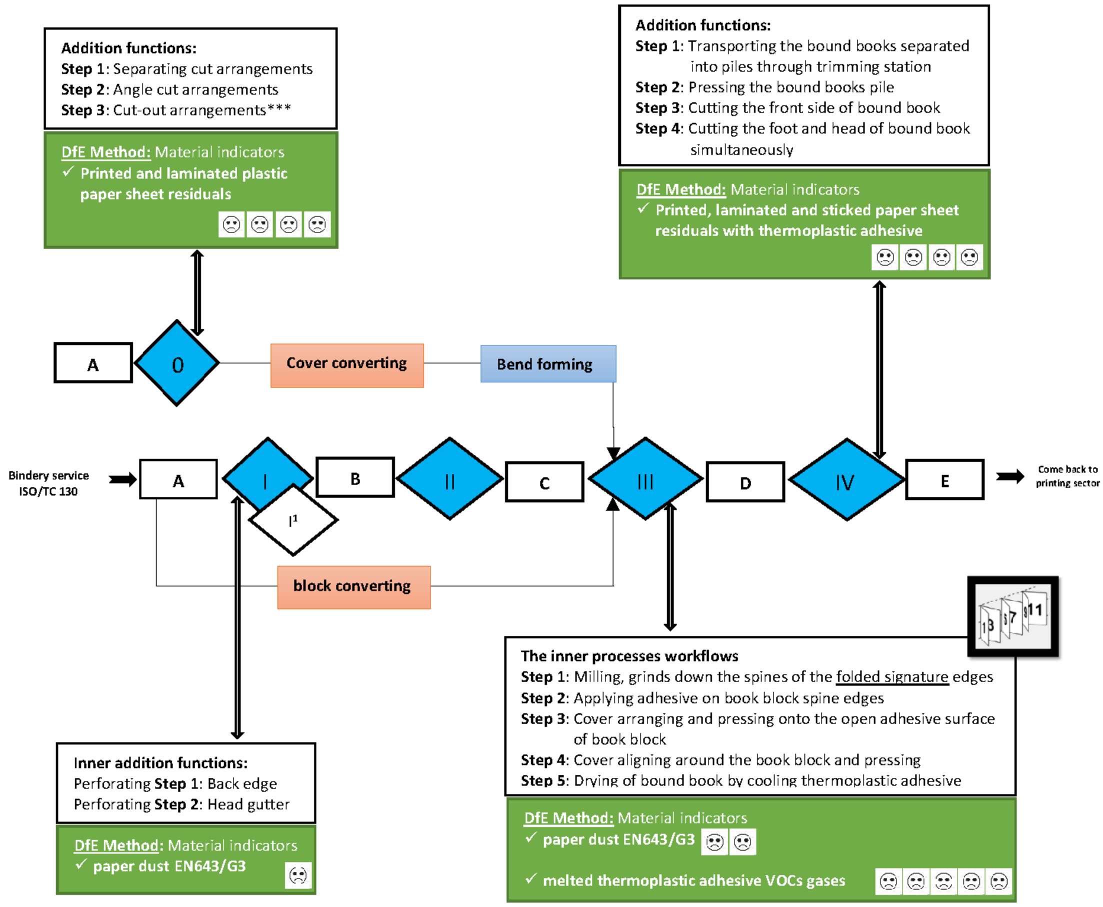

Figure 3: Processes with inputs and outputs in perfect binding workflow connected and capturing environmental impact of graphic arts materials (mass-bound book production)

DfE method guidelines give sustainable approach in binding manufacturing, in which application of non-renewable graphic arts materials should be minimized. Thus, amount of waste materials (residuals) created in production processes should be avoided, optimizing energy workflows in manufacturing must be required and amount of kraft paper for paperbacks packaging must be reduced (Euro pallets is preferable in mass production). Furthermore, designed book construction must stimulate sustainable behaviour throughout paperbacks optimized lifetime or increased its life span. It means that paperback is easier to repair and maintain, which prolongs its lifetime. Extended lifetime of bound book components (book blocks, covers) must decrease a need for new ones. Hence, remanufacturing possibilities are important throughout hierarchical and modular structure, using detachable points and standardized joints with minimized movements. Finally, the usage of virgin materials should be replaced with recycled ones, which are offered on the local market. On the other hand, we must mark all bound book products that consist synthetic materials with standardized materials codes. In Figure 6, the environmental impact comparison of graphic art materials is not significant in bound book productions. It is noticed that synthetic polymers (toner, EVA hot melt adhesive) have negative environmental impact. That problem could be avoided if the book construction is designed correctly, and the trim edges of paper residuals are minimized. On the other hand, the VOCs emission cannot be avoided due to non-renewable adhesive components in EVA hot melt adhesive. It is potentially hazardous waste, and therefore must be marked on DfE list as synthetic material. The Croatian small-size entrepreneurships in bindery sector should move towards replacing it with more "eco-friendly "adhesives that consist renewable raw materials. This is the right way to achieve sustainable edition bound book manufacturing that corelates to waste management.

Note 1: The rectangles present inputs and outputs in post press.	Note 2: The rhomboids present processes in post press.	Checklist for DfE method in post press.
P^A: High-grade paper sheets, size: 320x460 mm, EN643/G3 A^1: printed paper sheets: book block imposition A^2: printed paper sheets (cover) C: book block D: semi-bound book product E: bound book product	0: cutting: knife principle I: digital printing + I^1 gathering printed paper sheets III: perfect binding method: joining block and cover L^{A2}: laminating printed paper sheets - cover ISO 12637-4:2008	Potentially hazardous waste: 5 Smiles Hard recycling waste: 4 Smiles Partially recycling waste: 3 Smiles Recycling waste: 2 Smiles Neglecting waste: 1 Smiles ISO 16759:2013

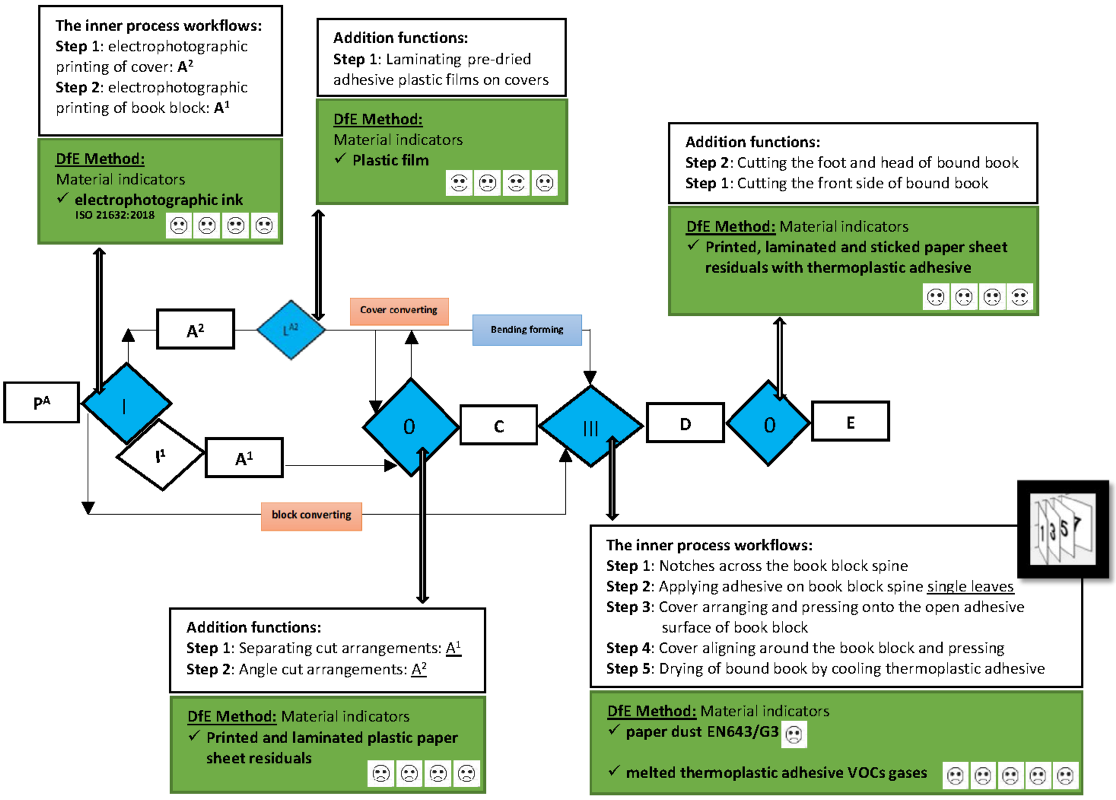

Figure 5: Processes (inputs, outputs) in digital printing and perfect binding workflow connected and captured through environmental impact of graphic art materials (on demand book production)

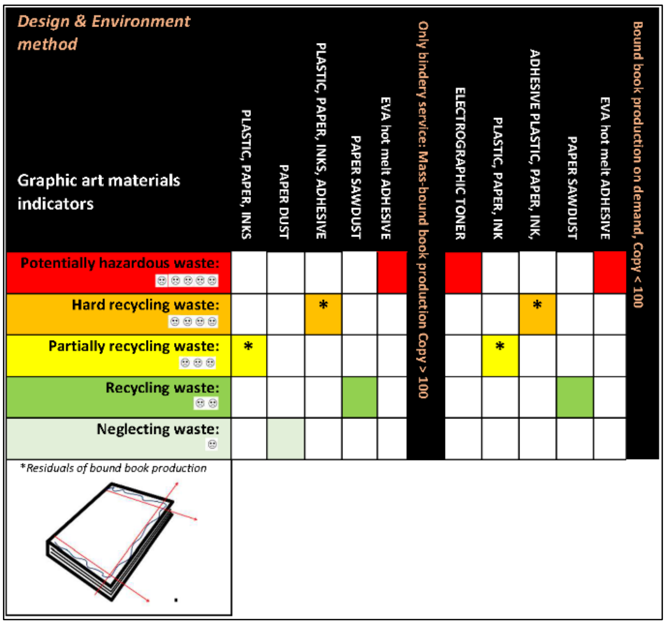

Figure 6: Comparison environment impacts of each included graphic art materials in bound book production

Technical carrying out of a bookbinding plan can't be achieved without skills acquired through experience and education. Theoretical and practical understanding permanence of graphic arts materials as well as converting them in binding technology workflow are extremely important during designed construction of bound book (book block, cover). Lack of knowledge and insufficient information about advanced graphic arts materials (paper, adhesive) and recently developed binding technology equipment could lead to lack of success. There are some rules for choosing high grade papers that lead to favourable book manufacturing. The nature of graphic arts materials includes produced raw materials manners which should be arranged to establish converting solutions, in which materials are able to remain chemically and physically stable over a long period of time. This knowledge and practical experience support correctly designed construction of bound book. The designing is observed through its volume and book block opening manners, by which pages create a harmonious book body. In that way, the pages in the central part of a book forms a layer on each side of the book, which grows in the middle and fall slightly the edges. Thus, smooth page scrolling is possible if the back (spine) of a book block is flexible. In that case book permanence is insured as a result of properly designed construction of block spine. The binding strategies provide the proper choice of graphic arts materials (paper, adhesive) that give optimal book endurance in accordance with its shelf-life. In the end, the binding costs should be strictly planned. The time binding manufacturing and graphic arts materials choices always must correspond to the real need of bound book products (Dasović et al., 2015).

Present published literature gives a specific overview on the existing bound book performance in accordance with the usage of different high-grade papers and adhesives. The overview of designed construction of paperback is given in Jermann`s studies. High-grade papers (uncoated, coated) are observed microscopically, and differences are noticed while having the book opened. Coated paper tends to peel due to poor adhesion between the surface coating and the paper substrates. Using rigid EVA hot-melt adhesive prevents the book to be opened properly, adhesive is solid and build thick film on paper substrate, which affect control of book block spine. This problem could be handled with paper drape performance. If paper drapes well, rigid EVA adhesive is an excellent choice in bound books mass production. Contrary, coated paper doesn't drape well, hence rigid EVA adhesive attempts to control book opening. Thus, drapability, adhesive-ability and cohesiveness describe paper performances to be bound with adhesive. Well-chosen binding solution ensures bound book usability and durability. Coated high-grade papers have higher potential energy on adhesive line, making page scrolling more difficult, and causing the book to open less easily. Understanding adhesive manners is important in the designed construction of block spine. Adhesives have different effects bond with different paper substrates. It means that adhesive thickness and elasticity directly affect block spine moving. If adhesive isn't flexible (rigid), the book doesn't tend to open easily and under loading adhesive often cracks. Book spine moving properties must be controlled with adhesive thickness layer on block spine (Jermann, 2008; Pál et al., 2018). Furthermore, book block sizes correlate to paper stiffness; increased paper basic weight prevents the book to open more easily and causes adhesive crack (Bracić, 2017). Increased roughness of high-grade papers affects faster bonding, which ensures reliable mass production of paperbacks with rigid EVA hot melt adhesive (Pasanec Preprotić et al., 2012; Pasanec Preprotić et al., 2010; Pasanec Preprotić et al., 2011; Petrović et al., 2012; Petković et al., 2017). These wide range of uncoated fine papers ensure propriety adhesive bond strength because of its rough surface. Different adhesive layer thickness and different paper thickness of block spine leads to reliable converting processes regardless of the number of copies. In some cases, these papers are preferable to use in craft bookbinding when only a few copies are produced. In craft book binding procedures of designing construction of block spine could be different in choosing adhesive methods (double-fan, rough spine) with single leaves as binding units in book block (Pasanec Preprotić et al., 2012; Pasanec Preprotić et al., 2015; Pasanec Preprotić et al., 2014; Petković et al., 2017).

4. ADHESIVES IN BINDERY: SUSTAINABLE APROACH

Nowadays, green technology means using various natural raw materials which are put into adhesive solutions. Those recyclable adhesives directly contribute to reducing hazardous pollutants and technological (output) residuals in bindery sector as well as reducing VOCs compounds emissions, which actually appear in a moment of applying adhesive on spine of a book block during converting procedure. These advanced adhesives lead to zero pollution and circular economy. Eco-engineered adhesive strongly encourages sustainable designing frameworks, it shifts bindery services towards "eco-friendly business". Maintaining advanced adhesive consistency is crucial in converting processes. "Eco designed" adhesive solutions should bring optimal results, including graphic arts materials throughout converting procedures which reduce bookbinding costs. It means that its prescription is able to provide converting quality standards (ISO 16762, 16759, 16763, ISO 20690, 21632) including specific graphic arts materials (papers, plastic, clothes, leather, etc.) which are used in bindery manufacturing (on-demand and in-line). The range of no-renewable synthetic hot melt adhesive resins are derived from petrochemicals. These resemble natural resins which can be tailored to meet adhesive bookbinding requirements. Thus, in irreversible process, thermosetting resins become insoluble after being heated at certain temperature. On the other hand, thermoplastic resins soften and melt when heated, and solidified again when cooled. Softening and solidifying are reversible processes that can be repeated many times (Nugusse, 2019; Eckelman, 1977). The reversible hot melt adhesives` main advantage is the short time in which bonding is achieved (Polkowski, 2015). The synthetic resins are thermoplastic ethylene-vinyl acetate copolymer (EVA) that are melted and applied on a spine of a book block while they are hot, and the adhesive bonds are hardened simply by cooling. Opposite to reversible, the irreversible adhesive binds to paper and hardens by a chemical reaction of the resin components in the adhesive. That irreversible process provides crosslinking reactions that forms the adhesive bonds which are triggered by external impulse of moisture to polyurethanes. Thanks to chemical reaction, reactive polyurethanes (PUR) hot melt adhesive provides durable and flexible adhesive-paper bond permanence under extreme temperature and moisture conditions (Heinrich, 2019). Generally, PUR hot melt adhesive assures the excessive stresses and maintains paperback block spine integrity as a result of strong chemical bond of adhesive with paper substrate, in which adhesive still remains flexible and no matter what the paper performances are (drapability, adheseability, cohesiveness). It also enables binding printed semi-product sheets without limitation (Brockmann et al., 2009). In fact, bindery service is able to ensure favourable edition perfect (adhesive) binding solutions including digital sheet-printed and litho sheet-fed printed semi graphic arts products. Comparing PUR with EVA hot melt adhesive, reversible thermoplastic adhesive has limitations, its bond-line elasticity can only be increased by adding great amount of EVA copolymers into thermoplastic adhesive.

In edition perfect binding manufacturing, the spine of binding units (signatures and single leaves) into book block are milled-off (signatures) or notched-off (single leaves), after grinding, the block spine of single leaves is bound with hot melt adhesive (Figure 4 and 5). The exposed paper fibres on block spine are imbedded into hot melt adhesive after paper dust is removed first. In converting procedure, thermoplastic EVA adhesive gives favourable resistance, thermal stability and reliable bonding permanence only with rough (highly cohesive) uncoated fine papers. The resin EVA copolymer properties influence on intensity of bond line strength, while the proportion of additional ingredients (tackifiers, oils/waxes, fillers, antioxidants, inhibitors) in the adhesive affect initial adhesion force and viscosity.

Usage petrochemical raw materials in hot melt adhesives (PUR and EVA) should be replaced with more sustainable raw materials in which edition perfect binding method is performed. In bindery sector, Croatian small-sized enterprises should take an interest in and support circular economy. Unfortunately, petroleum resources in current adhesive formulations prevent returning raw materials into the loop. Turning converting residual waste from edition paperback manufacturing back into valuable raw materials resources could run through changing business strategies toward more sustainable "eco-perfect binding solution", in which bindery sector significantly support eco-friendly initiatives and campaigns to producing the new high quality eco-labelled papers, which are recycled with effective mechanical and optical properties (Vukoje et al., 2018). Generally, eco- book design manufacturing concepts would contribute to creating novel approaches to improving converting procedures. The first is a melting adhesive without VOCs emission and the second is optimally generating amount of waste residuals that would significantly improve eco-efficiency in bindery sector. Generally, there are benefits to synthetic polymers in hot melt adhesives (PUR, EVA) derived from the renewable ones. Thus, the end-of-life scenario of synthetic adhesive is similar to printing inks. Adhesive is a small component that makes up the final bound book product. Fort that reason, adhesive would be compostable or recyclable like standard high-grade paper substrates. In a certificated compostable or recyclable standard process, adhesives are recognized as contaminants which remain in compost or standardized recycled eco-labelled papers. Small particles of synthetic resins occur in repulping environments; these "stickies particles" cause defects in standardized paper products through reducing mechanical and optical properties of recycled paper. The next challenge in bindery sector is to assure eco-adhesive permanence and to establish the full attachment of adhesive to exposed paper fibres on book block spine. Appearances in eco-adhesive failures are its weak bond with paper substrates and the effect of eco-adhesive which breaks apart by leaving its residuals on the paper substrates. In edition perfect binding manufacturing, the attention is to avoid appearance of paper cohesive failure as result of shorter fibres in recycled paper. As previously mentioned, the advanced engineered eco-adhesive formulation should lead to performing favourable bonds which occur at the interface of adhesive and paper substrate. The forces that develop at interface define thermodynamic work that determines the work of adhesion. Durable and strong adhesive joint performance could be reached by favourable mechanical properties of adherends (paper and adhesive), the residual internal stresses, favourable degree of interfacial contact and the joint geometry. A book design engineer has to reduce stress concentrations and the loaded stress should pass across the whole bonded area of the block spine. It is important that adherends are flexible under loading, whereas the rigid bond often finishes with splitting the adherends apart. Hence, certified paper adherend details and adhesives should be inspected and tested long before the bound book manufacturing began. The key to success is to achieve reliability and repeatability of adhesive bonds to using certified recycled paper substrates (Rbnesajjad, 2008). From the environmental point of view, conducted studies showed that petrochemical-based polymers can be replaced by biomaterials (modified starch, cellulose, lignin, chitosan). Vinneth et al. (2020) studied possibilities of developing sustainable thermoplastic adhesives that are renewable, no-toxic and biodegradable. New formulations of "eco-adhesives" offer excellent hot tack with combining of long open time and moderate setting time. However, its bond strength and durability need to be achieved in further research. Heinrich (2019) gave critical review on bio-polymers advantages compared to petrochemical ones. The research presented new functionalities novel molecular architectures which improve adhesive curing speed and adhesive bond strength. Abbas (2020) also presented the overview of examined the synthesis of a novel bio-based polyurethane adhesive with different biomaterials (vegetable oils, bio-poly oils, palm oil, soybean oil) which are easily available and less expensive. The performed research was determined by advanced PUR adhesive that improves competitive performance such as adhesiveness, bond strength, water resistance, thermal stability and peeling resistance. Finally, Magalhaes et al. (2019) concluded in their brief overview research that biopolymers are already large macromolecules, with a high density of functional groups, which lead to higher crosslinking densities. It is concluded that biopolymers contribute to a future society which is less dependent on non-renewable resources with reduced on carbon footprints. That kind of sustainable engineered bio-polymer adhesives are renewable and recyclable. Their advantages are based on ever-improving technologies to ensuring health and safety environment as a result of reduced production of carbon footprints.

5. CONCLUSION

A growingly agile supply chain, including models in-line and on-demand production, responds to market needs for sustainable manufactured solutions and advanced graphic arts product values. The printing sector sticks together with the sector of bindery service that shift towards sustainable concepts of engineering designed book products. Achieving economic growth and sustainable development should be reached by using advanced graphic arts materials like certified recycled paper substrates and bio-based adhesives, which lead towards efficient management of natural resources. Because implementing environmental framework in bindery manufacturing creates opportunities to improving good practices in eco-engineering designing. Sustainable manufactured book products should follow the real consumer needs avoiding books storage through the long period of time. According to the United Nations development program 2022-2025, Croatian entrepreneurs should be more environmentally aware of hazardous non-renewable graphic arts materials and should replace them with bio-based ones, buying certified “eco-graphic arts materials” from Croatian vendors. These practices should integrate sustainable information into reporting cycle, in which the graphic arts offset sheetfed printing sector works together with bindery service. The Croatian government should certainly support the improvement of science and technology capacities and promote more environmentally friendly manufacturing patterns as well as the consumption of “green” graphic arts materials and products. Therefore, the rules and regulations towards more sustainable book products should become a priority in developing the advanced solutions, in which book products are recycled or biodegraded as well as the manufacturing waste being returned the closed- loop. That sustainable designing for the future moves away from a traditional linear book manufacturing to a circular one. The advanced book engineering concepts lead to creating disposal stage of products, creating a new environmentally friendly book product. New sustainable strategies should inspire the engineers to re-think and re-design book products towards a circular economy by improving its efficiency. Life cycle of book product (“from cradle to grave”) goes through many stages, from usage natural resources such as energy and water for producing certified virgin paper to making technological waste, pollutants and greenhouse gas emissions in manufacturing. Thus, transforming graphic arts materials into book products have a negative impact on the environment. Another negative impact on the environment is transport solutions because of which digital bookselling would be more preferable option. Furthermore, it is also important that manufactured book purpose corelates with book function, efficiency, appearance and durability as well as the choice of graphic arts materials (papers, adhesive, accessories) which need to follow the book task. Book disposal at end of its life cannot be explained through what consumers or book publishers do with the produced book. Accordingly, the eco-book designing concepts should make a smart step forward to improving the environment outcomes and reducing costs in the long-term, too. For all of those reason, worldwide Framework for ISO/TC 130 Graphic technology standards should enable the most important stakeholders to take responsible roles to creating the new initiatives for developing sustainable practices which will maintain and ensure natural system solutions which will contribute to higher standards of leaving.

6. ACKNOWLEDGMENTS

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CALCULATION OF CUTTING FORCE BY BOOK-EDGE TRIMMING WITH DISK KNIVES

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Abstract*: The paper proposes formulas for theoretical calculation of forces when trimming book-edges with a disc knife. The theoretical model is based on experimental data obtained by the authors. The authors calculated the approximation parameters from own experimental studies. The kinematic parameters of the cutting process and the approximated value of the unit cutting force were used in the calculation formulas. Calculation makes it possible to predict value of total cutting force depending on diameter and sharpening angle of knife, value and direction of its angular speed, feed rate, thickness and distance of book block from axis of knife rotation.*

Key words: book cutting, circular knife, disk knives, book-edge trimming

1. PREFACE

Paper cutting operations are important operations of printing. The process of cutting paper stacks and books with a circular knife is relatively poorly researched. Krabisch (1962) found that the strength and quality of the trimming of brochures largely depend on the thickness of the block, the feed rate, and the rotary speed and direction of rotation of the circular knife. The main obstacle in using this method for processing thick book blocks is a significant increase in trimming forces and the phenomenon of excessive heating of the knife as a result of rubbing against the paper, which causes local "burns" and deterioration of the cutting quality. Research conducted by Grushevski (1963) confirmed the limitation of the possibility of qualitative trimming of books. Anyway, some of known cutters are used for book-edge trimming and brochure cutting. In order to speed up the process and to select its optimal parameters some additional researches needed.

2. BACKGROUND

Various authors studied the cutting of various materials with disk knives, while various hypotheses about the direction of the cutting forces, about the effect of the transformation of the knife-sharpening angle and about the ratio of the forces of normal cutting and sawing were proposed. As for the direction of the cutting force, two main hypotheses were considered, Daurski & Machihin (1980): the total cutting force is directed against the speed, or the cutting force has two components: the normal force, directed normally to the knife blade, and the sawing force, directed tangentially to the blade. According to the results of our experiments, the first hypothesis is not confirmed when cutting book blocks, since the vector of total cutting force is always directed at some angle to the vector of cutting speed. When applied to a flat knife moving along an inclined trajectory, Reznik (1975) suggests introducing a sliding cutting coefficient equal to the ratio of horizontal force to vertical force, i.e. the ratio of sawing force to cutting force. Obviously, in this case, the sawing force also includes the friction force during the sliding movement of the knife along the book block. In previous papers, the authors have dealt with theoretical studies of the kinematics of the process of cutting book blocks with a circular knife mounted centrally and eccentrically, and published some results of experimental studies of cutting forces, (Janicki, 2020; Janicki, Petriaszwili & Komarov, 2016; Janicki, Petriaszwili & Komarov, 2017; Petriaszwili, Janicki & Komarov, 2019; Petriaszwili, Janicki & Komarov, 2020; Petriaszwili, Janicki & Komarov, 2021; Petriaszwili & Janicki, 2017). This paper attempts to relate the results of theory and experiment and to establish some mathematical relationships between the kinematic parameters of the process and the cutting forces.

3. EXPERIMENTAL RESEARCH

Our testing equipment allowed us to register the change in the longitudinal force *Fx*, transverse force *Fz* and vertical force *Fy*. The studies conducted on the equipment, showed that the value of the vertical component of the cutting force ranges a few percent of the values of longitudinal and transverse forces so it can be ignored (Petriaszwili, Janicki & Komarov, 2021). Figure 1 shows the relationship of the recorded forces *Fx* and *Fz* with the normal cutting force *Fn* and the tangential force, or sawing force, *Ft*. Knowing the values of the registered components of the total cutting force *F*, it is easy to calculate the appropriate values of the normal force and the sawing force (Figure 1).

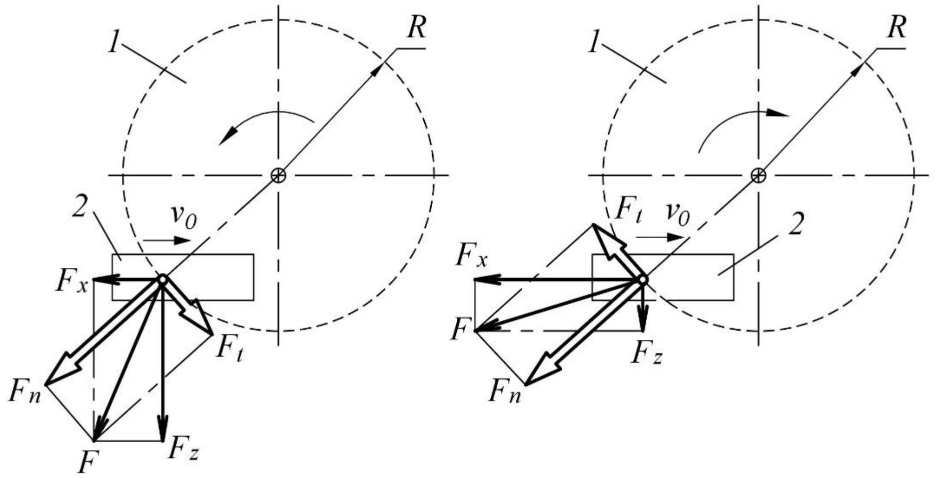

Figure 1: Different representation of the components of the forces acting on the block from the side of the knife during the forward cutting (left) and reverse cutting (right).
F - total cutting force, 1 - circular knife, 2 - book block.

Figure 2 shows typical graphs of dependence of the measured cutting forces *Fx* and *Fz* on the distance to the knife rotation axis. Graphs of normal *Fn* and tangential force *Ft* in the right chart are obtained by means of recalculations according to Figure 1.

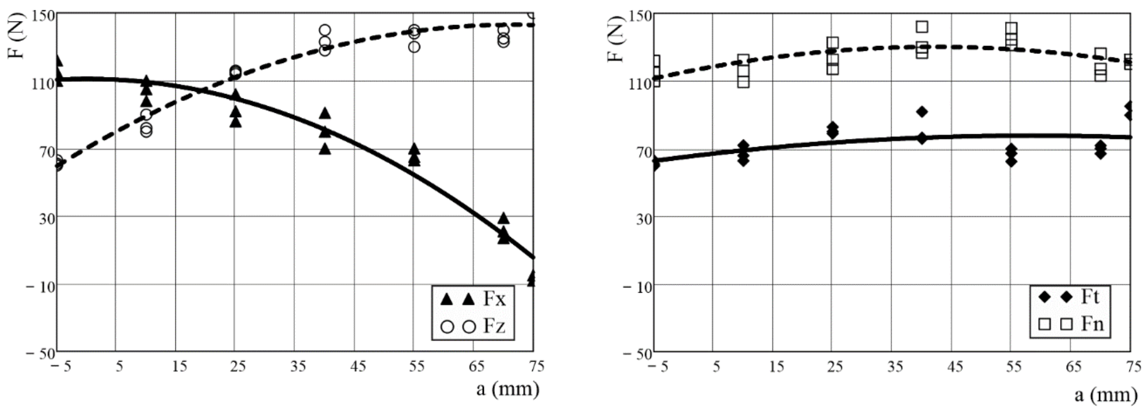

Figure 2: Typical graphs of the dependence of cutting forces on the distance of the middle point of a book block to the axis of rotation of the knife. Left – measured forces, right – recalculated nomal and tangential forces

The result of our experiments showed that the ratio between the tangential force and the normal force, or the sliding cutting coefficient, is an almost constant value for certain conditions. This is evident from the right chart in the Figure 2. Hence, for further research it is sufficient to determine what the normal cutting force depends on. To do this, it is convenient to represent it in the form of unit cutting force, which is equal to the ratio of a value of the normal force to the length of the cut. Unlike a flat knife, the cutting length of a book block with a circular knife depends on the height of the book block and its position relative to the knife rotation axis (Figure 3).

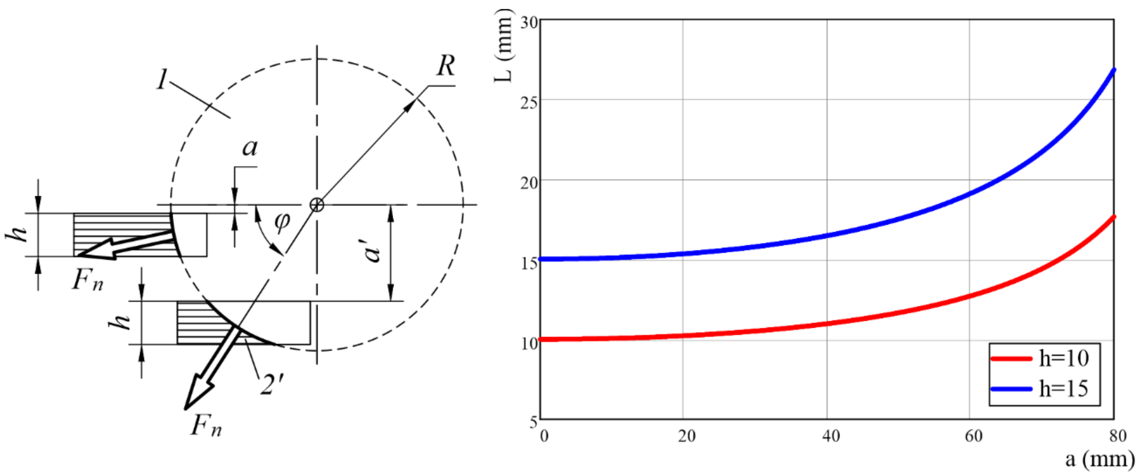

Figure 3: To the calculation of the arc cut length L. 1 - circular knife, 2 - book block, h - block thickness, a - distance to block from the knife rotation axis, R - knife radius. Left – two different positions of a book block, right – cut length depending on the distance a. Knife radius R=98 mm, block height h= 10 mm and 15 mm.

It is known from the studies by Mordovin (1962), that the main factor influencing the value of the unit normal force of cutting into a pile of paper or into a book block is the value of the transformed angle of blade sharpening. For a rotating circular knife, this angle is determined by the formula (Janicki & Petriaszwili, 2015):

$$\alpha_T = \arctan\left[\tan(\alpha_0)\frac{v_0\cos(\varphi)}{\sqrt{[v_R\sin(\varphi)\pm v_0]^2+[v_R\cos(\varphi)]^2}}\right] \tag{1}$$

Where the "minus" sign should be taken for the forward cutting and the "plus" sign for the reverse cutting. The value of the transformed angle depends on the position of the cutting point on the disk knife blade, i.e. on the angle φ, the feed rate v_0, the linear velocity of the blade at the cutting point v_R and the sharpening angle of the knife blade α_0. It follows from Figure 3 that the block position affects not only the cutting length, but also the direction of the normal force and its magnitude associated with the transformed sharpening angle. Figure 4 illustrates the change in the transformed blade sharpening angle at the midpoint of the cut as a function of the distance from the axis of rotation.

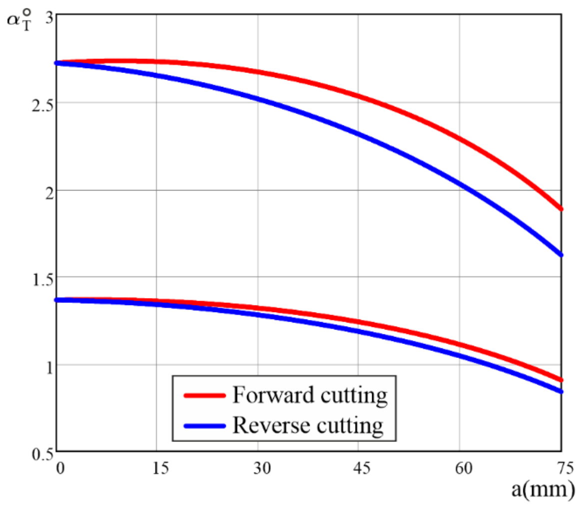

Figure 4: Transformed angle α_T depending on the distance of a book block from the knife rotation axis a. Cutting parameters: R = 98 mm, α_0 = 26 °, v_o = 0,5 m/sec, h = 10 mm, top curves - n = 500 rpm, bottom curves - n = 1000 rpm

As the distance to the axis of rotation increases, the transformed angle decreases, hence the specific normal force should decrease. But the cutting length increases, which in turn should increase the total normal force. As a result, the value of normal cutting force remains practically unchanged, which can be seen from Figure 2. According to the research of some authors, Ginzburg (1957), Komarov & Petriaszwili (1989), the normal cutting force with a flat knife can be approximated with sufficient accuracy by a power dependence in the form:

$$F = K_0 \cdot L \cdot \alpha_T{}^{\gamma} \tag{2}$$

Where α_T - transformed sharpening angle, L – cut length, K_0 and γ – empiric coefficients. Let us define the unit cutting force q_n as the normal force F_n divided by the length of the cut L. The empirical coefficients depend primarily on the type of paper being cut. We apply this approach to the approximation of the normal cutting force for a circular knife. When cutting with a circular knife, unlike a flat knife, the cut is arc-shaped, and the transformed cutting angle changes along this arc. But the thickness of the block is small compared to the diameter of the knife, so the arc of cut can be treated as a chord and the transformed angle - as a constant. For approximation, as follows from formula (2), we need to know the dependence of the unit force on the transformed cutting angle. We obtained the experimental dependences of the cutting force on the block distance to the knife rotation axis (see Figure 2). Let us calculate the value of the transformed sharpening angle and the cutting length for each measured point. Knowing the value of the cutting length, we calculate the unit normal force, take the transformed sharpening angle as the argument, and plot the corresponding dependencies. Figure 5 shows such dependences calculated from the data shown in Figure 2.

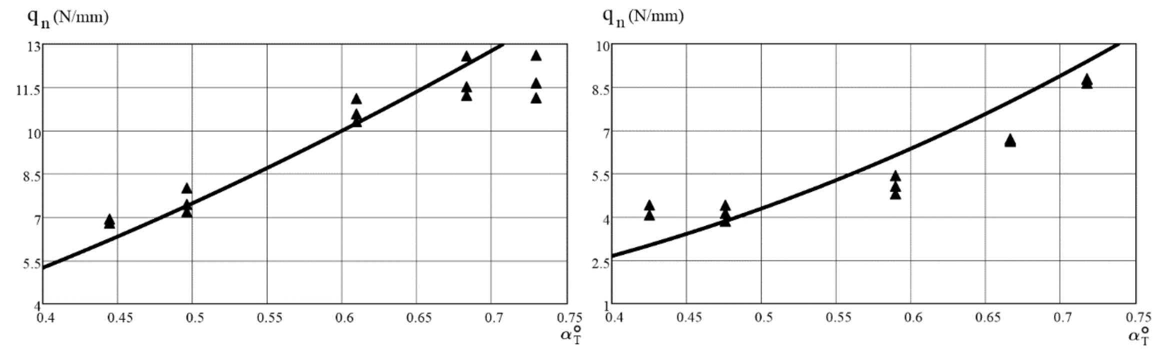

Figure 5: Dependencies of normal unit force q_n on transformed sharpening angle. Cutting parameters: diameter of the knife D=196mm, sharpening angle α_0 = 26 °, feed rate v_o = 0,5 m/sec, knife speed n=1800rpm, block thickness h=10mm, offset paper 70 gsm, left- forward cutting, right- reverse cutting

Regression analysis and approximation by formula (2) were performed by the method of least squares in Mathcad. The approximated values of the empirical coefficients are somewhat different for the forward and reverse cutting and for different feed rates and knife rotation speeds. But this is not essential for understanding of general regularities. In our estimation, the coefficients can take the following values: K_0=19.3 … 22.6, γ=1.6 … 2.2. According to our experiments, the ratio between the tangential force and the normal force remains close to constant and depends on the thickness of the block. As an example, Figure 6 shows the relationship between the tangential and normal forces at different positions of the block relative to the rotation axis of the knife.

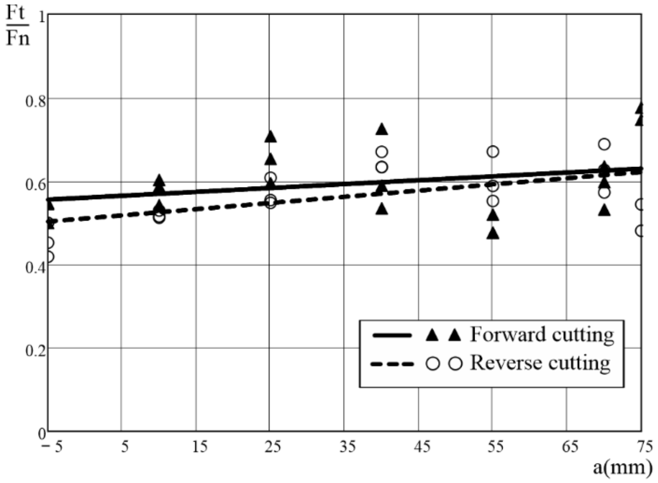

Figure 6: Ratio of tangential and normal forces. Cutting parameters are the same as in Figure 5

4. THEORETICAL CALCULATION OF FORCES

Based on the above, we will make the following assumptions when deriving formulas:

- The book block remains stationary while the knife rotates and moves toward the block at feed rate.
- The total cutting force acting from the blade on the block consists of a normal component, directed along the radius, and a tangential component, directed tangentially to the blade in the direction of the linear velocity of the blade point. The normal component raises due to the destruction of the sheets of paper as the blade plunges in, and the tangential component is equal to the sum of the sawing force and the frictional force.
- The value of the unit normal component of the cutting force depends on the value of the transformed angle of the knife blade sharpening at the cutting point according to formula (2).
- The sliding cutting coefficient is equal to the ratio of the tangential component to the normal component of the cutting force, and is a constant for certain cutting conditions.

Let us imagine a disk knife blade as a set of elementary straight prismatic knives of infinitely small length dl with the sharpening angle corresponding to the transformed angle in the current position of the elementary knife on the blade. Each elementary knife moves along its own trajectory (Figure7.):

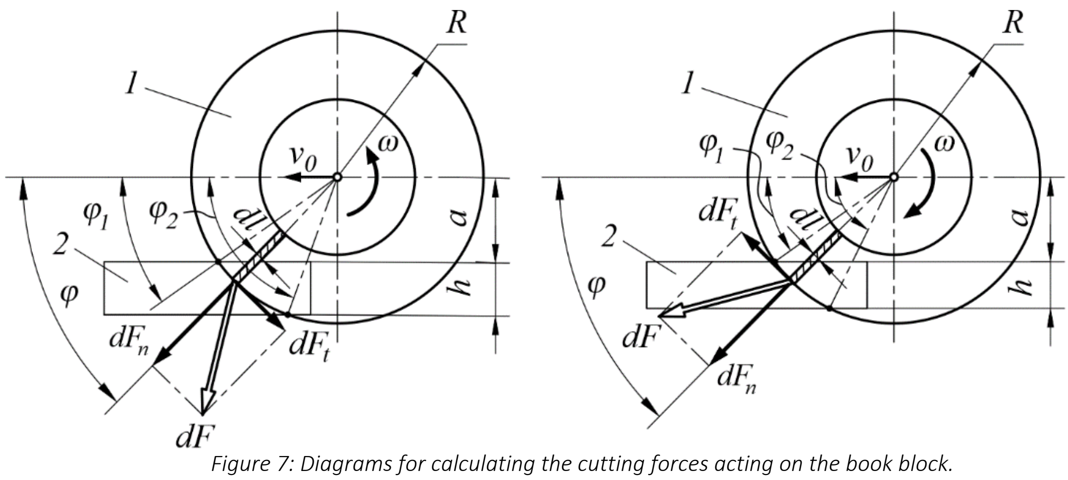

Figure 7: Diagrams for calculating the cutting forces acting on the book block.
1 - circular knife, 2 - book block.Left- forward cutting, right- reverse cutting, v_0- block feed rate,v_R - linear speed of knife points on the blade, φ- angle of the knife rotation, ω- angular speed of the knife, h - thickness of the book block, a - distance of the block from the knife rotation axis

The elementary knife performs oblique-sliding cutting. Let us calculate the elementary normal cutting force dF_n on the blade of the elementary knife taking into account (1) and (2):

$$dF_n = K_0 \left\{ \arctan\left(\tan(\alpha_0) \frac{v_0 \cdot \cos(\varphi)}{\sqrt{[v_R \sin(\varphi) - v_0]^2 + [v_R \cos(\varphi)]^2}} \right) \right\}^{\gamma} dl \tag{3}$$

We express the elementary tangential force through the sliding cutting coefficient *f,* which we assume to be constant:

$$dF_t = dF_n \cdot f \tag{4}$$

To find the total longitudinal and transverse cutting forces, we need to project the normal and tangential components onto the horizontal and vertical axes and integrate the obtained expressions with the angle φ from φ_1 up to φ_2. Let us perform the obvious transformations and obtain the final dependences:

$$F_x = \int_{\arcsin\left(\frac{a}{R}\right)}^{\arcsin\left(\frac{a+h}{R}\right)} K_0 \left\{ \arctan\left[\tan(\alpha_0) \frac{v_0 \cos(\varphi)}{\sqrt{[\omega R \sin(\varphi) \pm v_0]^2 + [\omega R \cos(\varphi)]^2}} \right] \right\}^{\gamma} R\left[\cos(\varphi) \pm f \cdot \sin(\varphi)\right] d\varphi$$

(5)

$$F_z = \int_{\arcsin\left(\frac{a}{R}\right)}^{\arcsin\left(\frac{a+h}{R}\right)} K_0 \left\{ \arctan\left[\tan(\alpha_0) \frac{v_0 \cos(\varphi)}{\sqrt{[\omega R \sin(\varphi) \pm v_0]^2 + [\omega R \cos(\varphi)]^2}} \right] \right\}^{\gamma} R\left[\sin(\varphi) \mp f \cdot \cos(\varphi)\right] d\varphi$$

The upper signs are taken for reverse cutting, the lower signs - for the forward cutting. Integral in formulas (5) cannot be taken in closed form, that is why we carried out calculation by numerical methods using Mathcad. Comparison with experimental data shows, that formulas (5) give a good approximation in a certain range of parameters. As an example, Figure 8-10 show a comparison of experimental data and calculations by formulas (5) for different cutting parameters.

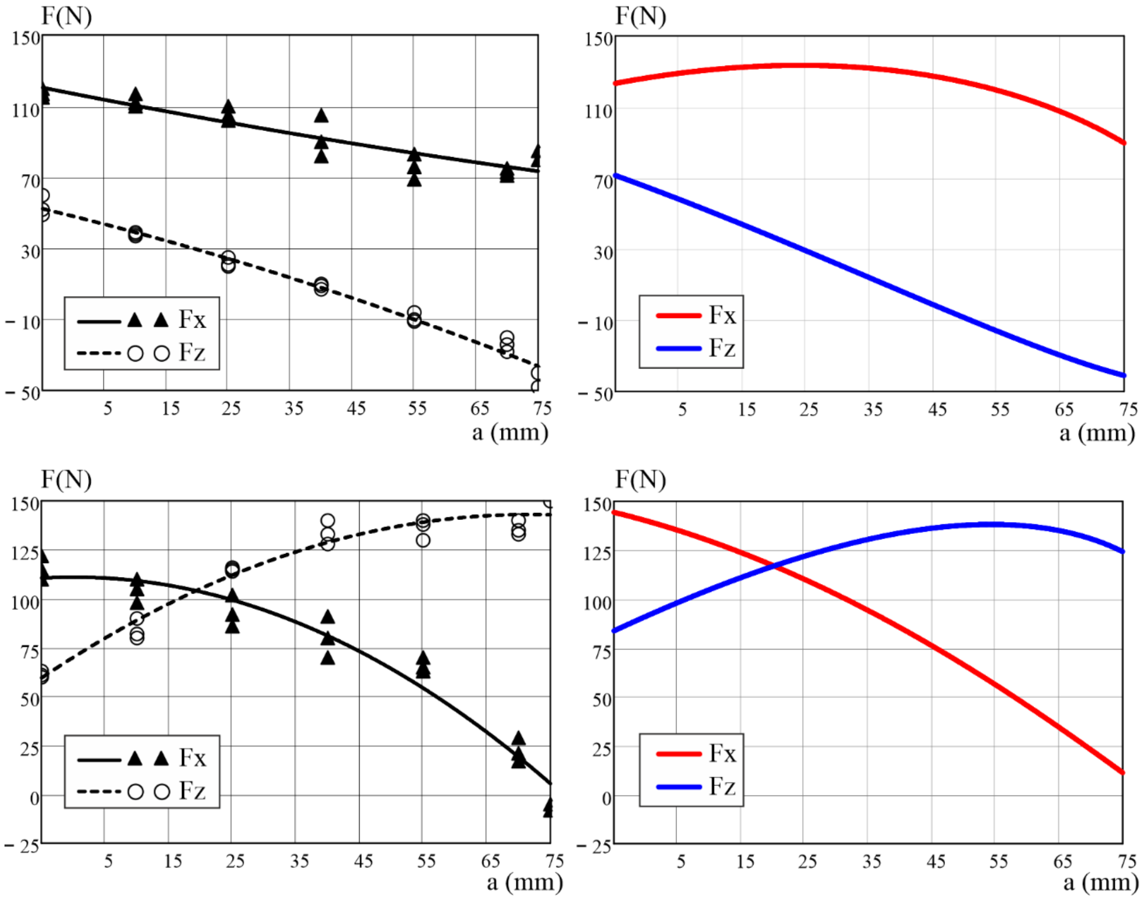

Figure 8: Comparison of the values of longitudinal and transverse forces at different distances of the block from the axis of rotation of the blade. The upper drawings represent the reverse cutting, the lower ones show the forward one. On the left there are results of the experiment, on the right - calculations according to formulas (5)

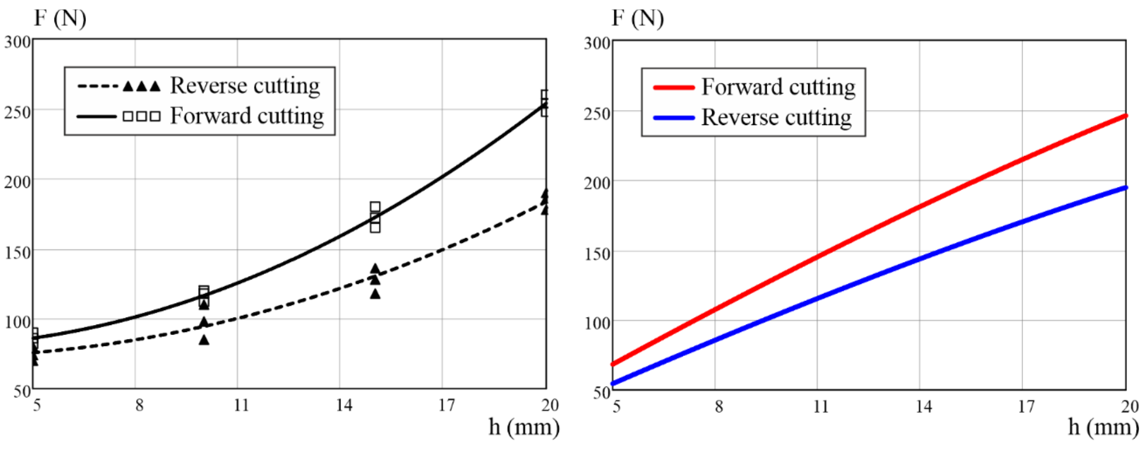

Figure 9: Comparison of the dependence of the total cutting force on the block thickness.
On the left there are results of the experiment, on the right - calculations according to the formulas (5)

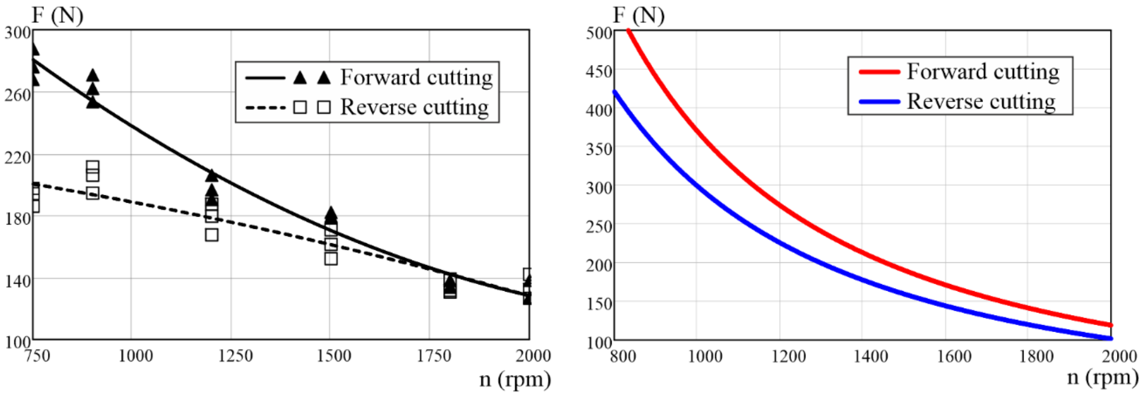

Figure 10: Comparison of the dependence of the total cutting force on the knife angular speed. On the left there are results of the experiment, on the right - calculations according to the formulas (5)

Calculated charts of cutting forces somewhat differ from the charts built according to the measured forces. They differ by value and by form due to the simplified model. But they show trends and common dependencies on different parameters of cuttings. The largest deviation is demonstrated by the dependence on the knife speed at relatively low rpm (Figure 10). However, in the range of operating speeds, the approximation accuracy is quite acceptable. The other dependences show a good approximation.

5. CONCLUSIONS

Comparison of the calculated values of the cutting force with the experimental ones shows a good match of the results in a certain range of parameters. With the help of these formulas, it is possible to study the influence of various settings for the process of cutting a book block with a disk knife with sufficient accuracy. There is no need to perform time-consuming and expensive experimental studies in full.

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THE EFFECTS OF FLATBED CREASING TOOL ON PRINTED PAPERBOARD

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Abstract: *Flatbed cutters are in increased demand and usage due to their developments in tool speed and size of the cutting area. The creasing tool on flatbed cutters are mostly creasing wheels as opposed to flat knives in die cutters. The wheel creases the paperboard in a way that can damage the top layer causing breaking in the printed surface visible after folding and sometimes even before. The end result can decrease the attractiveness of packaging and other creased paperboard products. This paper investigates the results of flatbed creasing of different types of printed paperboard and suggests possible solutions to the problem. Examined paperboards differed in grammage, grade, and thickness, and they were creased with different depth levels. The results indicated that some types of paperboard are not suitable for packaging even if they are adequate grammage. Furthermore, controlling the creasing depths can reduce ruptures of the top layer and improve final folding quality.*

Key words: Creasing tools, flatbed cutter, damaged print, packaging, folding

1. INTRODUCTION

The most common type of creasing in packaging production is die cutting This type of production is widely used due to its high level of automation and a large amount of cut and creased sheets in a short amount of time. The downside is that each packaging needs its own die-cut plate and counterplate template production. This becomes a problem when there is a need for a smaller production amount due to limited edition packaging, promotional packaging, custom packaging smaller selling possibilities. Then most packaging producers opt for production using flatbed cutters. The main difference is in the creasing tools used. Die cutters use creasing rulers (stationary tool) and flatbed cutters use creasing wheels (rotational tool). One of the other production differences is the result on the back of the paperboard. Die cutting form has a counterplate with groves for the creased paperboard to indent while flatbed creasing has a fleece background that allows the wheel to slightly impress in the sheet. This way die cutting form results in a better creasing formation on the front and especially on the back of the unfolded packaging sheet (Leminen et al., 2019).
Paperboards have multiple layers depending on the type and grade of cellulose, coatings and fillers. Mainly paperboards are made up of three layers: top, middle and bottom layers (Nygårards et al., 2005). The middle layers mainly contain the bulk of the material and carry the main structural weight of the material. The outside (top) layer usually is prepared for printing. Because different types of printing technology need certain properties for accepting printing ink some paperboards are not for universal use across the board. The paperboard making process and the cellulose used makes the material extremely anisotropic (Nygårards et al., 2005). Another factor that influences the material properties is permeability to water vapor. Higher levels of water vapor can decrease the structural stability of paper. This disadvantage makes finite models difficult to develop. There are some attempts published but are mostly for commercial use (Beldie et al., 2001; Fadiji et al., 2018; Huang & Nygårds, 2010; Luong et al., 2019; Marin et al., 2021; Nygårards et al., 2005; Nygårds et al., 2009; Park et al., 2020). The found models are mostly for die-cutting tools so there is an under researched category of creasing on flatbed cutters. Higher demand for limited edition and/or customizable packaging increases the need for research on the creasing properties of flatbed cutter results. This paper investigates the results of flatbed creasing of different types of printed paperboard with three different levels of creasing height. The researcher sheets will be printed on a laser printer which is most common for small issues of packaging which correspond with the researched creasing problem. The paperboards that demonstrate breakage of the top layer will be laminated with polyethylene (PE) foil as a possible solution to the problem. This solution is based on research from Andersson and Fellers that demonstrated increased Z directional properties of paperboard (Andersson & Fellers, 2012).

2. METHODS

2.1 Materials

The available paperboards for testing (DIN graded) are commonly used for printing paper with higher grammage. Paperboard specifications, and grades (according to DIN Standard 19303 "Paperboard - Terms and grades") are seen in Table 1. The paperboard was conditioned according to the ISO 187:1990 standard at a temperature of 23°C ± 1°C and humidity RV 50% ± 2% before and during the process of forming packaging samples.

Table 1: Paperboard sheets specifications

Paperboard name	grammage	DIN grade*	thickness	manufacturer
Incada Silk	240 g/m^2	GC1	365 µm	Antalis®
Incada Silk	280 g/m^2	GC1	445 µm	Antalis®
Maxi gloss	250 g/m^2	N/A	184 µm	UPM
Maxi gloss	300 g/m^2	N/A	225 µm	UPM
Maxi offset	250 g/m^2	N/A	275 µm	UPM
Maxi offset	300 g/m^2	N/A	330 µm	UPM

**DIN Standard 19303 "Paperboard - Terms and grades" (Publication date: 2005-09)*

2.2 Samples

Paperboards were obtained and printed with Xerox Versant 2100 Press in a local print studio. Xerox Versant 2100 Press printing machine was used for A3++ (229 x 483 mm) format sheets. All sample cutting layouts were prepared using EngView Packaging and Display Designer Suite software and cut on a Zund M-800 flatbed cutter/plotter. For cutting layout sheets a Z10 drag blade was used and a creasing wheel C203 with a diameter of 15 mm, a width of 0,7 mm, and a depth of a maximum of 1 mm. Which, according to previous research, is most similar in size of a die-cut creasing ruler (Giampieri et al., 2011; Huang and Nygårds, 2011; Leminen et al., 2021) The samples were creased in 3 depth levels: 0,5 mm, 0,7 mm and 0,9 mm with the measured force of 6,88 N, 10,2 N and 13,58 N respectively. The samples were named according to the variables presented in Table 2. The samples with the most damage to the top layer were laminated using a SERON FM-360 Roll-to-roll laminator and Superstick Nylon Gloss 30/320/1000/75 PE foil.

Table 2: Creasing sample's nomenclature

Sample name	grammage	Paperboard
240_	240 g/m^2	Incada Silk
280_	280 g/m2	Incada Silk
250_gl	250 g/m^2	Maxi gloss
300_gl	300 g/m^2	Maxi gloss
250_of	250 g/m^2	Maxi offset
300_of	300 g/m^2	Maxi offset
Plastification	**Foil thickness**	**Sample name annex**
yes	30µm	pl_
Creasing depth	**Sample name annex**	
0,5 mm	05_	
0,7 mm	07_	
0,9 mm	09_	
Fiber direction	**Sample name annex**	
Cross direction	CD_	
Machine direction	MD_	

2.3 Measurement and grading procedure

Creasing depth was measured using the Z-axis definition option on the Zund flatbed cutter. Using the same procedure, the force was determined using a scientific scale under the creasing tool and converted to Newton (N). After cutting and creasing the samples were folded and glued by hand simulating a standard process. Samples were automation given to 10 experts in the field of graphic technology to access the area of the folded crease acceptable or not acceptable for commercial use. The experts could use four grades: acceptable with no remarks; acceptable with visible damage to the top paperboard layer; unacceptable with visible damage to the top layer and unacceptable with significant damage to the top layer.

3. RESULTS AND DISCUSSION

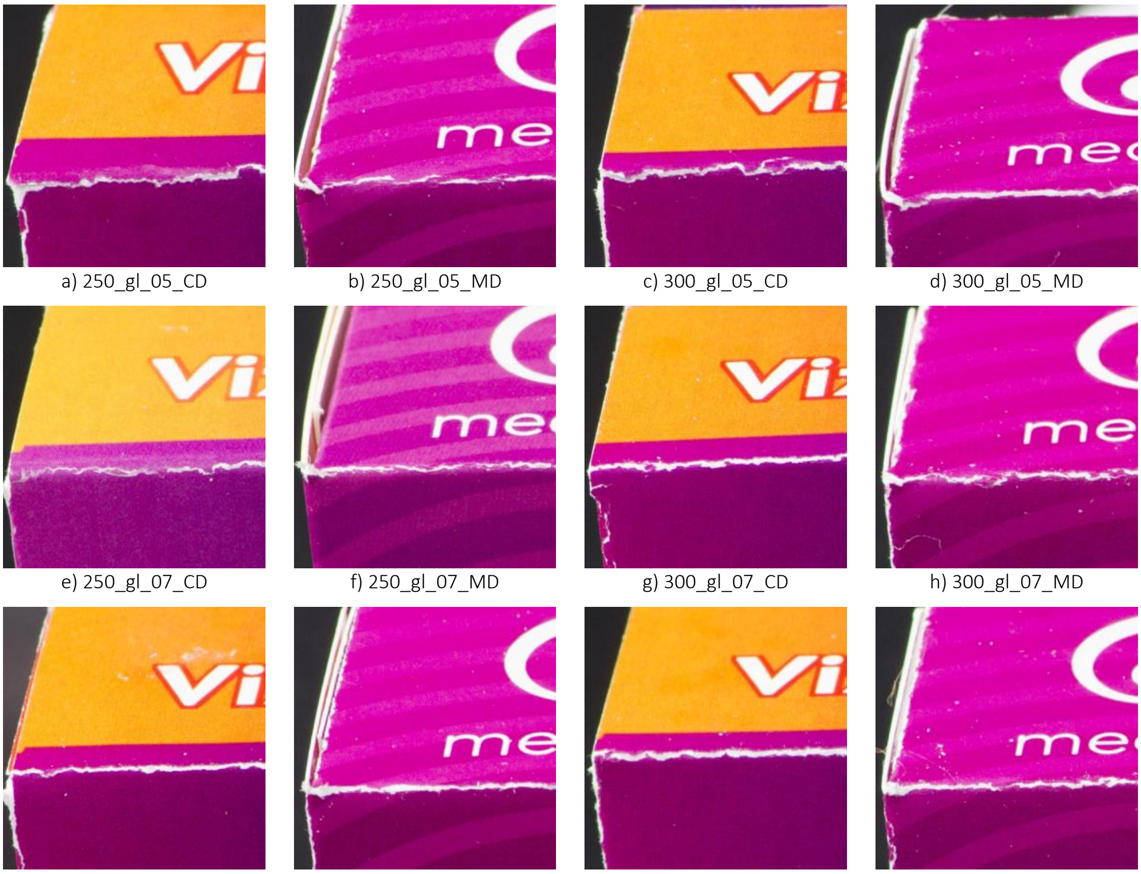
The goal of the experiment was to evaluate the quality of creased and folded paperboards as well as the laminated samples. The samples were evaluated by 10 experts in the field of graphic technology and print. For the purpose of this paper, the samples are presented as close-up images at the same position to ease comparison. In the production process, multiple samples were made from each paperboard type and creasing depth. The results of the folds were practically identical so experts were presented with just one packaging per sample type to avoid assessment fatigue. The packaging samples were examined in their folds parallel to the machine direction (MD) and cross direction (CD) fiber direction of the paperboard.

Figure 1. shows the control sample (Incada Silk) which is commonly used for folded graphic products of laser prints. This sample was not creased more or less than 0,7 mm in depth and was no PE lamination because it produces an acceptable packaging result. All experts (N = 10) agreed on these samples as acceptable without visible damage to the top layer.

a) 240_07_CD b) 240_07_MD c) 280_07_CD_ d) 280_07_MD

Figure 1: Incada Silk paperboard samples

Figure 2. shows two paperboard (250 g/m^2 and 300 g/m^2) creased with three different creasing depths (0,5 mm, 0,7 mm, and 0,9 mm). Folds parallel to the fiber direction are presented in the figure. Due to the different fiber directions in the paperboard sheet the sample images are taken at the opposite positions than in the Incada Silk and Maxi offset samples. Experts (N = 10) deemed almost all the samples unacceptable with significant damage to the top layer. The only exceptions were three experts (N = 3) that assest the 250_gl_07_CD sample (Figure 2. e) as unacceptable but with just visible damage and the sample 250_gl_09_CD (Figure 2. i) that was also graded as unacceptable but with just visible damage by one expert (N = 1). Both of the samples have folds parallel to the fiber direction which usually has better folding properties (Giampieri et al., 2011; Leminen et al., 2021). The damage to the top layer is less which can be seen in the previously mentioned sample figures. It is important to note that during the production phase his paperboard was hard to fold as the creasing indents were not embossed enough. There is some difference visible in different depths of the creasing wheel but only in the MD parallel fold. The 250g/m^2 demonstrated better results in 0,5 mm and 0,7 mm (Figure 2. b and f) depth while in the 300 g/m^2 a better result is only seen in the 0,7 mm depth (Figure 2. h). This can indicate that 0,7 mm depth could give the best result that can be achieved for this type of paperboard.



a) 250_gl_05_CD b) 250_gl_05_MD c) 300_gl_05_CD d) 300_gl_05_MD

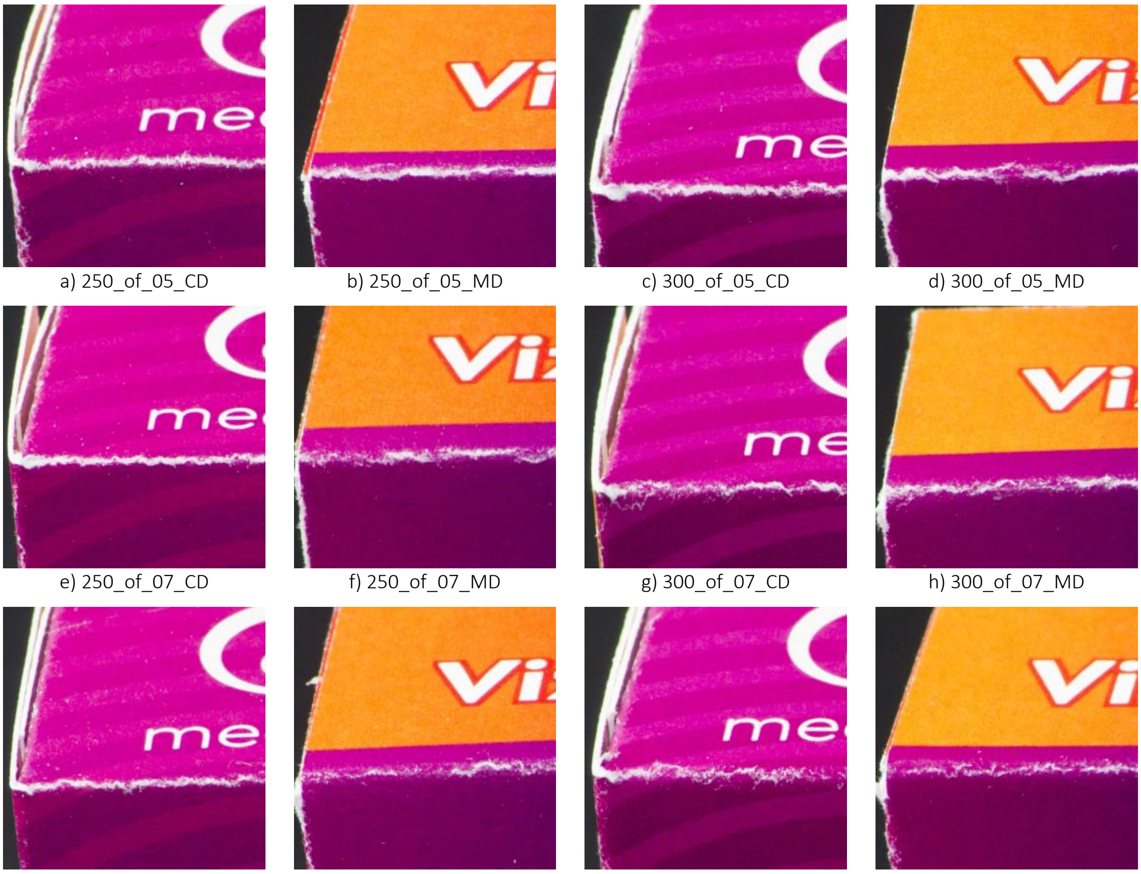
e) 250_gl_07_CD f) 250_gl_07_MD g) 300_gl_07_CD h) 300_gl_07_MD

i) 250_gl_09_CD j) 250_gl_09_MD k) 300_gl_09_CD l) 300_gl_09_MD

Figure 2: Maxi gloss paperboard samples

Figure 3 also shows two paperboards (250 g/m^2 and 300 g/m^2) creased with three different creasing depths (0,5 mm, 0,7 mm, and 0,9 mm). Experts (N = 10) deemed most of the samples unacceptable with significant damage to the top layer. The only exceptions were five experts (N = 5) who asset the 250_of_09_MD sample (Figure 3. j) as unacceptable but with just visible damage and the sample 300_of_09_MD (Figure 3. l) was also assessed as unacceptable but with just visible damage by seven experts (N = 7). Both of the samples also have folds parallel to the fiber direction that as in the previous sample can have better results. It is important to note that during the production phase his paperboard had a snapping effect when folded. This led to a rupture of the top layer. There is some difference visible in different depths of the creasing wheel where the deepest (0,9 mm) crease produced the best results. This effect needs future investigation to assess which creasing depth results in better folding quality.

The unacceptable paperboard samples were laminated to observe the creasing and folding results as a solution to the rupture of the top layer. The results of the samples are presented in Figure 4. All experts graded the samples as acceptable without visible damage. The additional conclusion of the grading was that the laminated samples fold deemed of higher quality than the control samples. The folding process for the Maxi gloss samples were again hard to precisely fold and would still have lesser quality results due to the less precise folds. This is visible as wider folds in Figure 4. c) and g). It is important to note that the lighter segments on the folding segments in the images, dominantly in the 250_sj_07_CD_pl sample (Figure 4. c) are reflections due to the high glossiness of the laminated surface.

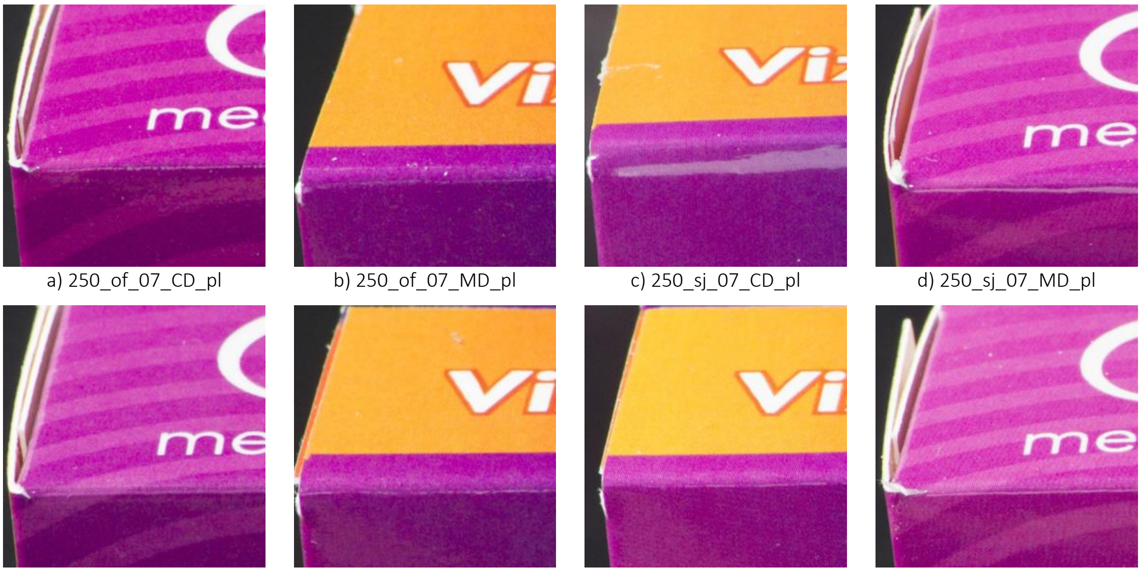


a) 250_of_05_CD b) 250_of_05_MD c) 300_of_05_CD d) 300_of_05_MD

e) 250_of_07_CD f) 250_of_07_MD g) 300_of_07_CD h) 300_of_07_MD

i) 250_of_09_CD j) 250_of_09_MD k) 300_of_09_CD l) 300_of_09_MD

Figure 3: Maxi offset paperboard samples



a) 250_of_07_CD_pl b) 250_of_07_MD_pl c) 250_sj_07_CD_pl d) 250_sj_07_MD_pl

e) 300_of_07_CD_pl f) 300_of_07_MD_pl g) 300_sj_07_CD_pl h) 300_sj_07_MD_pl

Figure 4: Laminated paperboard samples

4. CONCLUSIONS

This research was aimed to investigate the difference of creasing and folding between different paperboards grammage and type. The paperboards were creased with different depth levels, laminated and evaluated by experts. The results led to these conclusions:

- The examined 250 g/m^2 and 300 g/m^2 Maxi Offset and Maxi gloss paperboards are not suitable for packaging even if they are adequate grammage and stiffness
- Crease parallel to the machine direction of the paperboard fibers provide better folding and less damage to the top layer
- Using different creasing depths can reduce ruptures of the top layer and improve final folding result
- PE lamination achieves preservation of the top layer when paperboard is creased and folded.

These conclusions are limited to paperboards used in this research but they are an indication for a procedure for achieving best folding results for using flatbed cutters and available paperboards. This paper suggests users to thoroughly examine different creasing depths to achieve preservation of the folded top layer, and if there are no other options, lamination can be offered as a solution.
Further research should be expanded on comparing die cut and flatbed creasing and folding results as well as using a larger amount of different paperboards that are commonly used for smaller print orders on laser and inkjet printers. Also additional research should be made with other type of creasing wheels and drag creasing knifes used for flatbed cutters and complement the expert assessments with more objective measurements.

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EXPLORING THE TENSILE STRENGTH OF PERFORATED PAPER FOR PACKAGING

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Abstract: *Contemporary packaging is more than just packaging and has other various roles that raise the product value. Technology development enabled packaging design to become more complex and improve quality and performance. Cutting different and complex shapes and forms has become a standard requirement in the packaging industry. Perforation has become one of the central elements of the packaging to aid the hole opening and product use, to aid the box forming process, and for design purposes. Packaging material requires sufficient tensile strength to maintain the primary role of packaging. Therefore, it is important to investigate the tensile strength of perforated paper in order to control the strength and durability of the packaging. Our research aims to investigate whether the paper material's tensile strength changes by using different perforation designs. We designed different perforations varying the bridge width. Cutting is done using CO2 laser technology Trotec Speedy 300 machine system. The obtained results show that different perforation designs (variations of bridge and gap width) require a different amount of force applied to break the paper material, regardless of paper grammage. Meaning that the same type of perforation design has the same tensile strength regardless examined grammage. This paper suggests further research and experiments regarding perforation for packaging.*

1. INTRODUCTION

There are various perforation purposes in the packaging and paper industry. One of them is to facilitate the folding and tearing off paper. Others are mainly used to allow a sheet of paper to tear out smoothly at a specific point without damaging the packaging material. For example, ease of tear is important for products such as return envelopes, postcards, stamps, tickets, information sheets, and coupons (Gattuso, 1989). Another use is the press-forming process which typically utilizes pre-cut and -creased paperboard blanks, which are subsequently formed into three-dimensional shapes (Leminen et al., 2013; Tanninen et al., 2014).

With laser technology, contemporary packaging is required to be much higher quality than earlier, and wider design possibilities are enabled. Cutting very small details and complex forms became industry standard. Besides the enhanced possibility compared to mechanical cutting and perforation, laser technology has many advantages over mechanical cutting and perforating. When using mechanical perforation, the perforation pattern can be damaged because of the physical contact between the perforating tool and the paper (Gattuso, 1989). Mechanical perforation can cause that holes to be incompletely perforated or missing and tend to weaken the material due to broken fibers (Piili, 2013). Incomplete or missing perforations increase the perforation pattern's tensile strength (Gattuso, 1989). Furthermore, the holes of the mechanical perforations close back after the perforation pins are removed, therefore preventing the air cannot from passing through (Gattuso, 1989). In contrast, laser holes are clean and remain open, allowing the air to pass through. Microscopic analysis showed that the pressure applied to both sides of a bridge performed in cardboard by the punching pins causes microscopic cracks responsible for weakening the perforation pattern (Gattuso, 1989). Their research also showed that the tensile strength of the laser micro perforation pattern is higher than the tensile strength of the mechanical micro perforation pattern (Gattuso, 1989). The loss of strength caused by the damaged bridges of the mechanical perforation pattern is higher than the additional tensile strength brought by the layer of fibers smashed at the bottom of the hole (Gattuso, 1989).

Mechanical tools such as knives on cutter machines also provide fiber sticking edge of the material, compared with laser (Piili, 2013). On the other hand, by using a laser to make a perforation, the holes that are created are open and of equal size (Mommsen and Stürmer, 1990; Brockmann, 1999). However, according to John Powell (Powell, 1998), there are many advantages of cutting paper using laser technology. Advantages are:

- It is a contact-less process, without bending or distortion of material during a cutting operation, unlike mechanical cutting
- Kerf width is very small (approximately 0.1 to 1 mm); consequently, it is possible to cut very small details without tool radius limitations
- It is a thermal process, and material evaporates during the cutting process
- Very high speeds of cutting
- No need for changing the tool – laser beam is the only tool
- High quality of cutting and engraving without defilement of material
- Easier workflow, design is created on a computer and directly sent to the laser
- No need for creating a die; therefore no need to change knifes

Since laser provides the highest cutting quality, this paper aims to test the laser perforation tensile strength, examine cutting perforation and test different perforation bridge widths. Furthermore, we investigate the tensile strength of different perforation designs and their dependence on paper grammage.

1.1. Tensile strength of the paper

An important requirement for the paper substrate is sufficient tensile strength for smooth and undisrupted processing operations without tearing (Riley, 2012). The tensile strength test is conducted according to ISO standard ISO 2758:2003. Tensile strength is a force required to break the material (Kirwan, 2005). During the influence of force, the material shows elastic properties up to a certain point. This means that tensile strength applied to paper material is proportional to deformation or elongation caused by applied force (Kirwan, 2005).

2. METHODS

2.1 Materials

The selected paperboard (*Zenith*) is commonly used for packaging food and drugs. Typical applications for this paper are (Ningbo Zhonguha Paper, 2022):

- Personal and Health care products
- Pharmaceuticals
- Media packaging
- Electronics and Entertainment products
- Book covers (215 g/m^2)
- Cigarette packaging (Offset printing, 215 g/m^2 for iner box and 235 g/m^2 for outer box)
- Base board for foil lamination
- Base board for vacuum metallization
- Chocolates and Confectionery packaging
- Desktop calendars

Paperboard specifications are shown in table 1.

Table 1: Zenith paperboard specifications

BASIS WEIGHT	g/m^2±3%	215	235	250	270	295	325	350	380
SIZE DEVIATION	mm	0 - 2							
MOISTURE CONTENT	%	6.0±1.0							

Testing conditions (ISO) temperature (23±1°C)
Testing conditions (ISO) Relative humidity (50±2%)

2.2 Samples

After laser cutting and perforating, the tensile strength of samples was tested using *Shimadzu Compact Tabletop Testing EZ-LX*. Samples were tested using a measurement cell of 2.5 kN, and the testing speed was 25 mm/min (Shimadzu, 2016). Samples were prepared for testing according to the standard for

tensile strength testing recommended by TAPPI T 494-om-1. Sample dimensions are 25mm in width, and 180 mm in height, with a constant stretching force speed of 25 +- 5 mm/min.
Perforation designs are tested on three different paper grammages: 295 g/m^2, 325 g/m^2 i 380 g/m^2. Several perforation designs were investigated, shown in figure 1. The bridge width and gap width are varied; the variations are:

- 2 mm bridge, 0.5 mm gap
- 2 mm bridge, 1 mm gap
- 2 mm bridge, 2 mm gap
- 2 mm bridge, 3 mm gap
- 3 mm bridge, 0.5 mm gap
- 3 mm bridge, 1 mm gap
- 3 mm bridge, 2 mm gap
- 3 mm bridge, 3 mm gap

Figure 1: Perforation designs

3. RESULTS AND DISCUSSION

One–way ANOVA is used to investigate whether there is a statistically significant difference between the breaking force of different perforation designs, shown in table 2.
Analysis showed that there is statically significant difference between different perforation design, for every paper grammage tested: 295 g/m^2 ($F=50{,}870$, $p<0{,}001$), paper 325 g/m^2 ($F=694{,}450$, $p<0{,}001$), paper 380 g/m^2($F=734{,}910$, $p<0{,}001$). Therefore, another analysis is conducted to find a perforation design requiring the smallest force to break and the highest amount of force. For paper 295 g/m^2 the smallest amount of force is required for perforation with a 2 mm bridge and 3 mm cut ($M=5{,}90$), and the highest amount of force is required for perforation of a 2 mm bridge and 0.5 mm cut ($M=12{,}16$). For paper 325 g/m^2 the smallest amount of force is required for perforation with a 2 mm bridge and 3 mm cut ($M=5{,}90$), and the highest amount of force is required for perforation of a 2 mm bridge and 0.5 mm cut ($M=12{,}51$). For paper 325 g/m^2 the smallest amount of force is required for perforation with a 2 mm bridge and 3 mm cut ($M=6{,}80$), and the highest amount of force is required for perforation of a 2 mm bridge and 0.5 mm cut ($M=14{,}18$). Results show that perforation design was not affected by paper grammage.

Table 2: Differences between perforation design for each grammage

Material	Perforation designs	M	SD	F	p
295 L	2 mm bridge 3 mm gap	5,909	0,299	50.870	0.000
	3 mm bridge 3 mm gap	6,812	0,343		
	2 mm bridge 2 mm gap	7,339	0,365		
	3 mm bridge 2 mm gap	8,855	0,406		
	2 mm bridge 1 mm gap	9,503	0,574		
	3 mm bridge 1 mm gap	10,567	0,505		
	3 mm bridge 0.5 mm gap	12,111	0,639		
	2 mm bridge 0.5 mm gap	12,160	0,523		
	Total	9,157	2,270		
325 L	2 mm bridge 3 mm gap	5,902	0,354	694.450	0.000
	3 mm bridge 3 mm gap	7,029	0,286		
	2 mm bridge 2 mm gap	7,523	0,384		
	3 mm bridge 2 mm gap	9,309	0,401		
	2 mm bridge 1 mm gap	9,705	0,414		
	3 mm bridge 1 mm gap	10,820	0,417		
	3 mm bridge 0.5 mm gap	12,349	0,455		
	2 mm bridge 0.5 mm gap	12,516	0,559		
	Total	9,394	2,331		
380 L	2 mm bridge 3 mm gap	6,804	0,368	734.910	0.000
	3 mm bridge 3 mm gap	8,086	0,315		
	2 mm bridge 2 mm gap	8,593	0,342		
	3 mm bridge 2 mm gap	10,656	0,296		
	2 mm bridge 1 mm gap	10,862	0,549		
	3 mm bridge 1 mm gap	12,020	0,447		
	3 mm bridge 0.5 mm gap	13,773	0,583		
	2 mm bridge 0.5 mm gap	14,185	0,517		
	Total	10,622	2,539		

4. CONCLUSIONS

The research aimed to evaluate and investigate the difference between various perforation designs using CO_2 laser technology. Therefore, different bridge widths and gap width of perforation were tested, and their tensile strength property. The results led to the conclusions:

- Regardless of paper grammage, perforation of a 2 mm bridge with 0.5 gaps required the highest force to break, whereas perforation of a 2 mm bridge with three gap widths required the lowest force to break.
- The highest force is required to tear perforation of 2 mm gap 0.5 bridge width, which is perforation with the smallest amount of cut area, therefore, requires the highest force to break.
- The tensile strength of paper material depends on the cut area size.

Obtained results can guide further investigation about packaging durability when using perforation and how much perforation lowers the tensile strength of the packaging. This research is a preliminary study to investigate the perforation designs further using laser technology. In addition, further research can be based on comparing laser perforation cutting and mechanical perforation regarding the analyzed difference between these two technologies.

5. ACKNOWLEDGMENTS

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CUTTING WITH LASER IN POSTPRESS

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Abstract: *Laser technology in post-press is used for various products to get a unique shape. It has been used in producing packaging prototypes, finishing and marking the surface of both paper and other materials, thus making the graphic industry more flexible and diverse. Whether in the coming years, the production of graphic products, especially packaging, will be able to rely on the advantages offered by laser technology depends on the extent of degradation of materials that are cut by the laser. In addition to the visual analysis, it is necessary to carry out experiments examining whether material degradation occurs during laser treatment or whether the structure, homogeneity, and mechanical characteristics are kept. Perhaps the most effective method to show if the packaging obtained by laser cutting can be used in the industrial production of packaging is a comparison with the characteristics of packaging materials obtained by traditional cutting methods with the cutting and die-cut machines. The work examines which parameters need to be examined and compared so that laser cutting can be applied in packaging production.*

Keywords: CO_2 laser, die-cutting, packaging, paper, post-press

1. INTRODUCTION

Use of laser technology in processing and cutting material has shown many advantages over conventional techniques. Speed of operation, accuracy, precision, suitability for the environment, and good hygienic conditions distinguish laser technology. Laser cutting technology has opened up new opportunities in the packaging market compared to conventional packaging manufacturing techniques. The advantages are reflected in the diversity of packaging shapes, sizes and complexity, with fewer design limitations, as well as opportunities to improve the quality of packaging production. The quality of laser-cut products is reflected in the cut edges that are clean, glued, and do not contain material fibers that come out of the cutting edge. The profitability of this technology for small runs has contributed to the growth of smaller crafts and special workshops. Laser cutting is computer controlled, fast direct method, easy to use, and the line drawing representing the path of the cut can be changed one after the other by software, which is an advantage. Also, the speed of the process is largely influenced by the fact that this technology does not require tool replacement - a laser beam is a universal tool that moves along a software-defined path. Laser devices must be equipped with systems for vacuuming fumes that arise in the evaporation material process. Depending on the material being processed, different fumes can be expected in the immediate nearby during the cutting process, so it is necessary to ensure good ventilation.

2. PAPER AS LASER CUTTING MATERIAL

Paper and cardboard are materials that appear to have a smooth, uniform and flat surface, while at the micro level, one can see their structure - they are composed of interlaced cellulose fibers (Kirwan, 2005; Riley, 2012; Piili, 2013). As such, papers can be printed and have physical properties that allow the initial paper shape to be changed so that flexible, semi-rigid and rigid packaging can be made (Kirwan, 2005).
There are many different types of paper and cardboard. The properties that paper has, such as strength, appearance and many others, vary depending on the following influential parameters (Bajpai, 2018):

- type and quantity of fibers;
- how the fibers were processed in the separation process;
- treatment of fibers, as well as in producing paper and cardboard.

Paper and cardboard can be characterized by weight per unit area (paper grammage) and thickness (Bajpai, 2018).
Regarding paper thickness, papers that fall over 200 g/m^2 are defined as cardboard according to the ISO standard (English: International Organization for Standardization) (Kirwan, 2005). Therefore, specific papers are classified as cardboard even though they weigh less than 200 g/m^2. On the other hand, the

organization CEPI (Confederation of European Paper Industries) counts cardboard as those papers that weigh more than 220 g/m^2 (Bajpai, 2018). All papers and cardboard can be processed by laser for cutting, die-cutting, or engraving.
Paper materials are characterized by properties that allow them to be folded into flexible, semi-rigid, and rigid packaging by cutting, folding, shaping, corrugation, and gluing operations (Kirwan, 2005). Paper materials can be used in a wide range of temperatures, from packaging for frozen food to boiling temperature, for example, when heating in a microwave oven (Kirwan, 2005).
The properties of paper and cardboard depend on the ingredients used for their production and the type and amount of fibers used. These properties of paper are related to its appearance and technical packaging performance (Kirwan, 2005):

- The appearance of paper and cardboard related to colour and visual impression e.g., printing, has a significant influence on the appearance of the packaging.
- The performance related to strength, consumer protection and efficiency of packaging.

Paper materials have a smooth, flat and uniform surface, however microscopic images show that paper materials have a complex structure consisting of a network formed by interwoven fibers originating from wood. The paper contains filler particles (clay/kaolin, calcium carbonate or other minerals) (Piili, 2013). Also, paper is a composite material consisting of cellulose, hemicellulose and lignin (Hosoya, Kawamoto & Saka, 2007). Some paper materials are coated with a thin layer of mineral pigments (usually clay/kaolin, calcium carbonate or other minerals or a mixture of the pigments mentioned above) or a thin layer of plastic (Piili, 2013). Some paper materials contain layers of different paper materials, for example, a middle layer of mechanical pulp and a bottom layer of chemical pulp (Piili, 2013).
Fibers are usually much longer (the average fiber length is 1 mm) than thick (average fiber thickness is 100-200 microns). Due to these dimensions, the wood fiber network looks like a 2D network. When the air between the fibers is considered, the fibers form a 3D network. Such a 3D structure of wood fibers strongly affects the optical properties of paper materials. Paper materials contain different optical barriers: pores of different shapes and sizes, mineral pigments, long fibers, etc. (Piili, 2013). Light can perform transmission, scattering, reflection, diffraction, and absorption when it interacts with paper materials and their components (Pauler, 2002).
All these characteristics of paper change the way it reacts to the laser. Increased moisture in paper will increase the laser strength needed to cut through the paper (Malmberg, Immonen & Kujanpää, 2006). One of the requirements for paper substrates is that they have the sufficient tensile strength to pass through the processing process and usage without tearing (Riley, 2012). In addition to the breaking point, an important characteristic is the elongation at which the breaking occurs, and the tests are performed on dry and wet papers (Riley, 2012). The tensile strength test is standardised according to the ISO (International Organization of Standardization) ISO 2758:2003 (ISO 2758 2003).
By definition, tensile strength represents the force required to break a material (Kirwan, 2005). Under the action of this force, the material exhibits elastic properties up to a certain level. Force applied to the paper strip is proportional to the deformation or elongation caused by the applied force (Kirwan, 2005).

3. POSSIBILITIES OF LASERS IN PAPER CUTTING

Finishing, post-press is a segment of the printing production flow in which the printed product is given the appropriate form or function (Kipphan, 2001). When it comes to packaging material, it can be open or closed, cut to a final format and formed into a hollow body in the process of forming the packaging.
Cutting is usually done conventionally with paper-cutting knives (guillotine). Depending on the application, the knives can be integrated into the printing machines or be separate devices. As an alternative to knives, innovations have brought the possibility of cutting paper with a water jet and cutting paper with a laser (Stepanov et al., 2015).
When cutting paper materials, the quality of the cut is reflected in the variations in dimensions, which can occur in the process of final graphic processing during cutting, folding, and binding (Kipphan, 2001). However, even minimal deviations from the desired paper dimensions can seriously damage the final product's quality when cutting. Therefore, a high level of cutting accuracy is necessary, and it depends on the properties of the material of the product being cut (Kipphan, 2001).

Cutting quality includes the following parameters (Kipphan, 2001):

- deviations concerning the defined cutting edge
- format deviations in the cutting direction
- cutting edge accuracy - deviation from a straight line
- uniformity of the cutting surface

In the conventional way of paper cutting with a guillotine, the quality of cutting also depends on the tool itself (Kipphan, 2001):

- life of the cutting knife
- the angle of the knife
- pressure force
- the sharpness of the knife

The use of laser cutting is limited to individual sheets because the focus of the laser beam is relatively narrow and is not suitable for cutting thicker layers of paper or thicker materials (Pinćjer et al., 2020). By changing the lenses used to focus the laser beam on the material, the focal length can be increased, but it is limited to sizes of about 1cm. The use of the guillotine is necessary for the preparation of materials when it is necessary to cut paper stacks to the appropriate format for printing. However, laser cutting can successfully replace the cutting of different packaging shapes achieved by die-cut.
The conventional way of cutting paper and cardboard, which implies the use of a mechanical way of cutting by the action of the blade on the material, can lead to various problems during cutting, such as the poor quality of the cut material or the destruction of the material itself (Piili, 2013). When cutting material with knives, one can single out a cutting method of crucial importance for obtaining the shape of the packaging, which is die-cutting. The die-cutting operation involves cutting the printed product into another shape or adding perforation to the product (Johansson, Lundberg & Ryberg, 2011). A die is a wooden board on which there are holders for knives that are bent to take the shape that needs to be obtained after cutting (Johansson, Lundberg & Ryberg, 2011).
Since the die-cut operation is performed with knives (tools), depending on the job, the tools are changed. The most used tools are (Wyrzykowski, 2020):

- Cutting knives - used to cut the packaging material.
- Slitting knives - enable partial cutting of material.
- Creasing knives - similar to partial cutting, only, in this case, the knife creates a fold line on the packaging material. The crease allows the material to bend on both sides, thus giving greater flexibility to the material.
- Perforation - perforation implies the creation of a line formed by holes in the material. This operation does not separate the material however, it facilitates the separation of the material if necessary.

It is impossible to achieve creasing with a laser, so preparing a paper to fold can be achieved with a laser by perforation or partial by cutting (slitting).
One problem that occurs during the mechanical cutting of materials is dust, which consists of particles of fibers and pigments that are torn from the material by the blade of the guillotine (Piili, 2013). This kind of dust can cause problems in production. In addition, the cutting edge of the material contains fibers that protrude beyond the edge itself, which can cause many problems in further production (Malmberg, Immonen & Kujanpää, 2006). For example, Figure 1a shows an SEM microscopic image of the cutting edge's appearance under a mechanical blade's action. In contrast, in Figure 1b, the appearance of the edge after laser cutting can be seen.

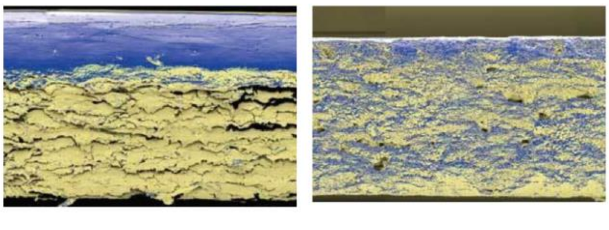

Figure 1: a) SEM micrograph of an edge that was cut by a mechanical blade and b) an edge that was cut by a laser (Malmberg, Immonen & Kujanpää, 2006)

4. COMPARISON BETWEEN LASER AND MECHANICAL CUTTING

Below is a comparison of conventional material cutting (mechanical cutting) and laser cutting by Rämö (Rämö, 2004):

- Laser cutting is a flexible way of cutting. If the shape of the cut is changed, there is no need to change the cutting tool. It is only necessary to change the drawing on which the cutting is done in the software.
- Laser cutting is a non-contact technique. Therefore, no tool can be worn off or damaged in contact with the material.
- A large amount of dust appears as a by-product of mechanical cutting. Laser cutting does not create a large amount of dust. Also, if by-products in the form of dust appear during laser cutting, they can be removed during cutting with the help of suction systems that collect fumes and dust.
- When cutting with a laser, the loss of material is less.
- Laser cutting provides the ability to cut complex geometric shapes at high speed.

Laser cutting of materials can provide a unique solution to manufacturing requirements. The use of lasers is ideal for applications that require cutting complex profiles and edges with high accuracy. Laser can cut materials of different thicknesses, cutting the same part in large quantities (mass production) or cutting very soft and hard materials (Eltawahni, Benyounis & Olabi, 2016). Laser processing of paper materials opens up new possibilities for improving the appearance of graphic products. Laser technology made it possible to make the appearance of these products unique and original.
Figure 2 shows examples of products with more complex geometry. This type of geometry can be made with higher quality with laser cutters (Trotec, 2020).

Figure 2: Examples of products with more complex geometry that are made by laser (Trotec, 2020)

5. THE INFLUENCE OF CUTTING ON PAPER

We can expect the paper to suffer a specific degree of degradation using laser or conventional cutting. Paper material is subject to degradation if it is exposed to external influences. The result of degradation can be a decrease in paper strength and a change in structure (Stepanov et al., 2015). A question arises about which type of cutting degrades the paper and which experimental method can answer that question. Indeed, changes in aesthetics and performance after cutting are essential for the further use of paper.
It has been observed that paper materials change colour during or after laser treatment, primarily newsprint, copy paper, and some cardboard. These materials contain high levels of different types of cellulose with a significant amount of lignin, such as SGW cellulose, thermo-mechanical cellulose (TMP), or chemical-thermo-mechanical cellulose (CTMP), as well as impurities. These types of cellulose are increasingly present in paper production due to the reduced price of paper products. Therefore, paper colouring is a problem that needs to be solved so that lasers can be applied to producing paper materials (Stepanov et al., 2015).
SEM analysis showed the difference in cutting edges between conventional and laser cutting. However, new research is needed to show how these edges affect the material's tensile strength. For example, will edges obtained mechanically result in lower tensile strength, or will the laser adversely affect the tensile strength due to the way the beam changes the chemical composition at the point of interaction with the material?

6. CONCLUSION

Cutting paper materials with a laser beam can be combined with digital printing machines. The advantage of digital printing is the ability to produce small runs with a quick change of the printed image. The advantage of this way of cutting is that there is no change of tools when changing jobs, while the image that needs to be cut is changed in the program (Boyle, 1999).
Authors Malmberg and others (Malmberg, Immonen & Kujanpää, 2006) list situations in which it is recommended to use a laser for cutting paper materials:

- when the cutting process is done by hand,
- when working with small editions below 1000 pieces,
- always with products that are printed using the digital printing technique,
- when it is necessary to achieve a high degree of cutting accuracy, as well as cutting of complex geometric shapes,
- when making samples or series of samples,
- if expensive material is used for the processing of which a high degree of manufacturing accuracy is necessary,
- in production where different types of products are made and when a high speed of delivery is required.

According to the author John Powell, the following advantages of cutting materials with a laser stand out:

- Laser processing of materials is a non-contact process requiring the material to be lightly attached or positioned under the laser beam. Flexible materials or light can be cut with great precision without warping or distortion during cutting that can occur if the material is mechanically cut;
- The width of the cut is minimal (typically about 0.1 to 1 mm). Therefore, excellent details can be made without the limitations of the machine tool radius of tooling devices;
- A laser is a computer-controlled device. The job changes on the computer;
- Laser cutting is a thermal process, but the heated surface is small and most of the heated material is removed during cutting. Therefore, the influence of temperature is minimal if a layer of material is placed;
- High cutting speed compared to other cutting methods;
- In most cases, laser-cut components will be ready for use immediately after cutting without the need for a cleaning operation;
- Thanks to the very narrow cutting edge, the components to be cut can be placed very close to each other, which contributes to less material waste. Therefore, the components being cut may share a cut line. However, this may not apply to all jobs;
- The laser as a device has a high price, while the costs of its use are low. Therefore, it is possible within specific industries to pay off the purchased device in less than a year;
- The process is quiet compared to other cutting devices, which contributes to the improvement of the working environment, as well as more efficient work of the operator;
- A laser as a device is very safe and reliable to use compared to mechanical cutting devices;
- One tool for all shapes – the laser beam is a universal tool for all geometric shapes and material thicknesses;
- High-quality processing of paper materials - the laser enables paper engraving without soiling;
- Creating fine details – small font sizes and delicate patterns can be engraved. Easy workflow – the design created in the graphics software is sent with the Print command to the laser software;
- Absence of a die - therefore, there are no tools, parts, or costs to replace knives on a die.

7. ACKNOWLEDGEMENTS

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STATISTICAL APPROACH IN FOLD CRACK DISTRIBUTION ANALYSIS

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Abstract: *The folding process is one of the most commonly used print finishing operations in graphical production. Therefore, surface damages on coated papers and paperboards, which are frequently appearing during this process, can have significant negative economic and environmental impacts. To reduce the adverse effects, fold crack resistance has become an active field of research. In the last decades, there were several computer-aided visual assessment methods introduced for fold-crack evaluation. These techniques were based on similar concepts of digital image analysis to quantitatively characterise the surface damage, but they had differences in utilisation as well as in the used image feature. In this study, fold crack distribution has been introduced as a new digital image feature for quality assessment. Fold crack distribution can be determined as a measure of crack scattering over the folding line. In this paper descriptive statistics, mean value, standard deviation and coefficient of variance have been used for qualitative characterisation of surface damage. The obtained results for mean value demonstrated increasing tendency by increasing the basis weight and had slightly lower value for samples in machine than cross direction. These results confirm the basic assumptions that on thicker substrates (i.e. on samples with higher basis weight) the cracks are larger, longer or grouped and that the folding process generates higher surface destruction is cross than machine direction. In the case of standard deviation, results suggest that in a case of varying mean values, crack distribution should be defined via coefficient of variation. Based on this analysis, the proposed approach to the calculation of crack distribution can serve as a new image characteristic for the qualitative measurement of the fold-crack resistance of coated papers.*

Key words: fold-crack resistance, damage distribution, coated paper, quality control

1. INTRODUCTION

Surface damages on coated papers and paperboards occurred during the folding process are one of the most frequently encountered problems in the printing industry. Since the folding process is one of the most commonly used operations in the graphical post production it could cause severe financial losses and significant environmentaly adverse effects (Holik, 2013; Soltani et al., 2016; FOGRA, 2020). To reduce the negative effects of folding process, the fold cracking resistance was gaining importance and has become an active field of research. Along with the commonly used mechanical testing methods, different computer-aided assessments have been introduced lately as new techniques for quantitative surface damage characterisation (Barbier et al., 2002; Rättö & Hornatowska, 2010; Yang & Xie, 2011; Barbier et al., 2012; Rättö et al., 2012; Sim et al., 2012; Oh et al., 2015; Oh et al., 2016; Pál et al., 2017; Rajabi Abhari et al., 2018; Najafi et al., 2019; Wang & Ding, 2020; Pál et al., 2021). These newly proposed methods are based on image processing and analysis and have similar basic concept of damage registration, digitization, and image feature calculus. However, they differ in sample preparation method, digitization process, and image processing steps. Furthermore, they have defined only one image feature, only for quantitative damage characterisation, instead of taking advantage of using additional features provided by the computer-aided assessment methods. To overcome these differences in applications and to introduce new digital image features for fold-crack evaluation, detailed research has been conducted.

In this study, a new digital image feature, the fold crack distribution, has been introduced, analyzed and discussed its potential usage for fold-crack quality assessment. The fold crack distribution (in some literature the term distribution is also referred as dispersion) is intended to numerically determine the crack scattering over the folding line. For that purpose, descriptive statistics, mean values with standard deviations and coefficients of variation have been used.

2. METHODS

2.1 Sample preparation

For the purpose of this experiment, glossy coated offset papers have been used in five different nominal basis weights: 90 g/m^2, 115 g/m^2, 130 g/m^2, 150 g/m^2 and 170 g/m^2 (Symbol Freelife Gloss, Fedrigoni, Italy). The increasing basis weight of the selected papers was intended to simulate the expanding tendency of surface damages. The selected papers were determined by basis weight, thickness, ash content, roughness and tensile strength according to the corresponding ISO and TAPPI standards (ISO 536:2012, ISO 534:2005, TAPPI 211om-02, ISO 8791-2:2013, ISO 1924-2:2008) and the results are presented in Table 1.

Table 1: Basic parameters of the selected papers

Properties		Samples				
Nominal values of basis weight [g/m^2]		90	115	130	150	170
Basis weight [g/m^2]		89.72	111.42	125.2	141.65	159.76
Thickness [µm]		65.50	80.20	92.50	113	122.5
Roughness [ml/min]		33.77	14.85	9.55	14.15	10.15
Ash content [%]		40.70	40.23	45.63	40.15	40.26
Tensile strength [kN/m]	MD	4.22	4.62	4.76	6.05	7.16
	CD	2.82	3.01	3.58	4.24	4.91
Elongation [%]	MD	4.67	4.50	4.40	4.85	5.47
	CD	10.37	8.96	10.29	10.55	9.87

Prior to folding, the sample papers were printed on KBA Rapida 75 offset machine in full tone cyan (World Series Cyan, Sun Chemical) to make the cracked surface properly visible. The folding process was done on Horizon AFC546AKT industrial folding machine, using one buckle folding unit with standard folding rollers and roller gap adjustments. The folding process was performed at standard climate conditions (23°C, RH 55%), 48 hours after the printing process. 50 samples of each paper grade were folded in both paper grain directions, marked further on as MD (machine direction) folded and CD (cross direction) folded samples.

2.2 Digital sample acquisition

For the complete investigation, three different digitization devices were used to create digital samples of the folding line. However, for this analysis, only scanned samples were used. The scanning process was done on Canon CanoScan 5600F flatbed scanner with the following setup: scanning resolutions of 1200spi, sRGB color space, no advanced image settings, file type BMP and color depth of 24bit. The scanning window was 4x25mm, and it was set up along the folding line, capturing the damaged areas approximately in the middle of the scanning window. During the scanning process, the paper samples were mounted on a holder with five different inner angles (15°, 30°, 45°, 60°, 90°), placed in a flat position (i.e. 180°) or were completely folded and stacked on each other (for inner angle of 0°). 20 images were generated for each parameter combination (paper grade, fiber orientation and inner angle) and used for image analysis.

2.3 Image analysis and feature extraction

White areas on the images of the coated paper samples are correlated to the surface damages that occurred during the folding process (Rättö & Hornatowska, 2010; Yang & Xie, 2011; Barbier et al., 2012; Rättö et al., 2012; Sim et al., 2012; Oh et al., 2015; Oh et al., 2016; Pál et al., 2017; Rajabi Abhari et al., 2018; Najafi et al., 2019b; Wang & Ding, 2020; Pál et al., 2021). To determine the white pixels` percentage on the digitized folded paper samples and the corresponding additional image features, an image processing algorithm has been developed with the following requirements (Sinha, 2000; Apro et

al., 2011; Malek, 2012; Takemetoyo et al., 2007; Nashat et al., 2014; Goncalves et al., 2015; Sengupta et al., 2015): autonomous work, noise suppression, accurate surface damage mapping to the binary image, computationally as simple as a possible solution. The algorithm`s workflow is described below. After the digitization of material samples greyscale images were generated from the original RGB images via red channel extraction. The binary (black and white) images were formed from greyscale ones by segmentation using Otsu automatic thresholding technique. Due to the nature of printed surfaces, additional white pixels were detected alongside the folding line. Since they were not associated with the crack lines but to the large-scale print non-uniformity, detached coating particles, etc., they were eliminated by following masking technique. After the folding line detection with its exact position and direction determined by Hough transform, the image was divided into ten zones and weighted average of white pixel amount was calculated in each zone. Based on the weighted average value, the masking kernel`s width was determined and all the white pixels outside of the masking zone were erased. The resulting binary image in vertical orientation was used as the input file for image feature extraction.
The crack distribution calculus is based on the arithmetic mean value and its corresponding standard deviation of white pixels` sums registered in every row of the analyzed image, according to Equation 1. and 2., respectively:

$$\bar{x} = \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right) \tag{1}$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)}^{2} \tag{2}$$

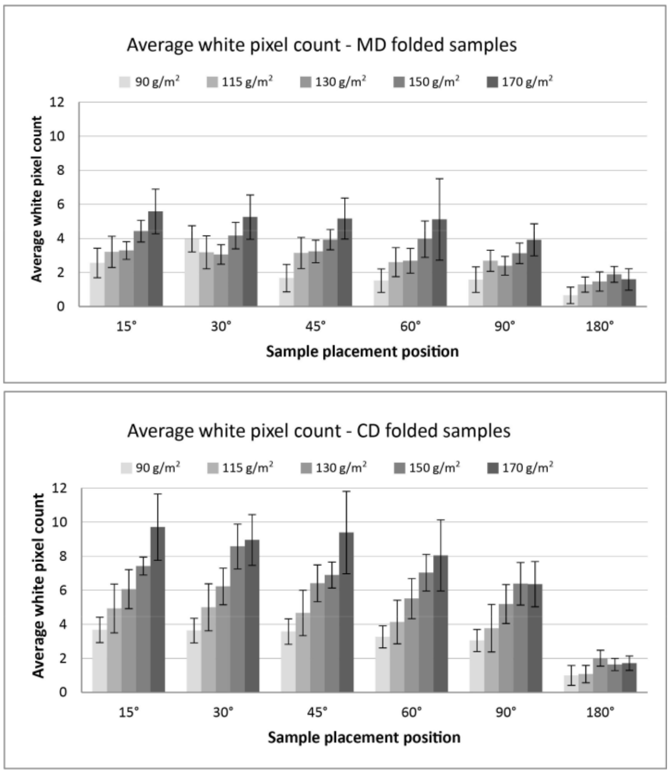
where:x is a sum of white pixel in one row of the image (later in the text: white pixel count),
n is the number of rows in the image,
$\bar{x}$ is the arithmetic mean value of white pixel count and
S is the standard deviation of white pixel count.

Lower values of standard deviation indicate that the surface damage is evenly distributed along the folding line, while higher values are corresponding to a few and/or bigger and disjoint damages. Although crack distribution is determined via standard deviation, the coefficient of variation is a more interpretable form. Therefore, results are presented in that manner. This image feature can only be applied to samples scanned with inner angle of 15°-180°, where only one folding line was displayed. For samples scanned with inner angle of 0° this approach cannot be used, since 15-20 material samples were visible at the same time, covering the entire observed image and the sum of white pixels in every row represents already an averaged value of those 15-20 folding lines. All the pre-processing, processing and feature extraction steps were done in MATLAB® R2011a package with the corresponding Image Processing Toolbox™.

3. RESULTS

The mean values of average white pixel count, its standard deviation and coefficient of variation were calculated for each paper grade, folding directions and sample placement positions. The obtained results are presented graphically in Figure 1a-b. Similarly, the mean values of white pixels count's standard deviation and coefficient of variation were also calculated along with the relevant descriptive statistics and the results are presented in Figure 2a-b and 3a-b, respectively. Error bars indicate the corresponding standard deviations.
As it can be seen on Figure 1, the white pixel count values have an increasing tendency by increasing the sample papers' basis weight and have slightly higher values for CD folded samples (Figure 1b) than for MD folded ones (Figure 1b), although some deviations can be observed. These results follow the literature data (Barbier et al., 2012; Sim et al., 2012; Oh et al., 2015; Oh et al., 2016; Pál et al., 2017; Wang & Ding, 2020) and the primary hypothesis that papers with higher basis weight and thickness generate larger surface stresses during the folding process**,** especially in the cross direction (CD folding), which causes larger or/and connected surface cracks in the coating layer. The range of obtained values for MD folded samples was 0.66 ÷ 5.58 and for the CD folded samples 0.99 ÷ 9.71. The step-like increment of white pixel

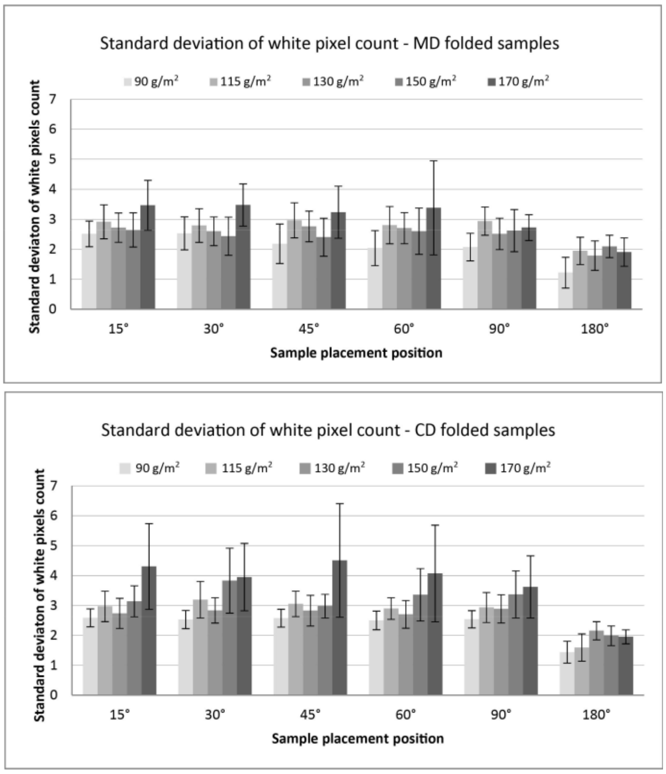
count values for CD folded samples was more uniform than for MD folded samples, indicating that the samples` basis weight has a more significant influence on the visible white pixels amount in CD folding than in MD. That difference is more emphasized for lower basis weights (90 g\m^2, 115 g\m^2 and 130 g\m^2) and for sample placement positions from 15° to 90°. For the inner angle of 180°, results were noticeably less uniform, most likely due to the flat scanning position. According to the sample placement positions, the obtained results showed similar changes in both folding directions. For the inner angle of 180°, results were noticeably lower compared to the other sample placement angles. These differences can be attributed to the flat position of the samples during the capturing process. By increasing the inner angle of the sample placement position (from 15° to 90°), the folded samples were slowly opened, while the crack lines gradually closed. Therefore, the surface cracks were reduced in size or disconnected. With the inner angle of 180°, the samples were in flat position, so the cracks were not visible enough (sometimes completely vanished) and the white pixel count values became significantly lower than for the other placement positions.



a)
b)

Figure 1: Average white pixel count for machine (a) and cross folded samples (b)

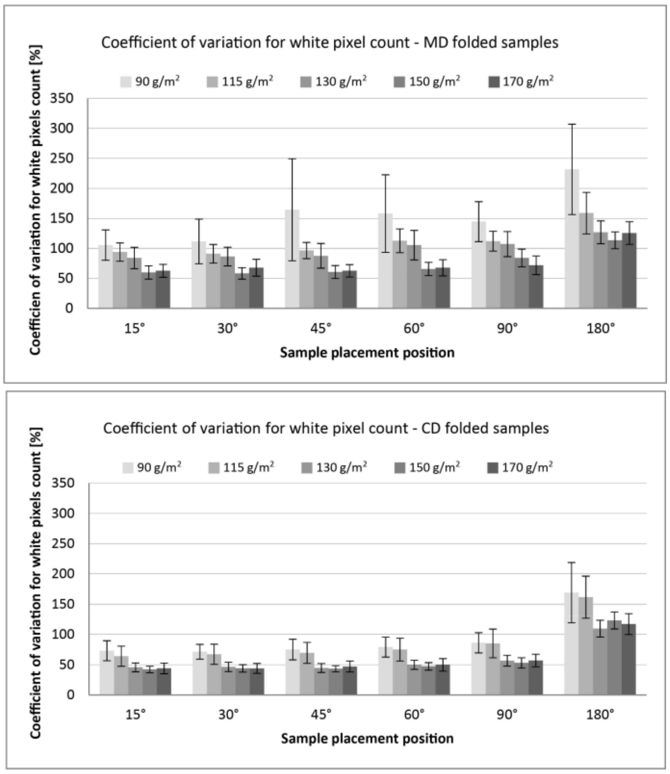
Results for the standard deviation of white pixel count (Figure 2) show some similarities with the mean values regarding the folding directions and the 180° placement position behavior. They have slightly higher values for CD folded samples (Figure 2b) than for MD folded (Figure 2a) and samples with inner angle of 180° gave visibly lower results, especially in CD folding direction. Besides similarities, there are two differences among the obtained results. One is regarding to the samples basis weight, another to the sample placement positions from 15° to 90°. Namely, there is no consistent step-like increment with the samples' basis weight (especially in MD folding direction) and the values for different placement positions were similar to each other. The range of obtained values were 2.04 ÷ 3.48 for MD folded samples and 2.50 ÷ 4.51 for CD folded ones, while for the inner angle of 180° the ranges were 1.22 ÷ 2.10 for MD samples and 1.44 ÷ 2.15 for CD samples. These results suggest that all samples had more or less similar crack dispersion over the folding line. However, after a detailed visual analysis of the original sample images, it has been proven not to be the case. Papers with lower basis weight have a few, minor or moderate crack patches along with fine crack lines randomly scattered over the folding line. On the other hand, on papers with higher basis weight, more intense surface cracks were registered with an even distribution of longer, thicker and connected crack lines with occasional larger crack patches. Thus, the results in this form do not reveal much about the nature of the coating damage, primarily due to the differences in the mean values. Therefore, the basic idea for using standard deviation for crack distribution metric cannot be validated without knowing the mean values. For appropriate data analysis in such a case of varying mean values, the crack distribution metric (at least in this study) should be defined via the coefficient of variation.



a)

b)

Figure 2: Standard deviation of white pixel count for machine (a) and cross folded samples (b)



a)

b)

Figure 3: Coefficient of variation for white pixel count of samples folded in machine (a) and cross direction (b)

Results of coefficient of variation for white pixel count [%] (Figure 3a-b), in general, have decreasing tendency by increasing the sample papers' basis weight and have significantly lower values for CD folded samples than for MD folded ones. Although, there are some minor deviations mostly for the thickest paper (170 g\m^2), the results follow gradual stepwise changes as suspected by (Barbier et al. 2012, Sim et al. 2012, Oh et al. 2015, Oh et al. 2016, Pál et al. 2017 Wang and Ding 2020). Papers with higher basis weight and thickness generate larger, longer or/and connected surface cracks in the coating layer which are evenly distributed along the folding line, thus resulting in low values of coefficient of variation. For samples folded in cross direction, this trend is more emphasized and extends to thinner papers. These results indicate that even samples with lower basis weights get long and connected crack lines during CD folding. The more uniform, step-like decreasing of coefficient of variation values for MD folded samples (Figure 3a) indicates that basis weight has a more significant influence on the crack distribution in MD folding than in CD. That trend is more noticeable for lower basis weights (90 g\m^2, 115 g\m^2 and 130 g\m^2) and for the sample placement positions from 15° to 90°. The range of obtained values for the mentioned samples were 84.03% ÷ 164,39% for MD folding, and 44.66% ÷ 86.28% for CD folding. Samples with the two highest basis weight (150 g\m^2 and 170 g\m^2) and the same inner angles had ranges from 58.38% up to 84.09% for MD folding and from 42.17% up to 57.04% for CD folding. The surprisingly similar values for all CD folded samples with inner angles between 15° and 90° suggest that sample placement position has little or no effect on crack distribution.
By comparing the results according to the sample placement, similar changes could be noticed in both folding directions. For the inner angle of 180°, results were noticeably higher than the other sample placement angles (the ranges were 113.58% ÷ 231.78% for MD samples and 109.64 ÷ 169.09 for CD samples). This could refer to the fact that by increasing the inner angle of sample placement, crack lines were gradually closing at the very tip of the folding line, reducing the total area of surface damage. At an angle of 180°, the samples were completely flat, and only large crack spots remained visible, randomly scattered along the fold line, giving rise to typically high values of the coefficient of variation.

4. CONCLUSIONS

In this study, the applicability of crack distribution via descriptive statistics as a new digital image feature for fold-crack assessment has been presented and analyzed.
The obtained results, in general, demonstrated that the mean white pixel count has an increasing tendency by increasing the basis weight of the substrates and had a slightly lower value for samples folded in the machine than cross direction. These results confirm the basic assumptions that on thicker substrates (i.e. on samples with higher basis weight), the crack lines are larger, longer or grouped and that the folding process generates higher surface destruction in cross than machine direction.
The basic concept of using standard deviation for crack distribution measure seems to be correct since lower values indicate evenly distributed surface damages, often in the form of long and thick crack lines over the entire folded area. In comparison, higher standard deviation values correspond to a few, small or medium, but usually disjoint cracks. However, instead of the standard deviation, the coefficient of variation can provide more accurate results for a more realistic characterization of crack scattering, regardless of the difference in mean values. Based on the obtained results, it can be concluded that the proposed approach to the calculation of crack distribution can serve as a new image characteristic for the qualitative measurement of the fold-crack resistance of coated papers.

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DESIGN

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THE "DO-IT-YOURSELF (DIY)" BRAND DESIGN STRATEGY THROUGH COMPUTATIONAL DESIGN TOOLS

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Abstract: *The three-dimensional form of a product is a key element in the development of a brand identity through the computational design methodology. Brand identity has an in-depth relationship with the object's shape and product assembliness. In traditional mass production design methodologies, designers encode specific parameters into design rules that aren't used by end-users to customize their own products. The "Do-It-Yourself (DIY)" process enable users to express themselves through the design thinking approach. Self-design is a form of co-creation between designer's knowledge and customer's skills according to the branded product design parameters. Under this statement, the object's geometrical form and the product assembliness are fundamental principles in the promotion of a holistic design identity to the industry and to the market. The current paper combines the use of computational design with specific parameters of DIY bookcase/desk (i.e., height, length, width, number of shelves, etc.) in order to develop a generative design system for the mass customization of DIY bookcases/desks alternatives. The results from the end-user application offer, automatically alternatives 3D models under the "Do-It-Yourself" brand umbrella.*

Key words: computational design, branding, do-it-yourself, self-design, design thinking, mass customization

1. INTRODUCTION

The multidimensional role of brand identity embodies the product's shape and the final object's assembiness (Manavis & Kyratsis, 2021). Furthermore, the aforementioned modern approach of product brand image also includes design elements like material's texture and roughness, color, and the unique design style of the specific brand. Nowadays, novel Computer Aided Design (CAD) systems afford advanced features and capabilities that can be used to produce unusual geometries in product design engineering field (Tzotzis et al., 2021). More specifically, computational design is a supportive methodology for designing branded products according to the brand-new theory of the holistic design strategy. The Do-It-Yourself (DIY) design methodology refers to the specific creative approach in which designers thinking like end users. That means, the DIY projects includes toolkits, templates, tools, information, inspiration, and preliminary designs from designer's point of view (Hoftijzer, 2017). Finally, the DIY activities can be seen as the most self-sufficient ways of designing and making your own products.

2. LITERATURE SURVEY

Throughout literature there are reports about many theories and techniques related to the DIY design methodology and the self-design approach. Furthermore, some researchers developed applications for the automatic design of products via computational design tools according to mass customization concept (Kyratsis, 2020). All that -automated produced- geometries and forms are related to the unique brand image of the specific designer or design firm as reference.

2.1 The IKEA effect

Norton et al. (2012) refer the definition of the IKEA effect as the increase in valuation of self-made products. More specifically, the IKEA effect was seen when individuals who build IKEA boxes, folded origami animals, and built objects from a set of Legos (as a part of Norton's experiment) were willing to pay more for their finished product than the same product that was assembled by an expert (Ling et al., 2020). According to Kim (2015) the specific strategy (IKEA effect), while enjoying a marketing effect, has become an opportunity for promoting transformation to a practical customer-oriented, differentiated furniture image solely for IKEA.

2.2 The 'Do-It-Yourself (DIY)' design methodology

The Do-It-Yourself (DIY) design process enable users to express themselves through the design thinking approach. Hoftijzer (2017) refer that nowadays DIY has a contemporary role in market as a result of the computer science and digitization tools (i.e. user generated content made). Prendeville et al. (2017) provides a formulation of fourteen DIY principles (i.e. use modular design, use commonplace materials, facilitate for flexible construction, etc.). Furthermore, the DIY design approach applies to a great number of consumer products (i.e. furniture, electronic gadgets, jewelries, etc.).

2.3 Mass customization concept

Product customization uses a flexible production system to deliver a product to order that matches the needs of an individual user (Randall et al., 2003). Mugge et al. (2008) refer that product personalization gives individual users the opportunity to act as co-creators and partly conclude the appearance and the functionality of the product they buy. Furthermore, Mugge et al. (2008) suggest seven specific dimensions of mass customization concept: mental effort, physical effort, flexibility, initiation, goal of product personalization, personalization moment, and deliberateness. Ardito et al. (2011) presents a paper that explores the roles of end users in the life cycle of interactive system for furniture design. Kyratsis et al. (2019) present a case study that follows the automatic design process of a bicycle, which is a product that can undergo many design changes throughout its life cycle. The presented case study makes use of a CAD based API in order to show that key advantages of using it.

2.4 Computational design approach

Efkolidis et al. (2020) define the computational design approach as the modern design methodology of using textual or visual programming interface to create and modify forms and geometries. Furthermore, Krause (2003) dealt with the development of applications, by using the computational design methods to generate structures or objects. According to Sequin (2005) CAD tools (included generative design tools) are progressively also becoming more suitable for aesthetic engineering. Kyratsis (2020) presents a great number of design examples that are related to the automated process of producing unusual 3D forms for 3D printing applications. The implementation tools of the proposed computational design examples are Rhinoceros3D™ and Grasshopper™.

2.5 Product shape design as brand element

Manavis and Kyratsis (2021) note that branded product identity becomes a holistic design strategy to increase competitiveness though marketing and promotional tools. According to this theory, Manavis and Kyratsis (2021) present a novel methodology for automatic creation of products based on specific brand elements. All products are based under the main theme of Cycladic marble figurines from the Early Age, supporting Greek souvenir industry. Similarly, Castro e Costa et al. (2019) present a methodology that describes the development of a computational design system for the mass customization of ceramic tableware based on specific shape grammar rules. Castro e Costa et al. (2019) propose an online design application for the end users for the creation of their own products according to the design rules. Finally, Lopes Garcia (2018) describes a grammar-based design tool for the concept phase of multipurpose chair design (The ChairDNA Design Tool). The specific application enables the generation of alternative models of chair according to the manipulation of their parameters.

3. PROPOSED METHODOLOGY

The basic idea for the present research paper combines a number of concepts. The main reason of these design concepts is the automatic creation of products based on specific branding elements. This methodology was developed according to the computational design approach by using parametric pieces of software (Rhinoceros3DTM, GrasshopperTM and Shape DiverTM). Finally, a case study presents the customization design of unique 3D forms of bookcases/desks based on the concept of Do-It-Yourself (DIY). The proposed methodology is a result of two different design fields, a) the study of brand elements (branding principles) and b) the study of computational design techniques – computational design principles (Figure 1). Some of the branding principles according to the bibliography are brand identity, meaning, response and relationship (Phillips et al., 2014). Furthermore, concepts like decomposition, pattern recognition, data representation, generalization, abstraction, and algorithms are the fundamental elements of computational design thinking (Khan & Awan, 2018). The workflow of the proposed framework works with the following procedure: a) designer investigates a great number of products under the main brand concept, b) all the common branding elements - shape, geometry, style, texture, colour, materials etc., are transformed to design-rules according to grammar-based theory. The third and the final step is about the generation of the computational design models that they are based on parameters, which include all the brand references. The following case study investigates the automatic creation of furnitures under the specific Do-I-Yourself characteristics as branding elements.

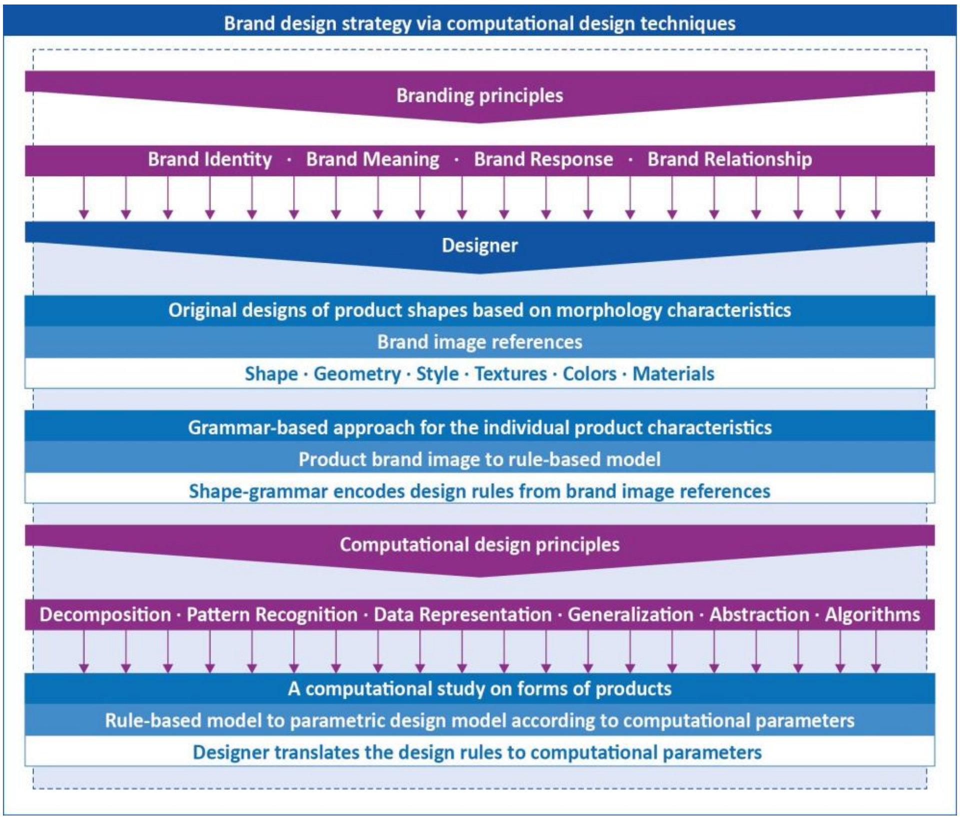

Figure 1: The proposed framework of the methodology

4. APPLICATION DEVELOPMENT

The application was designed with simplicity and ease-of-use in mind by using the helpful toolbox of Shape Diver^{TM}. Furthermore, the development of the application follows all the principles of user design experience for customized products: customization process, starting points, incremental refinement, exploit prototypes and the teach the customer (Mugge et al., 2008).

4.1 Design workflow and application

Every end-user of the proposed application is ready to create unique 3D models for alternative products under the original brand image. More specifically, the end-user specifies design solutions within the original branding concept by using the specific parameters which were developed by the designer at the stage of the computational design (Figure 1). Furthermore, the application exports a great number of crucial file formats for product design and product manufacturing purposes (Figure 2). Specifically, the application exports four different file types: a) an STL format of the produced 3D forms, b) a DWG file format with all the technical details of the final 3D products, c) a JPEG photo with the rendered version of the object and, d) a PDF report which includes all the step-by-step instructions for the final furniture's construction. The whole process of the proposed application it is known under the name of “Product Shape Generation to Support Brand Identity Elements”.

4.2 Implementation tools

The development of the application was based on three different design and programming pieces of software – one for each separate stage of the initial framework (Figure 3). More specifically, Rhinoceros3D^{TM} was used for the CAD models visualization during the design process. Grasshopper^{TM} was used for 3D CAD-based forms (according to CAD parametrization) and finally, Shape Diver^{TM} was used for the application development. The Shape Diver^{TM} is an online platform that it allows to end-users to design their own products under the specific parameters which are developed form designer's point of view.

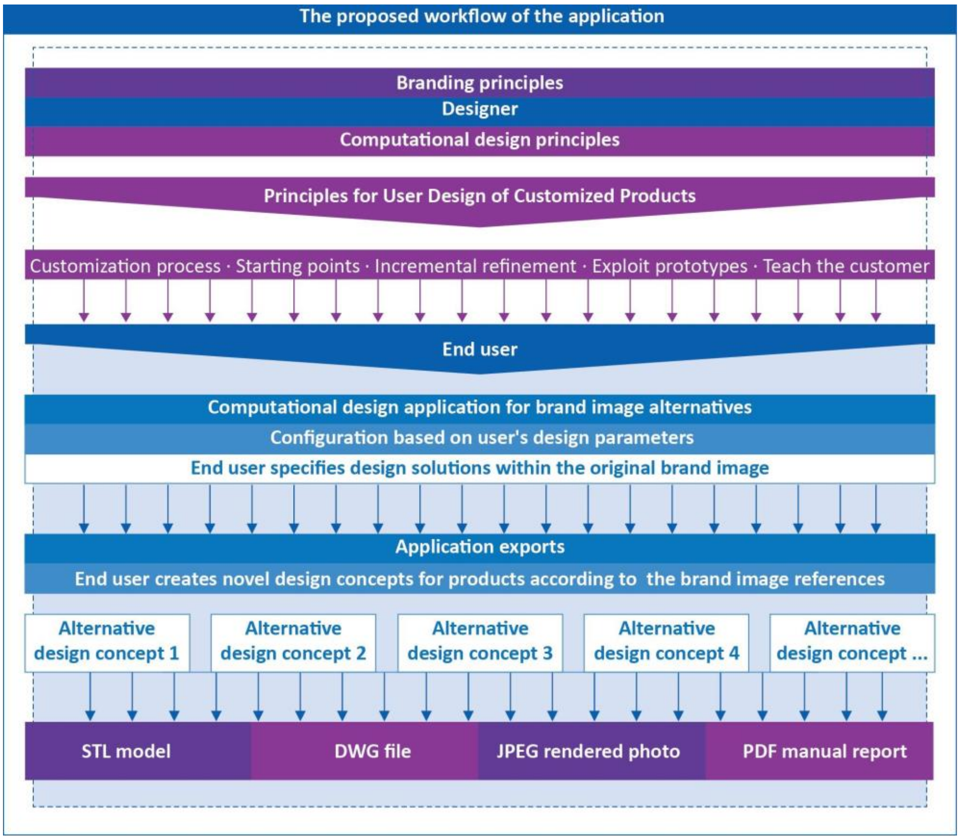

Figure 2: The proposed workflow of the application

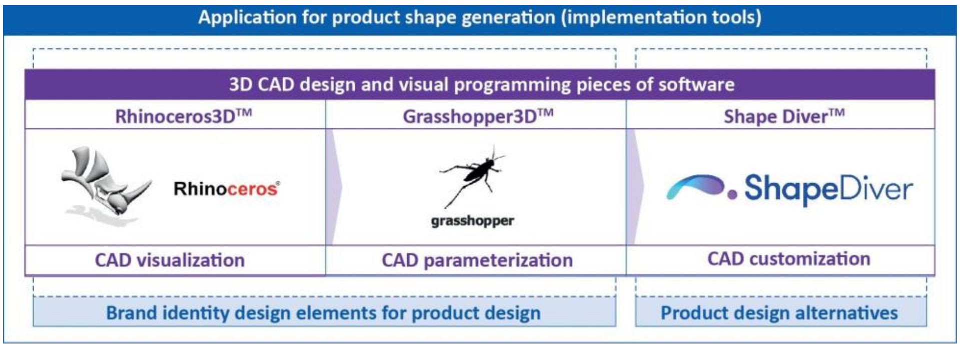

Figure 3: Implementation tools

4.3 Case study: D.I.Y. brand design strategy

The central idea is to model a modern bookcase/desk focused on the specific design-rules and parameters in relation with the brand elements of DIY style of construction. Some of these parameters are the number of shelves, the type of supports and the specific dimensions of each element separately. The basic model of the bookcase will be the initial reference for all the produced models that they will be customize via the proposed application (the end-user's point of view). Figure 4 illustrates the main concept of Do-It-Yourself brand strategy for furniture design via computational design tools.

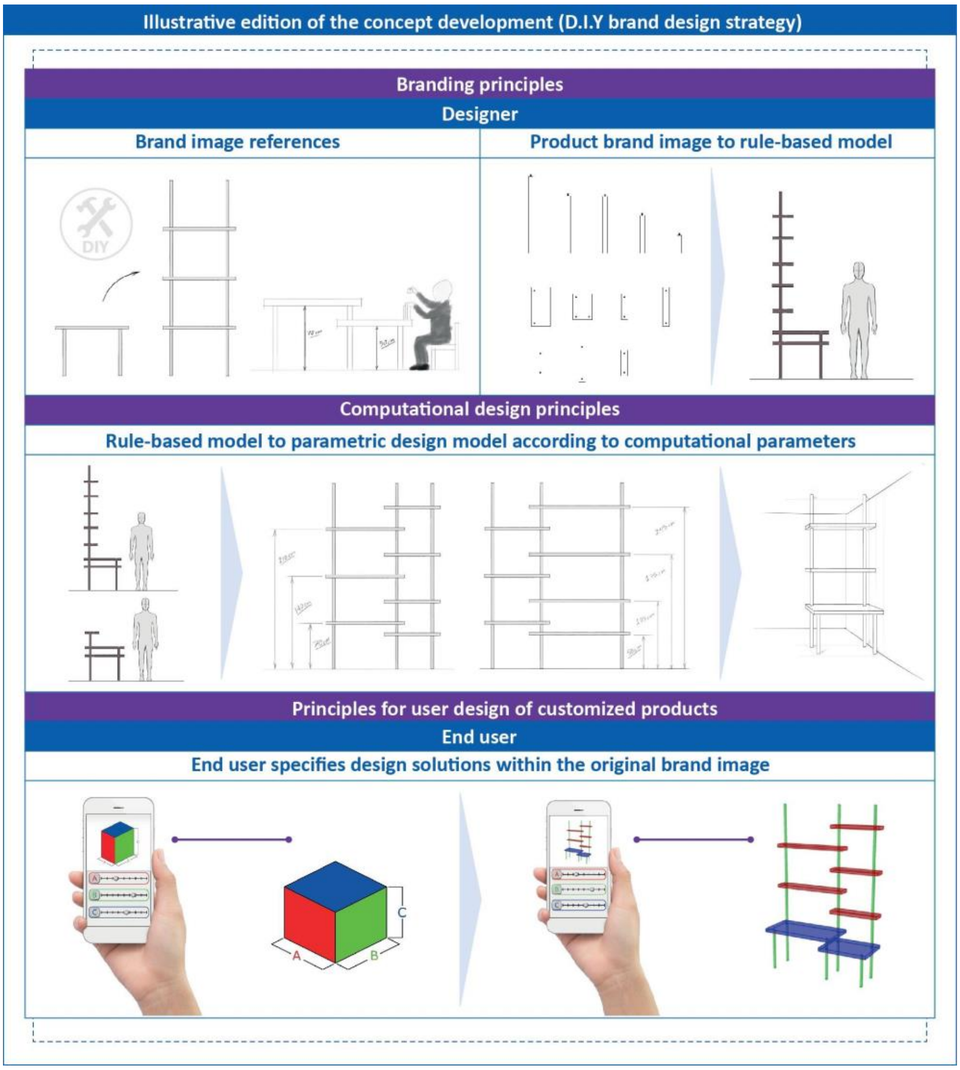

Figure 4: The main concept of the D.I.Y. brand strategy for furniture design via computational design tools

The brand image references of DIY design style are a) the type of assembiness and b) all the single elements that finalize the construction. Figure 5 illustrates the bookcase classification according to design style and the three different levels of the bookcase ontology. It is crucial to write down that there are too many similarities into bookcases designs between the varieties defined. Authors set six different categories for the common bookcase product: the traditional bookcase, the modular, the ladder, the corner, the floating and finally, the free style bookcase. All of the aforementioned type bookcases were used to create the design rules. Additionally, the authors note the object's ontology into to the single elements of the common shape of a bookcase. More specifically, a bookcase can be built from the following individual elements: shelves, supports, legs, back, side parts, uppers, cupboards, and drawers. All these different elements were translated to primitive shapes according to shape grammar methodology, in order to develop a parametric model. The developed case study encompasses three basic stages for programming and built the required customized products. The first part, named "Original Model", second is the "Rule-based Model" and finally, the third part is the "Parametric Model". Figure 5 illustrates the proposed three different parts of the customized product (section of the schematic bookcase for case study). The first part (Original Model) uses as an input the results of research about the bookcases classification and all the data from object's ontology. The next part of the procedure (Parametric Model) uses a piece of visual programming code written in Grasshopper3D™. At this stage, elements of the original model are translated to primitive geometries via shape grammar methodology.

The final step (Parametric Model) uses Grasshopper3D™ for creating the appropriate visual programming code. A series of design parameters and constraints is introduced, and the end-user is able to change them within a range of values. These configurations can generate a great number of alternatives based on the original model. Figure 6 illustrates the parameterization of the DIY-brand image of bookcase and desk.

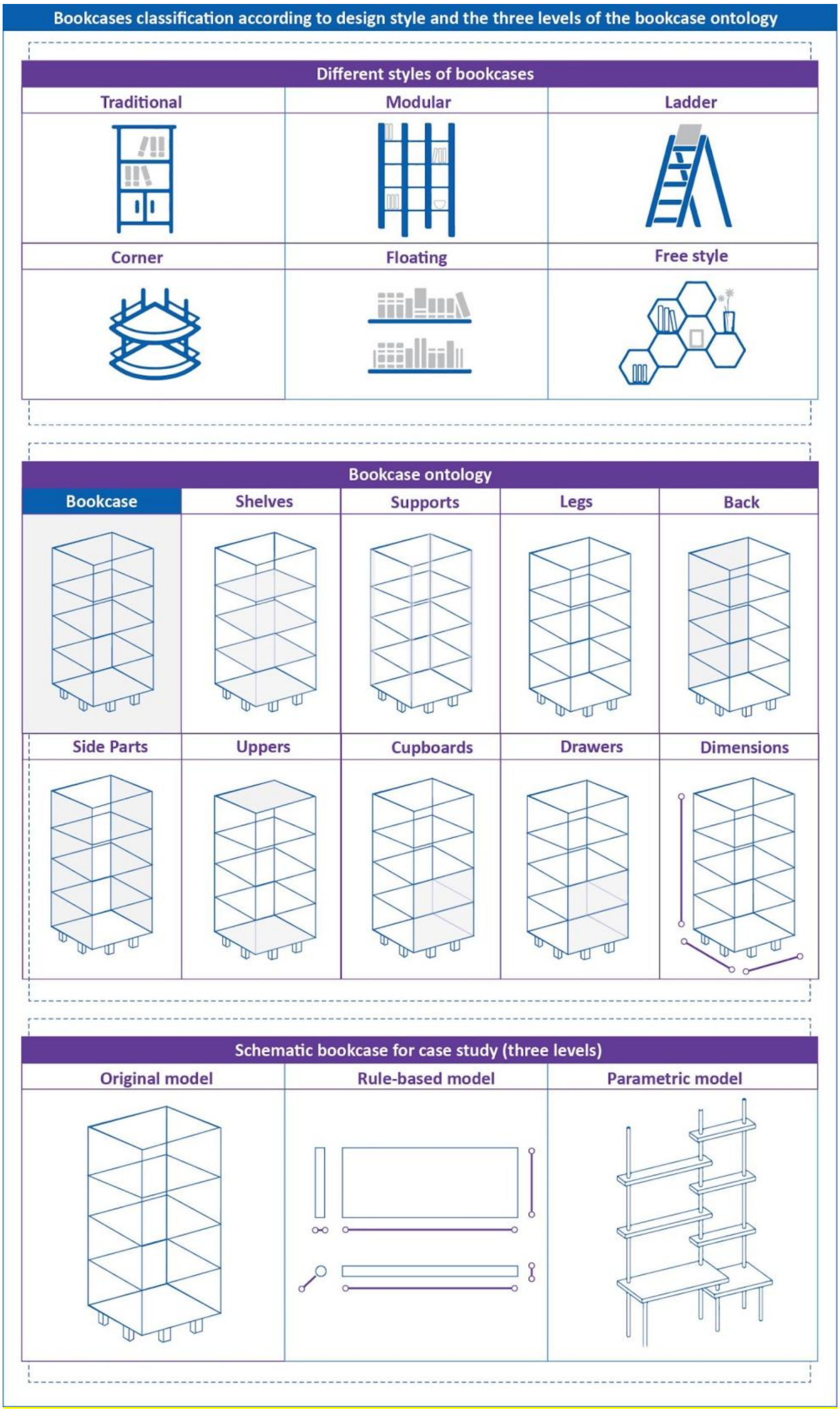

Figure 5: The illustrative edition of the framework and the application concept (D.I.Y. brand strategy)

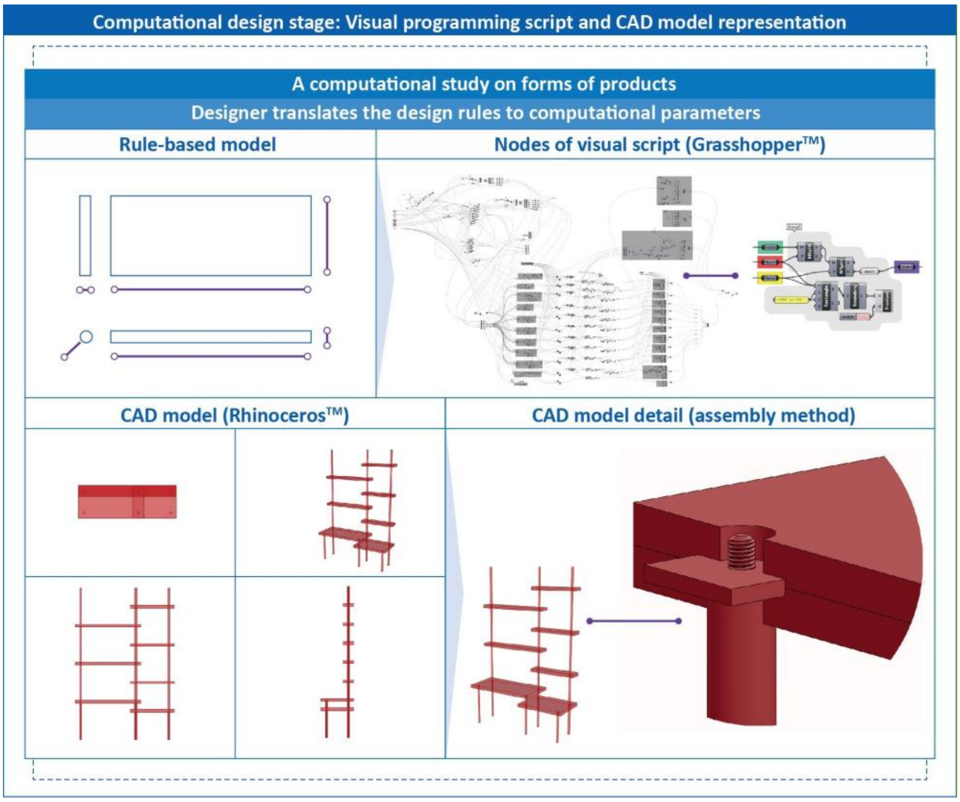

Figure 6: Computational design stage

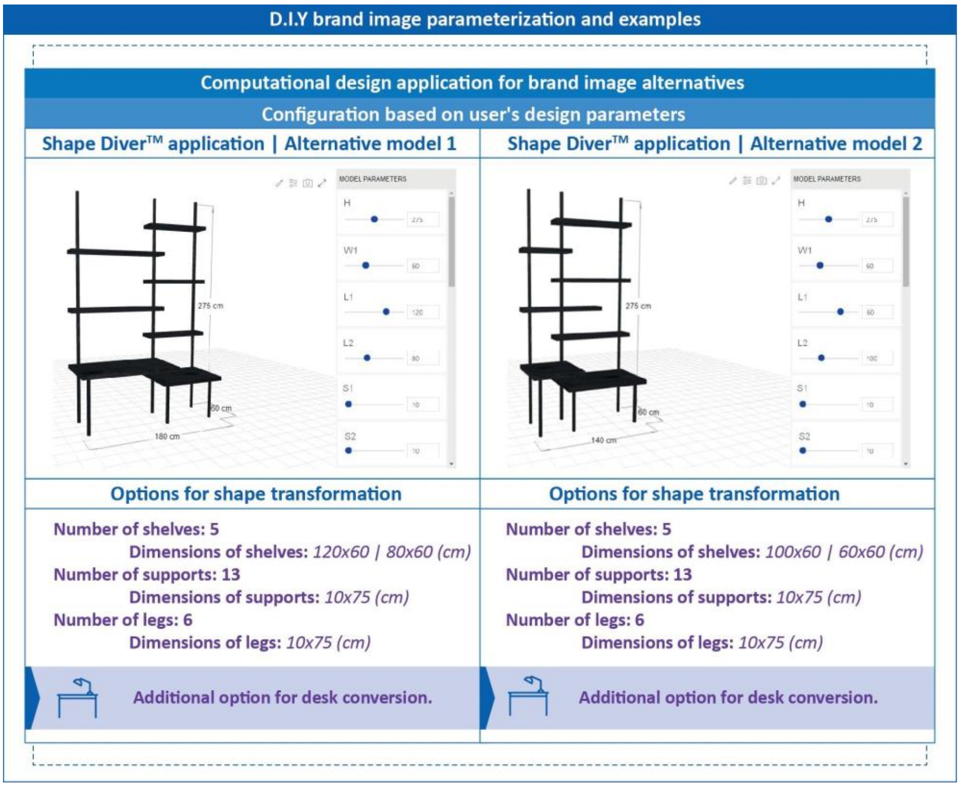

Figure 7: New bookcases/desks models and their technical specifications

The present case study shows an application for automatic creation of unique 3D forms with the aid of Rhinoceros3D™ and Grasshopper™. The end-user of the proposed application (Product Shape Generation to Support Brand Identity Elements) is able to insert numerical values for the parameters required by the online platform of Shape Diver™. Each design of bookcase/desk includes the following types of design-rules/parameters: number of shelves, dimensions of each shelf separately (length, width, height), number of supports, dimensions of each support separately (length and radius), number of legs, dimension of each leg (length, width, height). Figure 7 illustrates the final stage of the complete procedure and presents two alternative design (Alternative Model 1 &2) from the original shape DIY-branded bookcase. This approach emphasizes the development of a complete family of furnitures according to the all-branding rules that they were developed by the authors. The proposed models were produced under the Shape Diver™ online platform. All the numerical values (as shown in the Figure 7) are correspond to the real size furnitures.

4.3 Exported product design applications

The end-user is able to create his own bookcase according to DIY brand identity. In this case, the user has the responsibility to fill all the parameters to online application of "Product Shape Generation to Support Brand Identity Elements". The proposed methodological framework exports four types of file formats in order to development four specific applications for product design field. The STL model of a 3D form is a very useful format for digital fabrications purposes. Furthermore, the technical drawing (DWG) file is the most important element in order to produce the final furniture from a specific manufacturing procedure. The next exported file is about a rendered photographic representation of the shape. The production of the JPEG photograph it is based on the main characteristics of rendering synthesis: materials, textures, shadows, lights, and the environment elements. Finally, the application of "Product Shape Generation to Support Brand Identity Elements" exports a PDF report with all the instructions about the assembly of the final product. The construction manual is a very useful tool to the end-user for the final assembly of the bookcase.

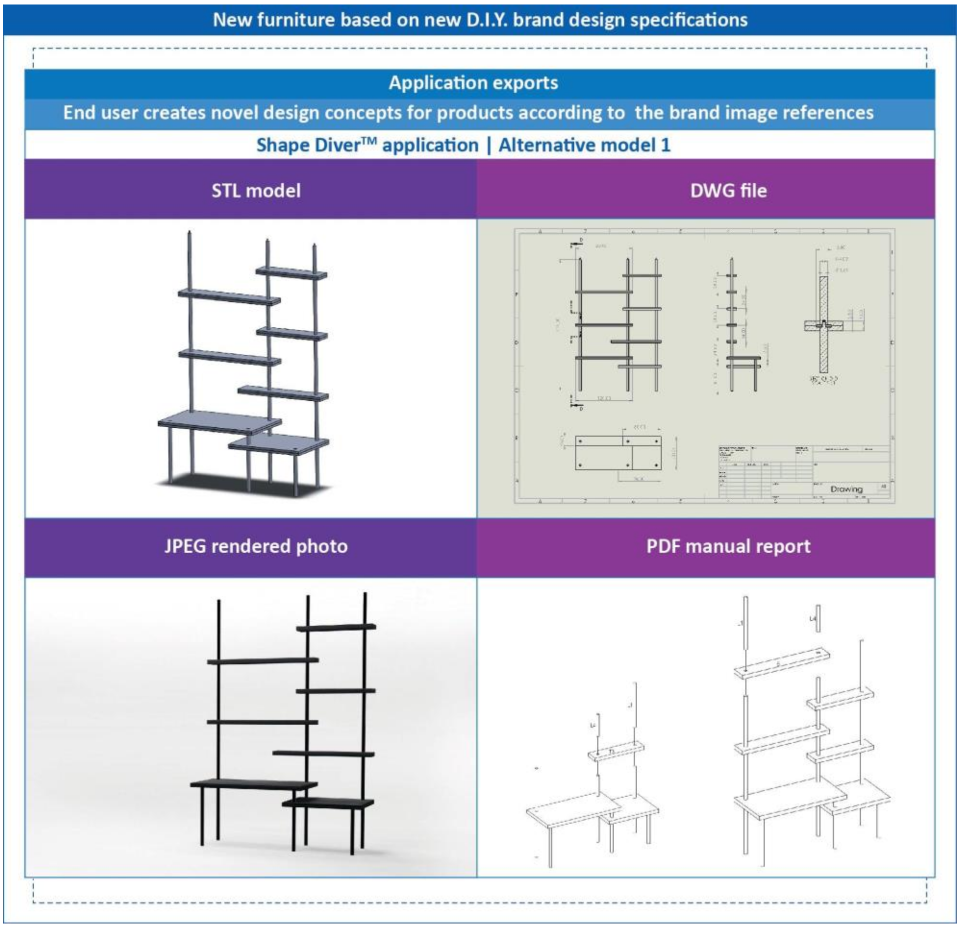

Figure 8: Application exports

5. CONCLUSIONS

The present work aims at developing a new methodology for product generation, focusing on product's image. The core idea of this paper is a combination of two different approaches: the computational design and the branding theory. Both approaches unite under the same framework and create a novel idea about an application of "Product Shape Generation to Support Brand Identity Elements". The purpose of this app is to explore, how to produce a series of similar products under the main theme of D.I.Y. method. The proposed application offers a great deal of advantages in the field of product design.

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DESIGN COMMUNICATION: FASHION DESIGN STUDENTS' PERSPECTIVES ON DIGITAL VS PHYSICAL MOOD BOARDS

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Abstract: *A mood board provides a blueprint of the design process in a particular situational design problem. With the developments in the technology the process of making and presenting a mood board has now migrated to the various digital platforms. Traditionally designers in creative world used to make physical mood boards and this has changed as some now prefer the digital mood boards. The effectiveness of mood boards cannot be overemphasised especially in the fashion design world as they provide the visual impression which is a key source of inspiration to the designer. In this study ten final year students enrolled into a fashion design degree program were interviewed to assess their perception of digital and physical mood boards. The students were given a task to respond to a situational design problem and tasked to create their mood board physically and digitally and then evaluate the process they followed in coming up with their fashion mood boards. It was revealed that many students preferred the physical method as it is more engaging to the designer and informative though it is time consuming unlike as compared to the digital mood board. It was also revealed that due to the decrease in print media as technology is advancing sources of material that can be used in developing a physical mood boards have become less especially for the students who relied heavily on printed magazines. The study concluded that students need to be taught the process of making physical mood boards first before they do the digital mood boards and also there is need to improve individual graphic design skills so that they can improve quality of their digital mood boards.*

Key words: design, fashion, mood board, students, graphics, technology

1. INTRODUCTION

Creatives strive to make their work instantly recognizable and distinguishable through being resourceful and transforming ordinary work into extraordinary works of art. In the past, designers created mood boards utilising other resources from print media such as magazines and newspapers, however due to the constant development and advancement of digital technologies in the contemporary environment, print content providers are no longer able to print magazines but rather share and sell magazines online. Print media has been around for many years, but due to technological advancements, social media has had a significant impact on how people receive knowledge and updates. People are flocking to the new technology, making it difficult for print media to actually print on large scale as the sector has been affected by advances in technology. As a result of these changes, some designers have already gradually transitioned from physical mood boards to digital mood boards, as they seek to improve communication between the designer and the final consumers of their work. A mood board, in particular, is a collage of arranged pictures, components, word, and other design features into a template that is symbolic of the final design's style and is used to generate any other form of concept design. Historically a number of designers have developed expertise in creating physical mood boards using newspapers and magazines, but due to the changing technology in the business world, a new relationship between designers and digital mood boards is starting to emerge. According to Cassidy (2011), a mood board is an essential part of the design process as it plays a role in development of the concept. The word mood board is frequently applied in a broad sense to refer to a variety of board types, each with its own set of applications. Mood boards can also be used to discretize objects and representations so that they become easily understood by the audience (Gentes, Valentin & Brulé, 2015). Endrissat, Islam and Noppeney, (2016) also state that a mood board not only sets the scene in terms of its content, but also acts as a visual and aesthetic object. A mood board that is also called a visual board is described as a sequence of photos, colors, and lettering that perfectly define the theme of a venture. That could include photos, visual representations, silhouettes, color schemes, textures, utterances, that help define the direction of one's project. Fashion mood boards were traditionally created in material reality, with magazine tear-outs, photos, and swatches pinned to a foam board, but now new technology allows a designer to now customize a mood board to their working style and brand needs. In general, a mood board clearly lays out the creator's ethics, making it possible for the creator to create components that are compatible with the main design (Brevi, Celi & Gaetani, 2019). A mood board, on the other hand, serves as an excellent communication tool when attempting to explain the creator's perspective or notion, making it easier to find inspiration. According to Brevi, Celi & Gaetani, (2019) mood boards assist a creator in awakening their creative buds so that they have a source of inspiration. They, on the other hand, assist a client in *"getting inside a designer's head"* by displaying the designer's intended vision for a piece of work. Designers frequently use mood boards to convey their creativeness and concepts in a form of media that can be shared with others in order to visually illustrate the style that they are pursuing (Edwards, Fadzli and Setchi, 2009). In some cases designers create mood boards by trimming newspapers and or even use images that are available for purchase on the internet as these are the main sources of imagery content that can be used in making up a mood board. In todays advanced world designers are now adopting use of different computer aided design software for the development and pitching their mood board ideas. Access to a vast array of online images (the internet) and photo manipulation techniques such as blending, morphing, fading, and blurring are made possible by digital technology (Edwards, Fadzli & Setchi, 2009) and these have become key in digital mood board development. In addition, photographs are very useful for both physical and digital boards, designers frequently photograph motor shows, art galleries, and architecture for inspiration. It could be argued that mood boards can be created solely from photographs that have been tailored to meet the exact specifications.

2. LITERATURE REVIEW

2.1 Design Communication

Mood boards, as finished products, are important tools for communicating with all those who participate in the design process. Fashion mood boards play a role of communication in the sector as they try to answer to the design problem at every stage from product design to manufacturing. Mood boards also improve innovative abilities and innovation fluency, in addition to exploration of the fashion and content of a design's contextual perspective (Freeman, Marcketti & Karpovaet 2017). The designer have to use their artistic skills in improvising resources or materials they have at their disposal process of making a mood board and they have to look for inspirations from their creative minds to find ideas that will respond to the design problem at hand. Ultimately, by using mood boards, designers may be capable of communicating graphically and effectively what appears to be a cluster of seemingly unrelated design ideas that are difficult to articulate through text or words with similar results (Freeman et al., 2017). In addition, Cassidy (2011) explained that, designers primarily use mood boards to bring together realted material through use of visuals and images. In fashion design mood boards are common to the idea development process as they help in outlining key element of designs like colour, fabric texture and styles. Inspiration boards are critical to a design project's ultimate effectiveness. They serve as a foundation and visual direction for a project, aid in the generation of new ideas, and keep reader on track to develop consistent, cohesive brand designs and it gives the designer a sense of design creativity through the gathering of inspiration. There are also storyboards that help the designer to plan several key illustrations features derived from the inspiration board. This generally points out that these three mentioned above work hand in hand in the design communication process.

2.2 Physical and Digital Fashion Mood Board

In general mood boards, story boards and inspiration boards can be digital or physical. Traditional ones are typically made of foam that can be cut up and painted. They may take a long time to create, but they have a greater impact on the kinesthetically inclined. Digital mood boards on the other hand, are easier to create, especially when working on collaborative projects as they might very well contain videos or sounds and are made easily available online (Garner & McDonagh-Philp, 2001). Mood boards allow designers to express tough or tricky ideas and provide the opportunity for innovative discovery. Garner & McDonagh-Philp, (2001) state that a mood board is more of a collection of discovered images that are patched to a board for display purposes; sometimes found artifacts or construction methods are combined to produce a 3D visual sensation.

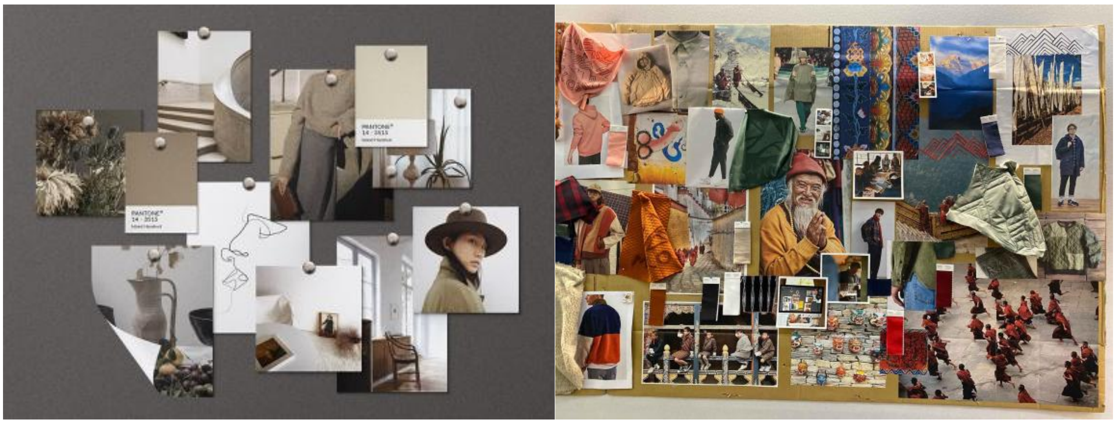

Figure 1: Digital Mood Board (left) vs Physical Mood Board (right)

A digital mood board is done electronically using computer softwares whereas a physical mood board is constructed out of a foam which can be cut up or painted on. The two types pf mood boards have different eefects towards the viewer and they play one role. Digital mood boards are easier to use in design communication because they can be shared electronically within a short space of time to different designers in diffrent places, whereas a physical mood board is difficult to carry around as it is usually bigger in size. A designer should be able to align and be creative enough to come up with a source of inspiration which will enbale them to critically align pictures and fabric swatches in a creative manner. The same applies to digital mood boards, for a designer to construct one, they have to be well educated on how computer aided design software works, so that the designer will be able to use the available information to create a mood board.

2.3 Steps in Making a Mood Board

According to Clancy (2022) there are certain steps that are considered in making a mood board and these steps are as follows:

1. Setting direction of the project, planning what needed to be done
2. Collecting existing material, which vary from the type of instrument being used to make the mood board, the existing material maybe from magazines or from the online media.
3. Adding inspiring imagery on the board to create a mood through pictures and colors.
4. Addition of motion and sound can be applied only if it's a digital mood board that's created using a video form. An online mood board allows you to embed examples of how movement and animation can help a piece of creative work.
5. To remain open to inspiration, requires the designer to focus and look into different ideas for new innovative inspirations.
6. Addition of color and fabric textures be it digitally or physically.

The process of making a mood boards is iterative in nature meaning one has to keep checking if it is still answering to the design problem as given.

3. METHODS

The students were given a situational design problem in the fashion design class and were tasked to come up with a physical moodboard and a digital moodboard of the same problem. They were then asked to evaluate both methods employed in coming up with the moodboards in an effort to establish their views and experiences they had in both cases. According to Cassidy (2011) moodboards can be viewed as a qualitative research tool as it seeks to explain the design using visual and text representation of the design concept or idea. The students selected for the task were final year students doing a degree in fashion design. Students in their final year will have gained experience from the first year where they learn the basics in fashion design up to the time they are expected to do their final capstone project. The process of making a moodboard is both creative and problem solving thus the process was also monitored through use of observation method. The students were also interviewed so that they could explain some of the challenges they faced in both scenarios of making up of thee moodboards. The questions designed for the interview were both long and short open ended questions so as to allow the students to explain themselves. In the observation guide aspects like time taken and how the students sourced for material or resources to use were assessed. The observations adopted the think aloud method as proposed by Van Someron et al. (1994) and also used by Cassidy (2011) in her study on mood boards with fashion design students. The observation were done during the class time for a period of two weeks so as to allow the students to research and discuss the fashion design problem task at hand. The think aloud method allows students to critique themselves as they try to solve the problem at hand and is one of the most effective evaluation techniques for designers Wright & Monk, (1991).

4. DISCUSSION

All the ten (students) managed to produce the two moodboards and participated in the semi structured interviews. The observations done and were recorded and key points highlighted in all the practical sessions when the students came to class for the development of their mood boards. All the students managed to create their mood board in both formats that is the physical and the digital mood board. The physical mood boards are iterative in nature and during the observations it was highlighted that some students kept changing their collages up until a point they thought they are now good visual presentations. For the digital moodboards the students were allowed opportunities to explore various software they were comfortable with in making up the mood board.

4.1 Design communication

All the students managed to respond to the design problem as given. The students worked faster in making the digital mood boards unlike the physical mood board. The design problem for the fashion task was done by all the participants. During the follow up interviews one participant stated that in terms of communicating her fashion idea she preferred the physical mood board as it gave her more freedom in freely expressing her current mood as through use of texture, color, fabric and lines. She stated that "*a picture is a thousand words and I prefer having the right image that I will cut out from the magazine and paste it onto my working board together with my hand drawn sketches*".

In this study the students managed to come up with their mood boards and in other successfully managed to communicate their design ideas as this is one of the key attributes of a mood board to communicate (McDonagh & Storer, 2004). A poorly constructed mood board may not be interpreted the same way with different viewers and in this study the students preferred to add both text and hand drawn sketches to help the viewers understand their design ideas. As a design tool mood boards have to effectively try to communicate the concept without much explanation. The students also agreed that their efforts in making the mood boards was affected by the fact that in fashion it is the final product that really matters. The journey one would have gone through in the process of solving the design case might not really matter to the student but the ultimate product. This view is also shared with Gentes, Valentin and Brulé (2015) who state that rarely do students keep these mood boards as they do not view them as a final product. As a design tool to communicate the task is now left to the lecturer or teacher to formulate the curriculum in such a way that the student appreciates the role played by mood boards in design. De Wet and Tselepis (2015) proposes a framework students can use in trying to create authentic mood boards and this can also apply to both cases of making the mood boards so that owners of images used are acknowledged. Duplication of online images on the digital mood boards was highlighted as students shared similar content online.

4.2 Digital mood board in fashion

The students managed to use general creative design software such as Adobe Illustrator, CorelDraw, and AutoCAD. Other students also managed to use free mood board applications like Pinterest, Canva and GoMoodboard. From the interviews with students it was highlighted that use of these software or applications to make fashion mood boards was somehow difficult as most of the students had to learn some of the tools for the first time. Despite the easy sharing of digital files that happened amongst students sharing images to use for the task at hand most of the students argued that the detail they would have wanted to add to make their mood boards was difficult to put across. Fashion design mood boards require more detail so that the design can be easily communicated. Digital mood board is easy to share with clients or friends but from the interviews it was noted that it has very high chances of failure in interpretation. In fashion design education the mood board is expected to reflect on the original idea of the student designer who creates his / her mood board, but the challenge that comes with the process is issue of accountability on images used. The students had challenges in working around the templates on some of the platforms and they cited that use of templates can be problematic as they do not give you much flexibility whilst at the same time you are worried of changing the template that you will have identified as the best layout. One student stated, "*The templates from the application are not working well with my design especially the imported hand rendered sketches, so I have to cut out some detail so that I can make my design fit.*"

4.3 Physical mood boards

The making of physical mood boards meant the student had to collect images from newspapers, magazines, flyers and other various sources. Due to changes in technology the print media has been on the downward trend and as such students faced some difficulties in getting wide varieties of images from different sources. From the observations students spent a lot of time making the physical mood boards as they tried as much as they could to put the detail they thought was relevant. One student participant stated, "*I have to make sure my fashion idea is well communicated so I have to add fresh leaves and grass to really put emphasis on life and sustainability of my product*". The use of mood boards in fashion helps to capture the emotional experience from different viewpoints. The physical mood boards seem to be better according to the students in capturing this emotional experience and were more detailed in presentation. During the interviews the students also highlighted that there is originality in the making of the physical mood boards thus giving the students a learning experience and ability to self-introspect their design ideas. The physical mood boards also promote realistic concepts that can easily be understood by the viewer irrespective of their lack of understanding of fashion ideas. According to Costa et al. (2003) use of the actual images in the making of a mood boards help to develop a better understanding of the design idea at hand, in this study it was revealed that though it took some time to collect or gather images to use for mood boards, that process in itself also gave the students time to do more research and even learn about other new things as they used different magazines and printed media. It was also highlighted that use of use of images alone is not adequate hence a combination of text, images and hand drawn sketches in the making up of the mood boards. As fashion design students they also argued that showing drawing skills also improves or convinces who ever will view the mood board of their particular design as there is originality and reality.

4.4 Inspiration and design thinking

The results from the interviews carried out with the students highlighted a number of important aspects covered by the moodboards. It was noted that through use of mood boards one can expand their design thinking horizon as the new ideas are generated. Through mood board one can easily understand the designers taste and preferences. Mood boards are valuable design tools as they provide communication and inspiration both to the designer and viewer hence the name interchange inspiration board. The study also revealed that mood boards if used correctly, they can become key in the recruitment process especially in fashion design sector though this is not to say they replace the resume of the applicant. Mood boards provide a room for the designer to organize the gathered visual content in a constructive way that allows a clear flow of thought process and the background inspiration. Theoretical assumptions of the constructivist theory (Knowles, 1975) on adult learning highlights that students are self-motivated and self-directed to learn. The theory also states that the passion to learn is developed through real life tasks and problems students face on a daily basis and these experiences become sources of learning. In design field the engagement with real life experience develops the student's capacity to create or come up with a new design idea. From this study through the making of physical mood boards this knowledge and experience can be gained by the students easily. In this study the students opined that in fashion design mood boards improve their analytical and artistic skills in the entire fashion design process a view also supported by (Garner & McDonagh-Philp, 2001). Digital mood boards are easily adaptable than physical mood boards as they require less time to create though skill to manipulate are key for the students to first develop. Mood boards, in general, are designed to be quick, easy, and inexpensive to create, particularly when compared to potential errors and subsequent modifications. The primary goal of mood boards is to make the judgement call process as simple as possible. They also enable the individual to select from two or three visually pleasing strategies, reducing the risk of overburdening them. Mood boards, on the other hand, are only recommendations.

Table 1: A summary breakdown of the key marking points used in the observation guide

	Case 1 Physical moodboard	Case 2 Digital moodboard
Construction (time)	Takes a lot of time	Takes less time
Viewer engagement	Highly engaging	Depends on hardware, software and resolution of the screen
Resources	Requires a lot of resources to be put together	Just a computer with the design software
Creativity	Allows one to show their creativity	Limited or affected by the software
Effectiveness in communication	Very effective especially when viewed in person	Effective in geographically distant engagements
Sustainability aspect	Re use of discarded materials	Does not use
Resources	Need to collect images from magazines and other print media sources	Easily available online
Preference	Enjoyable and more engaging as it offers flexibility	Good to those who are good in manipulation digital fashion illustrations

5. CONCLUSIONS

Mood boards are important in the design industry in general. In the fashion industry they can assist in communication of the design. The process of developing a digital mood board was similar to that of the physical mood board though students preferred the physical mood board. In fashion design the physical mood board was found to be more expressive as it is more detailed than the digital mood board, which on the other hand is easily communicated unlike the physical mood board. Mood boards are important during the concept development stage as they dictate the project direction and once this is interpreted wrongly the viewers will fail to appreciate the design itself. In this study the students preferred adoption of the physical mood boards for the live presentations as these proffer more detail to the design thinking process. The study concludes that digital mood boards are easy to make as they require less resources but they do require the students to first develop their graphic design skills so that they can be as informative as the physical mood boards. The study also puts emphasis on the need for students to be taught the process of making the physical mood board first so that they appreciate its importance in the design thinking process and be able to then transfer this onto the digital platform. Mood boards are qualitative in nature and are important in visualizing the design idea and they play a key role in developing the student's creative thinking process.

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ANALYSIS AND DESIGN OF ANIMATED POSTERS

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Abstract: *Using a static or animated information on a medium, such as a poster, is a common decision to be made nowadays. Advertising solutions in the form of a screen that mimics a traditional poster format offer us a way to bring to life something that has been static for more than a century. Deciding if and when it is better to use an animated rather than a static (printed) poster is not always easy. The campaign budget has to be higher, and a decision must be based on the proven effectiveness and communicativeness of the medium in question. Research is focused on whether and how animation can improve perception. The main hypothesis is that animation of some graphic elements can improve the visibility and therefore the effectiveness of a poster. The first step of the research was to prepare a test material. In cooperation with Cankarjev dom, we animated five of their posters, the original of which was prepared only for printing. Different artistic styles and compositions were chosen. The second step was to animate some of the elements, focusing on the effectiveness and communicativeness of the final result. In order to determine the difference in the perception of static and animated posters, different methods could be used. Previous research has shown that the use of eye-tracking provides useful results. Like many other areas of graphic communication, e.g. photography, copywriting, graphic design ... eye-tracking has been influenced by the use of artificial intelligence as well. The use of neural networks fed with big amounts of real eye-tracking measurements gives us the ability to predict with great confidence the way the human eye looks at something. In our research, we used software called Expoze that analyses the content of an image or video and predicts heatmaps of how real observers would see the test material. The end result of the research gives us a detailed view of how we receive information from static and animated posters.*

Key words: *animated poster, artificial intelligence, eye-tracking, graphic design, motion perception.*

1. INTRODUCTION

While the general role of advertising has already been analysed in detail, the importance of advertising in urban areas has often been neglected. The rise of the advertising industry in recent decades has been accompanied by an increase in the amount and frequency of information we encounter on a daily basis. As the human brain can only absorb a certain amount of information, we as a society have begun to selectively choose the information that grabs our attention (Gulmez, Karaca & Kitapci, 2010). Animated posters have become an innovation in advertising and are most commonly used on social media and outdoor digital screens.

Animation is defined as a visual, dynamic message created through movement in a specific time frame (Baecker & Small, 1990). A sense of movement is created by successively changing images, with each successive image differing only minimally from the previous one. The use of animation in advertising began in the 1940s (Selby, 2022), with the term 'animated poster' originating with Swiss designer Felix Pfaellie. Animated posters present information in a specific sequence of frames, starting with the first (start key frame) and ending with the last (end key frame), and are designed to repeat their content imperceptibly over and over again (loop) (Harrison, 2018). The movements on the animated poster are smaller and simpler, not to be confused with longer animations or even movies (Dehrashid, 2021). The most commonly used ways to add movement to the poster are: Experimenting with typography and text, changing the colours and sizes of elements, adding smaller elements that highlight certain content of the poster, moving certain elements or playing with light on the poster itself. Animated posters are playing an increasingly important role in advertising as they can attract attention, inspire and entertain in a very short time. The advantages of animated over static graphics are: great creative freedom that allows designers to portray the brand more vividly and easily, achieve greater visibility and memorability, get the message across faster, hold the viewer's attention more easily and longer, enhance the user experience and stand out from the overwhelming amount of information (Sagiadinos, 2022).

Clear Channel is an American company that owns more than 330,000 outdoor advertising spaces and works with many large companies to create attention-grabbing campaigns in a highly creative way. It also strongly promotes the use of motion in advertising (Social + DOOH, 2022). Together with Talon, it conducted a survey in 2018 on the perception of animated posters compared to static posters. They concluded that adding motion to the ads strongly influenced the success of the campaign with an increase of up to 23%. They also confirmed the increase of viewer's level of reflection and retention by 8% and purchase intent increased by 20%. In general, they found that an animated poster is twice as noticeable as a static one and maintains the viewer's attention 60% longer (Clear channel, 2022).

2. MATERIALS AND METHODS

2.1 Materials

For this research we collaborated with Cankarjev dom, Slovenia's largest cultural institution and congress centre. The main idea was to select five of their static posters (Figure 1), then create animation posters based on the same design, and finally compare their effectiveness. We used different tools to create the animated posters. The whole process of animation was done on an Apple Macbook Pro 15 (2018) laptop. Adobe Creative Cloud software, Adobe Illustrator 2022 and Adobe After Effects 2022 for animation were used to transform the posters. The web tool Expoze.io was used to generate the heatmaps and the research was completed with two versions of a survey on the website Survey sparrow.
Figure 1 shows the static poster for the *20th LIFFe*, designed by the in-house designer of Cankarjev dom, Mag. Maja Gspan Vavpetič. It is a typographic poster, as all the main elements are represented with typography. The poster is characterised by the words "love" and "life" (or liffe) as the key concepts of the festival, which are always connected. Life without love is empty, just as the poster would be empty if one of the two words were left out and vice versa.

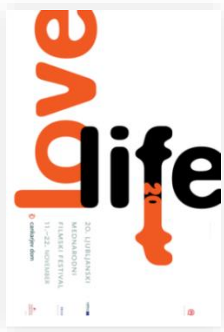


Figure 1: Poster for 20th LIFFe.

The poster was animated based on the idea of how life and love are connected, and especially on the important role of love in a person's life. Love for oneself, for one's partner, for one's family, for one's friends or love for hobbies, for things that bring a person joy and happiness, that inspire them and drive them forward in life. All this is contained in the word love. The words "love" and "life" are written in different directions on the poster because many people feel a lack of love (and therefore of one of the things mentioned above) at some point in their lives. In such situations, we look for ways to find these beautiful feelings again. Therefore, we have designed the animation (Figure 2) in such a way that we "find" the words themselves on the poster, which illustrates the idea described earlier.

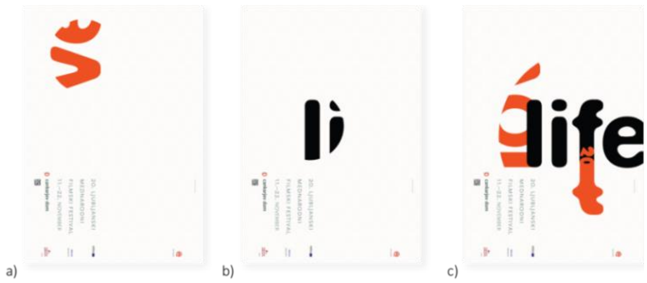


Figure 2: Animated poster for 20th LIFFe; a) starting keyframe, b) intermdeial keyframe, c) ending keyframe

The second poster we selected for animation was a poster design for the *26th LIFFe* (Figure 3). The idea behind the design was to write the name of the festival in different languages of the world (LIFFe, 2022). Each language has its own colour and line, and together the inscriptions form a colourful whole that forms the background of the poster. The design of the poster represents the meaning and the key message of the festival itself. Its main purpose is to introduce society to the works of different authors and cultures, while supporting smaller producers who are not yet established in the field. The different colours and sizes of the individual captions underline their variety and diversity. The foreground element of 'liffe' justifies its importance and presents itself as a solid pillar in this gathered mass of creators.

Figure 3: Poster fot 26th LIFFe

The animation concept was based on the idea of representing a large pool of producers and films that are very different from each other. We wanted to highlight this diversity by moving the captions outside the poster in the opposite direction each time (Figure 4). This creates a sense of a diverse community that ultimately has a holistic effect both on the poster and in the realm of the film itself, whose filmmakers are brought together by the festival.

Figure 4: Animated poster for 26th LIFFe; a) starting keyframe, b) intermdeial keyframe, c) ending keyframe

Figure 5 shows the poster for the 2022/2023 season and is a typical typographic poster. The word "ABONMAJI" is printed in linear black, bold and highly enlarged letters across the entire poster and divided into three lines by syllables. The viewer's secondary attention is drawn to the background lettering, which is smaller and in pink and illustrates the different contents of covered by the season tickets.

Figure 5: Abonmaji poster

When we brought movement to the poster, we wanted to ephasise the word "ABONMAJI" by successively enlarging the letters in each line, creating a visual effect that stood out from the rest of the poster. We depicted signs such as "MUSIC", "THEATRE" and "DANCE" as a steady movement to the left and right respectively (Figure 6).

Figure 6: Abonmaji animated poster; a) starting keyframe, b) intermdeial keyframe, c) ending keyframe

The *Veličastni* poster shown in Figure 7 consists of a photograph showing two dancers embraced in shades of blue, which form the background for the actual design. The name of the ballet company, the title of the performance and the composer of the music stretch from the left side of the poster across the middle. At the bottom, the word "magnificent" appears in the centre alignment, consisting of a yellow border in a slightly more playful tone.

Figure 7: Veličastni poster

When animating the poster (Figure 8), we wanted to give the viewer the feeling of a real ballet performance. We brought magic and elegance to the movement and played with lighting effects, which are an important part of any dance production. We designed the idea so that the animation appears very subtle at the beginning. The background is dark, you only see the flickering light particles that are also part of the static poster. Then, slowly and only minimally, the other elements of the poster are illuminated. In the next moment, a narrow beam of light appears from the left corner, gently sweeping across the entire poster as if following the dancers on stage. As the beam disappears, the rest of the poster is gradually illuminated so that we can briefly glimpse the overall image of the static poster.

Figure 8: Veličastni animated poster; a) starting keyframe, b) intermdeial keyframe, c) ending keyframe

The design of the poster (Figure 9) consists largely of a photograph of Nikola Tesla framed and interspersed with lightning bolts shooting from the top edge across the image of Tesla.

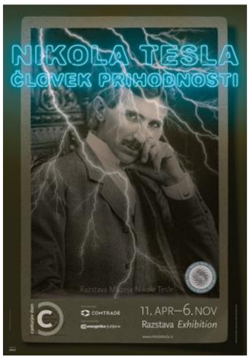


Figure 9: Poster for an exhebitiion of Nikola Tesla

We have kept the static image of Nikola Tesla as a stable element of the content. When adding movement, we focused mainly on the flashing of the lightning and the subsequent flashing of the neon sign. The animated poster (Figure 10) is darkened at first, appearing mysterious and arousing the viewer's interest. Then the first lightning flashes on the screen, followed by the flashing neon sign, followed by the rest of the poster. While the flashes continue to twitch, the penetrating gaze of Nikola Tesla rests on the viewers.

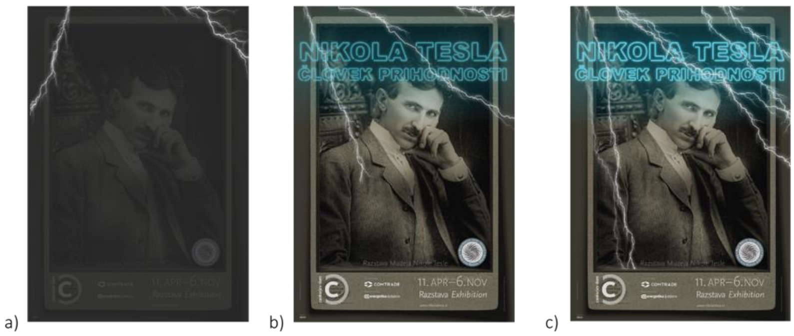


Figure 10: Animated poster for an exhebitiion of Nikola Tesla; a) starting keyframe, b) intermdeial keyframe, c) ending keyframe

2.2 Methods

Two different approaches were used to study the effects of static and animated posters. The first approach was more objective and used the AI predictive eye-tracking software Expoze.io (Expoze, 2022). With this tool we created heatmaps for both static and animated posters. The results are generated based on artificial intelligence, which is a great advantage in terms of the temporal component, as we do not need actual test subjects to collect the results. The programme was created with the help of thousands of contributors and now has a 95% reliability rate. To create our own material, we uploaded the images to the database on the website and within minutes the heatmaps were created.
The second approach was an online survey based mainly on the subjective responses of the participants, as we also wanted to check the memorability of different information on posters. In order to get the most meaningful results, we designed two different versions of the survey that differed only in the examples of posters that were presented to the respondents. In each version of the survey, all five posters were shown - but either as static or animated versions. The posters that were static in the first version appeared animated in the second version.
Sixty participants of different genders and ages took part in the online survey, 41 of whom were women and 19 men. Most of them were between 15 and 25 years old. Table 1 below shows their data.

Table 1: Charateristics of online survey participants

Gender		Age			
M	F	15–25	26–35	36–50	50+
19	41	27	10	13	10

Measuring the effectiveness of animated posters is difficult, not only because they are usually presented in city centres, but also because of the nature of the results, especially memorability, that we wanted to obtain. For this reason, we used two different approaches. While the results of the generated heatmaps provide information about the concentration of the gaze, the online survey provides important information about the memorability and effectiveness of the poster with communicating its content to the observants.

3. RESULTS

The aim of the work was to investigate the significance of movement on posters and to explore whether and to what extent animation contributes to the success of advertising. In particular, how it affects the observer, whether it holds his attention and whether it conveys a certain piece of information faster and more accurately.

3.1 Predictive eye-tracking testing with Expoze.io

First, we used the online tool Expoze.io to create heatmaps for static and animated posters.
On the heatmap of the *20th LIFFe* (Figure 11, a), the letter "o" was coloured with dark red spots, indicating that this area attracts the most attention. The result is quite predictable, as this is also a meeting point for the two main inscriptions on the poster and also a starting point for their reading. The less colourful areas are those that contain information about the name and date of the event at the bottom left. The logos at the bottom of the posters are the least colourful.
In animating the static poster, we focused on the most important technical information about the event, which did not get enough attention in the primary static version. With the additional movement, we wanted to give the viewer the opportunity to notice the date information first. The animation engages the viewers and at the same time forces them to follow the motion until after a few seconds the entire poster appears. By analysing a heatmap (Figure 11, b), we came to the conclusion that the poster with this particular motion provides some basic information that would otherwise be lost in the design itself. At the same time, we achieved a better perception of the individual sections with the animation and, above all, increased the engagement of the observer himself.

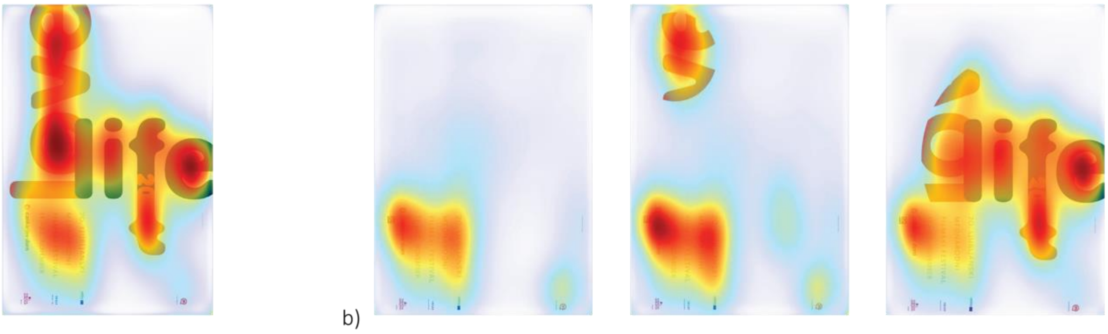


Figure 11: Heatmaps of the: a) static poster and b) animated poster for the 20th LIFFe

In the heatmap based on a static poster for the *26th LIFFe* (Figure 12, a), it can be seen that the upper left part of the posters is coloured the most intense dark red, which means that the concentration of gazes was highest there. We wanted to make sure that the viewer perceived both the background and the main text of the poster. The results show that the word "life" in black colour does not overshadow the background, which is also a very important component of this static poster. When designing the animated version, we focused on making the background even more visible to the viewer. This is the main reason why we decided to animate only coloured text in the background and move each line of text in its own direction (left or right). After creating the heatmap of the animated poster (Figure 12, b), the results show that we kept the background of the poster and even drew more attention to it.

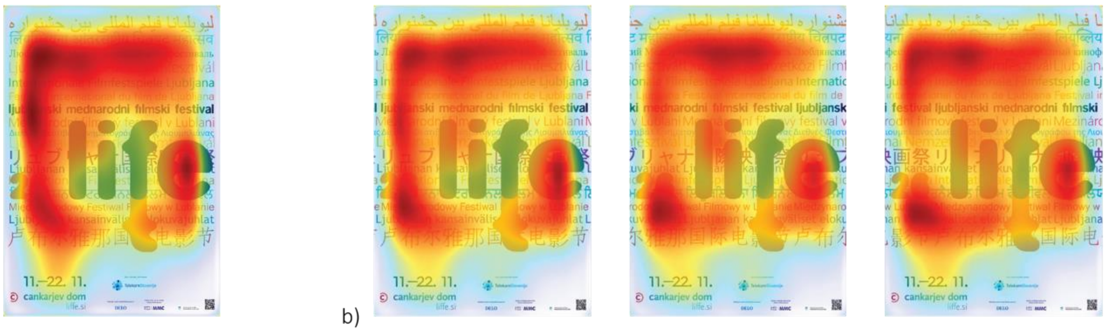


Figure 12: Heatmaps of the: a) static poster and b) animated poster for the 26th LIFFe

In a poster *Abonmaji* we are confronted with a large amount of information that needs to be communicated to the observer. All the elements of the poster are typographic and expressed with a linear font, which makes it even more difficult to bring movement into the poster so that certain information does not overshadow the others. The only exception is the logo of Cankarjev dom, which is quite large and displayed in a vivid orange colour. The heatmap of the static poster (Figure 13, a) shows that the logotype and the letter "O" in the word "ABONMAJI" are the areas with the greatest concentration of views and therefore attract more attention from the start. When creating an animated poster, we mainly wanted to shift the focus from the logo to the letter "A" in the word "ABONMAJI", which is not so clearly visible in the heatmap of the static poster. For this purpose we animated only the main word "ABONMAJI" in bold black letters to make it larger and stand out from the rest of the design. As can be seen in the heatmap of the animated poster (Figure 13, b), the logotype is still the most viewed area due to its colour and size. The concentration of views has shifted slightly due to other parts of the design. The other elements are coloured in roughly the same shades of orange as in the heatmap of the static poster, which means that the hierarchy of the poster has remained unchanged and the movement of the text in the background has not overtaken the main message of the poster.

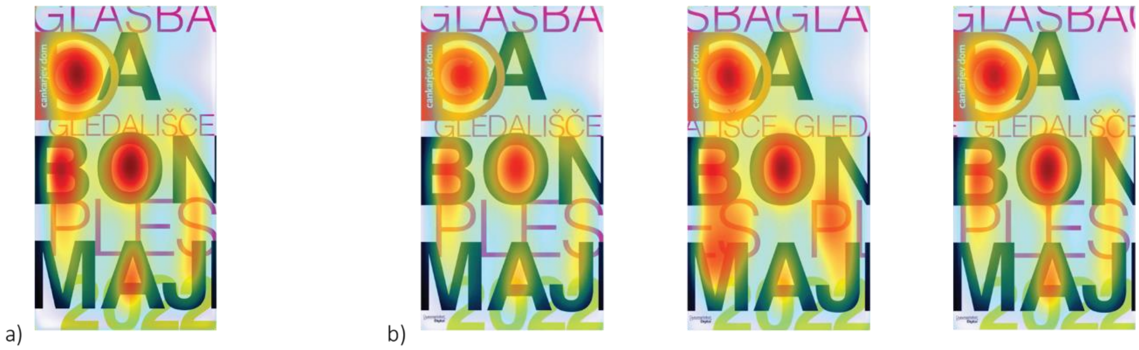


Figure 13: Heatmaps of the: a) static poster and b) animated poster for the Abonmaji

The static poster for the theatre performance *Veličastni* is designed in such a way that the dancers in the photo are in the foreground and immediately convey the main content of the image to the observer. The analysis of the heatmap (Figure 14, a) only confirms this idea, because the place where the two figures are located is also the place with the highest concentration of views. The area where the name of the ballet company and the title of the show are located is also very attention-grabbing for the observer. In contrast, the area where the date of the event is displayed is the least visible spot. When creating the animation, we took into account the fact that there are a large number of different elements on the poster itself. The movement was created with the aim of representing the magic and impression that a ballet performance leaves on the audience. We recreated a beam of light moving slowly across the poster as if it were following the dancers on stage. With this kind of movement, where only a small part of the poster was visible at a time, we forced the viewer to follow the light and gradually absorb the information shown. The heatmap of the animated poster (Figure 14, b) shows that the concertation of gazes moves with the animation through the entire content of the poster. In this way we have limited the visible area of the poster and allowed the observer to perceive only individual pieces of information at a time.

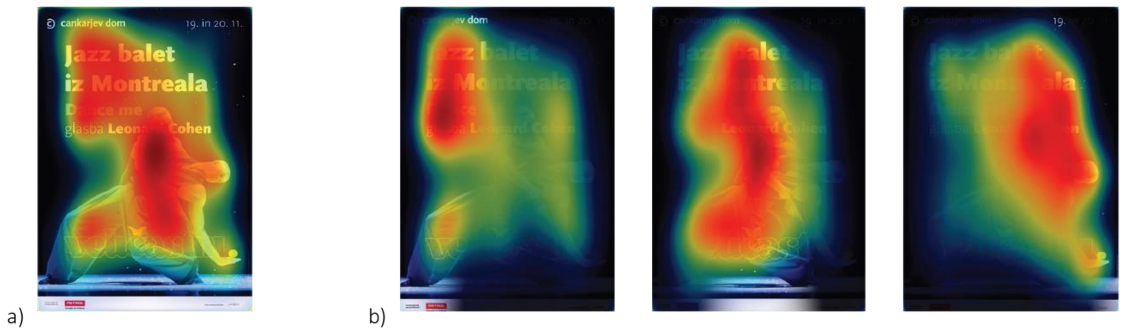
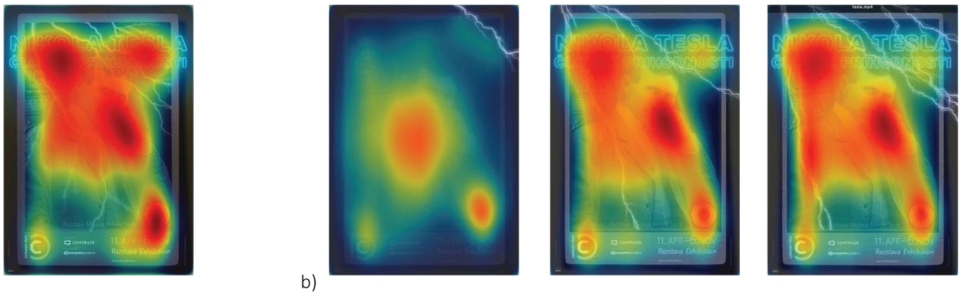


Figure 14: Heatmaps of the: a) static poster and b) animated poster for the Veličastni

The designer of the static poster for the *Nikola Tesla* exhibition wanted above all to emphasise the static look of the inventor himself, while at the same time drawing attention with the intense neon lettering and the bright lightning bolts in the upper part of the poster. After generating a heatmap (Figure 15, a) for a static poster, the results show that the area with the highest concentration of views is Nikola's eyes and the area around the logo in the bottom right. When creating the animated version of the poster, we took into account the desired hierarchy, which we emphasised even more by adding movement. In the first frame of the animation, the background is darkened, but just enough so that Tesla's gaze can still be seen. This is the first and most important element that stands out on the poster, just enough to catch the observer's attention. Later, two smaller lightning bolts appear on the screen, hinting at what is about to come. At the same time, the movement of the lightning does not occupy the viewer's attention, which is confirmed by the heatmap of the animation poster (Figure 15, b). As the animation progresses, more and more flashes appear and the neon sign begins to flash, drawing attention to the upper part of the poster. The animation therefore added a certain aesthetic effect, it did not disturb the primary poster hierarchy, but presented the poster in a more interesting and engaging way.



a) b)

Figure 15: Heatmaps of the: a) static poster and b) animated poster for the Exhebition of Nikola Tesla

3.2 Online survey

For each version of the survey, we received 30 responses, which means that a total of 60 participants took part in the survey. The two surveys were designed in such a way that the respondent was first shown each poster, with the additional option of rating the likeability of the poster. After that, there was always a follow-up question that referred to some contextual information of the poster, such as: "Who is the composer of the music?" or "What day does the event start?". In this way, we wanted to check whether animated posters attract more attention and convey information more effectively. We checked how much information respondents remembered after viewing the poster and whether the results were more accurate for animated posters compared to static ones.

First, we showed both groups of participants a poster of *Nikola Tesla*. In survey 1, we presented participants with a static version of the *Nikola Tesla* poster. Most respondents chose a rating of 4 (40.00%) on a likability scale of 1 to 5. Compared to the animated poster in survey 2, most respondents chose a rating of 5 (50.00%). Overall, the results showed that participants liked the animated poster much better than the static poster. Next, participants were asked what the subtitle of the poster was, choosing between three different answers. For the static poster, 26 people (86.67%) chose the correct answer, while for the animated poster, 28 people (93.33%) chose the correct answer.

In the following part of the survey we presented the *Veličastni* poster to the respondents. In this case, the static version of the poster was rated best by 5 people (13.33%), while the animated version of the poster was rated a 5 by 9 respondents (30.00%), which means that the respondents liked the animated poster better. Next, respondents were asked who the author of the music was, with a choice of four different authors. The correct answer was chosen by 17 people (56.67%) for the static version of the poster, while 25 people (83.33%) gave the correct answer for the animated version. The poster is designed in such a way that the beam of light gradually reveals the content of the poster so that the viewer can perceive the information step by step and thus memorise it better. This is the reason why the viewers paid more attention to the information when looking at the animated version of the poster.

In the third set, the poster for *Abonmaji* was shown. Participants rated the static poster with an average score of 3. For the animated version, most respondents chose a rating of 4 (40.00%) and a rating of 3 (33.33%). The results show that the results are quite similar and the animation does not have a decisive influence on the likeability of the poster. Next, we asked the participants about the artistic areas listed on the poster. They could choose between three different answers, with 70% of the respondents who looked at the static poster answering correctly, i.e. 21 people. For the animated poster, 24 people (80.00%) chose the correct answer. The movement on the poster helped the observer to better memorise a particular piece of information.

The static design of the *20th LIFFe* poster was rated 3 by 50% of the respondents, 8 respondents (26.67%) chose 5 and 7 respondents (23.33%) chose 4. The animated image of the poster was most often rated 3 (36.67%), with 8 respondents (26.67%) also choosing the highest rating here. It can be seen that the results are very similar and that the movement did not affect the likeability of the posters. Respondents were then asked which of the words on the poster was upright and written in orange. For the static poster, 16 respondents (53.33%) chose the correct answer. The animation was designed to show the content of the poster step by step. We conclude that this type of motion placement has a good effect on the observer's perception, as the animated poster performed significantly better. In fact, respondents who were shown the animated format answered correctly more often: a total of 21 (70.00%) respondents chose the correct word.

In the final section, participants were presented with the poster of the *26th LIFFe*. The liking of the static design of the poster was mostly rated as 4 (36.67%), followed by 3, which was chosen by eight respondents (26.67%). For the animated poster, most respondents chose a rating of 4 (33.33%), followed by 3 (30.00%). Five people gave both posters the highest rating of 5. Participants rated the two versions of the poster quite similarly, with a slight preference for the static poster. Participants were asked when the festival would take place. They could choose between three different answers, with 14 (46.67%) respondents answering the static poster correctly. The 56.67% of participants who were shown the animated poster answered correctly. This suggests that the animated poster conveys the information better.

We then asked respondents whether they thought that in a real environment the animated posters would be noticed more quickly than the static ones. Only 54 respondents answered the question, but 46 (85.00%) of them answered "yes". In the last question, we asked the respondents for their opinion about the movement on the poster. The majority, 27 (45.00%), think that an animated poster is noticed faster than a static one because of the movement. Six (10.00%) of the respondents think that the movement on the poster is distracting. 17% of the respondents think that the information on the poster is perceived faster because of the movement, while 5% of the respondents say that the movement has no influence on the information presented to the viewer. 14 respondents (23.00%) agreed with the statement that movement adds aesthetic value to the poster.

4. DISCUSSION

Predictive eye-tracking results include heatmaps of static and animated posters. The main purpose of this type of testing was to see if we could draw attention to important areas of content that are otherwise neglected by adding motion to the poster in an appropriate way. To this end, we have already provided improvements in the design of the animated posters and focused on improving the functionality of the poster rather than just adding a visual effect. At the same time, we had to be careful not to destroy the purpose of the poster by adding more elements to it. With the first poster for the *20th LIFFe*, we realised that the added animations only improved the hierarchy of the stop-gaze. Indeed, the nature of the animation gradually reveals the different parts of the content, which also allows the observer to focus their gaze on important information about the event - the date and the name - that was not sufficiently highlighted on the static poster. For the *26th LIFFe* poster, we added an animation to the back of the poster, as we assumed that the strong black lettering in the foreground would attract too much attention. It turned out that in both cases the attention was already drawn to the background and that the movement spreads the view evenly over the whole poster. For the *Abonmaji* poster, we wanted to highlight the main message - the word "ABONMAJI" - through animation. On the static poster, most of the attention was focused on the central "O", but by animating the central word, we were able to soften the focus of attention a little and draw a little more attention to the other letters in the word. Unfortunately, the difference was not that obvious, probably due to the high saturation of the poster with colours and the use of linear typography for all texts on the poster. With the animated version of the *Veličastni* poster, we wanted to divert attention a little from the central motif of the dancers. By using a beam of light that travelled across the poster, illuminating only one part of the poster at a time, we were able to force the viewer's gaze to also focus on the date of the performance and the name of the music composer. This made the viewer more informed and successfully integrated the animation into the poster. On the *Nikola Tesla* poster, we used the animation to first darken the content, just enough to show Tesla's gaze through the blackness, which remains the first and most important element. Next, the lightning bolts appear in the poster, also capturing the viewer's gaze, and the exhibition information at the very bottom of the poster is a little less noticeable.

Analysis of the heatmaps suggests that the added movement sometimes adds value by increasing interest in the poster itself or holding the viewer's attention. The most successful results were achieved with the *20th LIFFe* poster and the *Veličastni* poster, where we also drew the focus to the parts of the poster that contain important information but did not receive the desired attention in the static version.

The survey showed that in most cases the participants rated the animated poster better than the static one in terms of attractiveness. The exception is the poster for the *20th LIFFe*, where respondents rated the static version as slightly more appealing. The biggest difference can be seen in the posters for *Veličastni* and *Nikola Tesla*, where respondents liked the animated versions much better. Another indicator of the animation's success was checking participants' retention by answering questions about the posters' content. Overall, the animation achieved the desired results, as in all cases respondents were more likely to give the correct answers when viewing the animated poster than when viewing the static poster. This data demonstrates the successful integration of animation into the design and the importance of this type of work in communicating the poster content. The biggest difference was observed in the case of the *Veličastni* poster, where 56.67% of the observers answered the static poster correctly, while 83.33% gave correct answers to the animated version of the poster.

5. CONCLUSIONS

One of the main reasons why animated posters are still fairly unexplored is that they are still a relatively new advertising method and therefore not widely used. However, the main reason lies in the difficulty of verifying their effectiveness, i.e. measuring their impact on the viewer. Nevertheless, the success of the research is confirmed by predictive eye-tracking results and survey data. The main objective of the work was to investigate whether poster animation can serve as a tool to improve communication and increase the viewer's level of information. Nowadays we are surrounded by a large amount of information and it is necessary to find new and user-friendly ways to simplify, facilitate and speed up the communication process without getting lost in the information overload.
Using predictive eye-tracking analysis, we have shown that animation affects the observer's perception of the data. At the same time, we found how important additional movements are, which can completely change the hierarchy of the presented content. In most cases, the added animation also successfully drew attention to important parts of the poster that might otherwise have been overlooked. From the survey, we concluded that observers find the movement attractive and it engages their interest. The results of the survey also confirmed the important finding that the transformation of static posters into animations was well thought out, which helped the viewer to perceive and retain the information better. In all cases, it was found that the content, i.e. the information about the events, was better remembered by viewers of animated posters. The inclusion of carefully selected movements therefore increases the possibility of better presentation and communication of the poster content.

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PRELIMINARY REPORT ON DOODLING'S CULTURAL ROLE AS INTENTIONAL ART: A STUDY OF YOUTH PERCEPTIONS OF AESTHETIC SELF-EXPRESSION AND IDEA HELPER IN BRANDING

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Abstract: *The concept of doodles as a self-expression art-form is discussed through a quantitative study on the perceptions of youths towards doodling activity to produce ideas, to develop self-confidence, and in decision making for brands. The intentionality and purposes for doodling have been much critiqued by contemporary visual researchers. This paper considers the function of doodles in visual communication, and how contextual utilisation of doodles as a communication medium impacts individualistic expression as well as influencing consumer decision-making in brand preferences. Research also highlights doodling's capacity as visual representation of complex information. Primary research in the form of a survey and quantitative analysis of young adults' perceptions about doodling is analysed. Overall, the survey acknowledges doodle as creative self-expression. The use of visualisation in branding was found to be correlated, however, views about doodle as intentional art were not conclusively proven. Youths perceive doodle's role symbolically, chiefly in creating self-identity and projecting individualism. Doodling is a highly personal style to communicate or reflect on personal experiences, but the self-confidence to explore doodling in developing ideas is not a habitual practice that is encouraged among youths. Based on the survey, the effectiveness of doodles in branding or marketing practice is questioned as responses were mixed on the application of casual art styles for creative marketing approaches. Findings suggest further observation would enable consumer researchers to better understand doodling's effectiveness to shape cultural information based on self-expression, and to explore its influence on brand decision making. To conclude, creative industry, design educators, brand owners and industry stakeholders could collaborate to optimise creative solutions to improve perceptions towards doodles and doodling as a visual thinking, information processing and decision-making tool.*

Key words: branding, doodling, idea generator, intentional art, self-expression, visual thinking

1.INTRODUCTION

The intentionality and purposes for doodling have been much critiqued by contemporary visual researchers. The attributes, characteristics, functions, and symbolisms inherent in doodling will be critically examined in this paper. Through a scholarly review on related aspects including cognitive and visual thinking processes, the motivations, and perceptions towards doodling among various segments in society are considered, focusing on the impact of doodling on audiences, students, and consumers in activities such as learning, problem solving, memory, self-expression, and creativity (Andrade, 2009; Coward, 2022; Csikszentmihalyi, 2008).

As doodling gains increasing interest among academics of many disciplines, the main research objective is to reflect on the significance and provide key arguments to value the role of doodling activities to several key branches of knowledge, including visual communication, psychology, literacy, and marketing science (Hagtvedt & Patrick, 2008; Lurie & Mason, 2007).

For this paper, a wealth of literature on doodling was sought, under disciplines of studies ranging from visual thinking, neurology, psychology, and sociocultural (Chamberlain, 2013; Chan, 2012). The breadth of studies found has contributed to some degree in understanding aspects of doodling as a communication and artistic tool. This enables multidisciplinary researchers to view doodles as a human activity serving multiple contextual roles when practiced.

As an academic undertaking, doodling finds a natural place as a tool for study under the research field of visual thinking (VTS Journal, 2022). The strategies and applications of visual thinking can be seen in contemporary practices, but in essence, it is a form of literacy that involves a set of skills to find meaning in imagery. The learning theories and frameworks behind visual thinking practices are grounded in the highly influential studies of cognitive development pioneers such as Rudolf Arnheim, Abigail Housen and Jean Piaget.

Intentional doodling as visual elements are commonly used to reflects brands' corporate personality, a love for innovation, or simply as a unique presence in oversaturated consumer markets such as *Food and Beverage* (F&B), fashion, retail, and other lifestyle sectors. A case study of Google Doodle is presented in the paper.

Two broad hypotheses of research guided this study: First: The significant ways doodles contribute to the study of visual thinking and second: How to encourage greater exploration of doodles in developing youth self-confidence, in idea generation, memory retention, information recall, and for branding.

2. METHODS

The concept of doodling as self-expression and as idea generator through visual thinking and information processing was examined through a quantitative study on the perceptions of youths towards doodling activity. Questions were designed in an online survey conducted to understand the attitudes towards doodles as an intentional visual tool used in developing self-confidence and its role in decision making and developing preference for consumer brands.

A summary demographic showed the majority of 270 young adults sampled comprised 18-20 years old, undergraduates studying architecture and design at Malaysian universities.

Research aimed to understand doodling's capacity as visual representation of complex information among youths who may be under-exposed to creative communication approaches. Research also considers the function of doodles in visual communication, and how contextual utilisation of doodles as a communication medium impacts individualistic expression as well as influencing consumer behaviour such as decision-making, brand engagement and preferences.

3. RESULTS & DISCUSSION

Primary data from a quantitative survey of 270 young adults' perceptions about doodling was analysed. Overall, the survey acknowledges doodle predominantly as a form of creative self-expression. The use of visualisation was found to be correlated with visual thinking theories, with an association clearly established between visual thinking and self-expression. Youths perceive doodle's role symbolically, chiefly in creating self-identity and projecting individualism. Doodling is perceived as a highly personal style to communicate or reflect on personal experiences.

However, having the innate self-confidence to explore doodling to generate ideas is not a habitual practice that is encouraged as cultural practice among youths. Based on the survey, the effectiveness of doodles in branding practice is questioned as the application of casual art may not be appropriate as creative branding for certain sectors such as healthcare. Hence, views about doodle as intentional art in branding and design communication were not conclusively proven from the survey.

Overall, the survey acknowledges doodle as a signifier of identity and a mode of self-expression. The use of visual representation in branding of lifestyle sectors was found to be positively correlated.

However, the mentality about doodle as intentional artwork or style is not conclusively proven. These findings suggest further observation would be helpful to enable researchers from multiple disciplines from educators, marketers, and psychologists to better understand doodling's effectiveness in shaping cultural information based on self-expression, and to explore its influence on brand decision making.

In the final argument, results show that doodles have a significant role to help shape youth mindsets while having appreciable characteristics among both creative and non-creative communities. Branding is a viable, exciting platform to inspire youths to embrace doodling, while encouraging the idea of self-expression to improve confidence and creativity, besides providing an engagement touchpoint for the brand community. Many other methods are at the disposal of inspired creative communities, and commercial marketers and designers could tap these specific sociocultural contexts relevant for consumers in Malaysia.

4. CONCLUSIONS

To conclude, this research addressed a key aspect of doodling as intentional art as a mode for self-expression, to improve visual recall and memory, and as visual representation in branding. With huge potential to boost personal creativity and to provide iconic touchpoints to commercial marketers and

brand owners, creative doodle designing should form an essential module among creative educators and creative industry stakeholders such as advertising agencies and commercial or content producers.
More resources and effort could be allocated to foster fruitful collaborations between specialist doodle artists and institutions such as schools and universities to encourage doodling. With its immediacy and value as an information process medium, doodling can be an engaging solution to improve brand perceptions, for tapping youth potential for self-expression, developing confidence, and in consumer decision-making.

5. ACKNOWLEDGMENTS

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MIODRAG MIŠA NEDELJKOVIĆ (1927–2004)

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Abstract: *The periodization of fine and applied art after the industrial revolution and the response of alienated artists to industrial kitsch testifies to the utility and purpose of art—the artistic and social avant-gardes and the crown of all their endeavors in the heroic period. From art and craft pastiche, to utopian efforts to reform society through design, a rich linear syntagm was structured that intrigued and burdened the creatives from this region, who sought to introduce the land of peasants and barbarogens into the currents of industrial and social progress, culture and art. One of those individuals, in whom Morris and Marinetti, Van Doesburg and Itten, Gropius and Meyer, Vassarelli and Dibiffe... Müller-Brockman and Rand conflicted, tirelessly pursued the affirmation and institutionalization of applied art and design through pedagogical, editorial, theoretical and research work, as well as visual and graphic practice. Miodrag Miša Nedeljković was a modernist with a small 'm'*[1]*, artist and designer, theoretician and practitioner, who nomadically moved through the currents of modern and postmodern fine and applied art and design with renaissance curiosity, driven by intrigue and logic, was primarily concerned with the emergence and establishment of circumstances, and environmental issues.*

Key words: fine art, applied art, graphic design, design theory

1. INTRODUCTION

“My view of the global ’visual art empire’ was congruent with my attitude towards reality expressed as ’harmony of the universe’. I have of course considered the universe preeminently as the incredible flexi-ability of communication between the world of ideas and the world of things. The focus of this adventure were the relationships within it and their contradictory ability to break the initial model, free creativity and breed meta truth. Thus, the exploration of the primary was transferred from the visual universe to harmony in general. The primary secondary circle closed and the harmony of art endorsed the harmony of the sign in general, and therefore also the sign of meaning in general, the sign of function and information, thus harmony encoded all our systems of thought and meaning.” (Nedeljković, 1990).

2. EARLY LIFE

Miša Nedeljković was born in Niš in 1927. His mother, impoverished after the death of his father, couldn’t raise three children, so he and his sister were sent to the Queen Mary's Orphanage in Negotin, where they were educated until 1944. During his ten-year stay in the orphanage, Miša grew up in exceptional discipline and dedication to work. At the age of 17, in 1944, he joined the 10th Partisan Strike Brigade of the 22nd Strike Division of the National Liberation War. He was severely wounded in combat on Kopaonik, fighting against the ballistas and the German Prince Eugene Division. However, he returned to the battlefield after treatment and wasn’t demobilized until December 1945. After the war, he completed the Commercial Technicians High School in Zrenjanin, and worked briefly as a field operative in municipalities of Stara Pazova, Subotica, and Novi Sad.
Disillusioned by his work, he decided to develop his drawing skills. His first job as a draftsman was at The Agency for Economic, Cultural and Political Propaganda Jugoreklam in Novi Sad, where his talent was recognised and he was employed after completing his internship in 1952. Before long he became the

[1] Keedy (1998) indicates the existence of modernists, that is, modernism with a capital 'M', and modern designers with a small 'm'. The main difference is that with a capital 'M' it stands for style and ideology without limitation to historical moment and geographical location. Therefore, being a modern designer with a small 'm' simply means being committed to work in a way that is contemporary and innovative, regardless of the designer's stylistic or ideological bias.

Head of the Applied Graphics and Painting Department. As he advanced in the graphic profession Nedeljković felt drawn towards the institutionalization of applied art. When the Association of Applied Arts Artists and Designers of Serbia (serb. ULUPUS) was founded in 1953, he became a member, together with 16 fellow artists and designers from Vojvodina. Four years later, initiated from Belgrade, the branch of ULUPUS for Vojvodina was established.

In 1957, Miša Nedeljković enrolled at the Academy of Applied Arts – Department of Applied Graphics in Belgrade. At the admission exam, he ranked first with the commendation of *cum laude*. Due to his experience and refined skills the Academy transferred Nedeljković from third to fifth year of studies. He graduated in 1961, in the class of Professor Mihailo S. Petrov, with an average grade of 9.78. The same year, he was employed at the School of Applied Arts in Novi Sad, where he had worked for 11 years as a professor of the subject group related to applied graphics.

Figure 1: "Dawns Bathed in Tears" Suzana Bralo, Museum of the Socialist Revolution of Vojvodina, Novi Sad, 1985. p. 9

3. AFFIRMATION AND INSTITUTIONALIZATION OF APPLIED ART AND DESIGN

Miša Nedeljković was the third and last president of the ULUPUS branch for Vojvodina (1962–64). In 1962, the Vojvodina branch hosted for the first time the Plenum of the Association of Visual Artists of Applied Arts of Yugoslavia. The Plenum commenced the consideration of establishing a separate, equal association for Vojvodina. Already at the next Plenum of the Association, held in Sloven Gradec in 1963, on the initiative of the Management Board of the ULUPUS Branch for Vojvodina[2], a decision was made to recommend to the next Annual Election Assembly and Congress of the Association of Fine Artists of Applied Arts of Yugoslavia, the establishment of the seventh Association, for the territory of Vojvodina. Over 90 percent of the delegates voted for this recommendation, after which the recommendation was submitted and adopted at the next 6th Assembly and 3rd Congress of the Association in Ljubljana, in 1964. The Association of Fine Artists of Applied Arts of Vojvodina was founded on November 8, 1964, at the Founding Assembly in Novi Sad. The duty of President of the Association was first entrusted to Miodrag Miša Nedeljković.

In 1970, the Association of Vojvodina (serb. UPIDIV) was entrusted to prepare and organize the 9th Assembly and 5th Congress of the Association of Fine Artists of Applied Arts and Designers of Yugoslavia (serb. SPID-JU). The Association has accomplished this task with outstanding results by widely engaging all of its resources. As a result, the Association of Vojvodina was given mandate of the headquarters of the Association for the period of 1970-1973. Miša Nedeljković was elected president of the Presidency of the Federal Association of Yugoslavia, and Mirko Stojnić was elected secretary. After this term, Nedeljković was re-elected as president of the UPIDIV Management Board for the period of 1973–75.

[2] Miodrag Nedeljković, president. Mirko Stojnić, vice-president

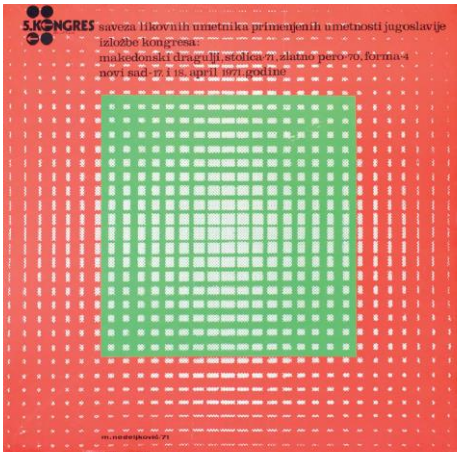

Figure 2: 5th SPID-YU Congress (silkscreen print), 70x70 cm, Novi Sad, 1971.

At the beginning of the eighth decade, the Association finally adopted a long-term program of development orientation towards design disciplines, followed by numerous discussions, lectures, articles and studies from that period, focused on the issues of defining the subject and concept of design, its importance and role, development and origin in accordance with the climax of the general project of modernity and environmental issues. From 1971 to 1977, Nedeljković was Head of the Design and Propaganda sector in Agroindustrija and Pobeda factories and planning officer for small urbanism in Urbis in Novi Sad. At the same time in UPIDIV, in line with the long-term development program of Vojvodina, the personnel development program was analyzed and objective social conditions of a wider scale were increasingly sought for the professional engagement of the membership (Nedeljković, 1985). In accordance with that policy, Nedeljković creates a Design Development Sector in Pobeda and co-opt several members of the Association into this Sector.

Nedeljković managed the Cultural Centre of the Workers' University from 1977 to 1983. One of the most significant projects realized by Nedeljković in that period was the organization and design of a large-scale art exhibition Days of Vojvodina Culture in Vienna, in the spring of 1981. For this exhibition Nedeljković realized one of his most effective posters in fruitful cooperation with photographer Silvester More and designer Robert Žemberi in the manner of international style (Figure 3).

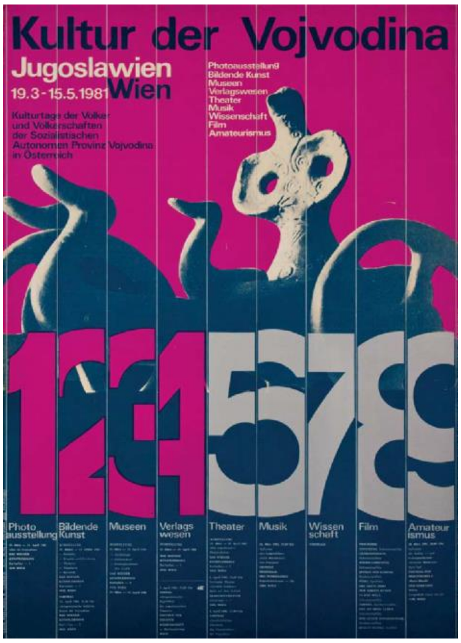

Figure 3: Culture of Vojvodina (silkscreen print), 84x59 cm, Vienna, 1981.

4. DESIGN, APPLIED AND FINE ARTS

Along with Arsovski and Stojnić, Nedeljković was among the first Yugoslav graphic artists who adopted and implemented the Swiss style of visual totality as an international universal visual language (Figure 4, 2 and 3) Sterijino pozorje and FORMA 1). Art historian Miloš Arsić, describes the manifestations of the international style in Miša Nedeljković's posters as manifestations of utility constants in which "the graphic-visual system of signs dominates, sometimes combined with the verism of the photo template... [Nedeljković] mainly opts for a structural analysis of some of the primary artistic elements, primarily the system of lines, points and surfaces, i.e. for contrast, rhythm and proportions. The geometrical organization of space prevails with an emphasized architectural stability, which is enriched by expertly guided organic cooperation of letters used in the sense of ’pure graphics’, the rationalism of straight lines with a distinct optical structure, the extreme moderation of accents of colour and the visual effectiveness of the ’raster’" (Arsić, 1985).

Figure 4: The First International Triennial of Theater Scenography and Costume – Sterijino pozorje (silkscreen print), 100x70 cm, 1966.

On his political and cultural posters, Miša Nedeljković does not determine the visual register of the message with visual abstract graphics. With means of expression of such a specific illustration, the interpretant metonymically or metaphorically becomes a signifier through an index in an image or raster, point, line, direction or radiation, and thus connotes collective, society, individual, inclusion, progress, networking, amplification and similar (Figure 2).

For more than five decades, Nedeljković has been actively engaged in graphic design, primarily book design, shaping visual identities and means of external and direct propaganda. For his professional accomplishments, Nedeljković received a total of 41 Awards, and for achievements in affirmation and improvement of the profession, he was granted 36 Recognitions and Certificates of Appreciation. In the first years of his professional development, Nedeljković was most prominent in book design, which is confirmed by numerous awards[3]. Nedeljković approaches each work, publication or periodical aligning with the style or principles he transposes from au courant forms or texts from his own artistic oeuvre. However, the visual rhetoric and poetics applied to book design is in accordance with the theme insofar as it is clearly a more artistic and poetic approach to literary works (Figure 5), compared to publications of technical communication and direct means of propaganda, where it is consistent with the principles of visual universal totality (Figure 6).

[3] Between 1961–71. Nedeljković has been awarded ten times for book design, and received eight awards from the Association of Publishers of Yugoslavia at the International Book Fair in Belgrade.

Figure 5: Book design for Forum, Novi Sad; Nolit, Belgrade; Belgrade Graphic Institute, Belgrade and others.

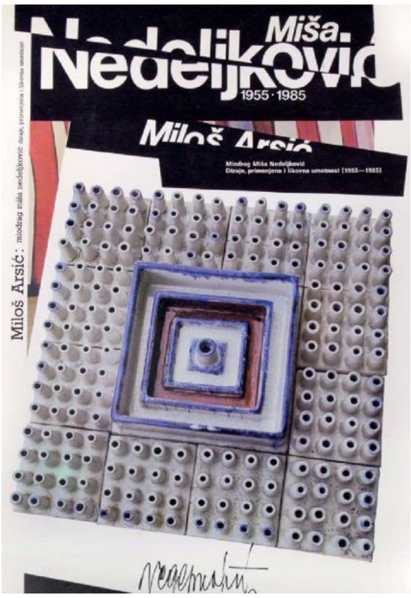

Figure 6: Book design – Miloš Arsić, Miodrag Miša Nedeljković: Design, Applied and Fine Arts (1955–1985), UPIDIV, Novi Sad, 1985. The ceramic panel "Alone" (cover image), from 1968, for which Nedeljković was awarded the gold medal of the Association of Independent Artists of Milan at the 26th International Exhibition of Ceramics in Faenza, is an idiosyncratic expression of Nedeljković; it is a reflection of the developed graphic visual language in majolica.

Figure 7:The ceramic panel "Family", from 1968, is another artistic gesture by Nedeljković in the same technique, in which he relies on the decorative style of moderate modernism or return to order, a stylization generated by concentric circles in a radially directed composition.

Miloš Arsić (1985), documents his approach to theoretical issues of applied arts and design through two primary views. The first, in which Nedeljković directly addresses the issues of solving specific tasks, that is, how to form effective utilitarian themes and forms[4]; and second, which underlines a unique commitment to the affirmation of applied art and design, aspects of organizational, pedagogical and theoretical research[5].

To whom, what, how, why, how much, is the title of Nedeljković's manual, published independently in 1974, in which the author defines an educational framework for studying the phenomenon of graphic communication, which integrates the principles of marketing and communication into a modern approach. Design as communication, according to the model of Shannon and Weaver, is the starting point for Nedeljković insofar as it can be complementary with the framework of structural semiotic analysis, which means that long before Baldwin and Roberts (2006), Nedeljković synthesized two different approaches to studying and understanding issues of visual communication through the educational framework. Striving for an exact and rational system, both in design and in theory, Nedeljković relies on the structuralist semiotic postulates of Roland Barthes and Umberto Eco, and the visual rhetoric of Guy Bonsipe. While, on the other hand, the issues of technique and effectiveness, defined by Shannon and Weaver, assume foundations from the economic propaganda theory of Richard Barton, and Yugoslav marketing theorists Dušan Mrvoš and Flora Sokolović, as well as the social psychology of professor Nikola Rot. The mentioned framework is internalized and supplemented in terms of content in several didactic tools that Nedeljković, as an author or co-author, publishes in several editions.

Nedeljković, in the spirit of “radical liberation of visual art from facade-mimetic, on account of structurally metaphorical values”, actively and self-reflexively expresses himself artistically in accordance with the general program directions of the seventh decade (Arsić, 1985)[6]. Works of art from this period are recognized as a catalysis of the influence of art and international collective creativity, as the cycle from this period is followed by a cycle of manual prints titled *Multiplication*, and a cycle of luminoplastic paintings, where Nedeljković uses art techniques and technology to affirm reciprocity of the contemplated and economic, and at the same time thematically, unique new creation and politically ancient (paintings *Red Cosmonaut*…(Figure 8); *Polis which did not accept defeat* (Nedeljković, 1985); *Pannonian Rhapsodies*; *Who Killed Christ*...). These cycles and each subsequent one encode, each for itself, a unique message whose target factor is precisely the message itself, that is, its visual representation in individual works where constant and alternative expressive elements participate in relationships.

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[4] Selected titles of Miodrag Nedeljković: *Economic Propaganda I and II*, (Nedeljkovic, 1968a, 1968b). textbooks; To whom, what, how, why, how much, manual, self-published (Nedeljkovic, 1974). Messages and their effect in the system of market communications, Pula, 18-20 May 1988. 7th SPID-JU Congress (Nedeljkovic, 1988); Textbook *Graphic Design and Type*, Textbook Institute Belgrade, in three editions: 1988, 1998 and 2006 (Nedeljković & Nedeljković, 1988); Marketing manual: What a graphic communication designer needs to know about marketing, Dnevnik, Novi Sad, (Nedeljković M., 2001).

[5] Selected titles of Miodrag Nedeljković: Subject and its culture, Index, Novi Sad, November (1971); From art craft to electronic technology, Catalog text in celebration of the 10th anniversary; UPIDIV, Novi Sad, 1974; Aesthetic product design: Design from factory practice, Pobeda, Novi Sad, March 1976; Aesthetic factors in design, Novi Sad, December 1985; Theses for conversations at Spens on the occasion of Design Day at "Forma-10"; Opinions and proposals for faster overcoming of the problem of modern staff training for the graphics industry of Vojvodina, Novi Sad, March 1987. Interview with the Chamber of Commerce of Vojvodina; Design—art of the ages, Novi Sad, April 1994. Consulting on design at the Novi Sad Fair; Program proposal for the establishment of the College of Design in Novi Sad, UPIDIV, Novi Sad, 1972 (group of authors); Applied art in Vojvodina and other texts for the Encyclopedia of Novi Sad, 2001.

[6] Miloš Arsić refers to works from three cycles of graphics and paintings: *Relationships*, *Transposition* and *War*; each of which presents self-reflexive notes on: geometric abstraction, optical structuralism, new expressionism and neo-surrealism.

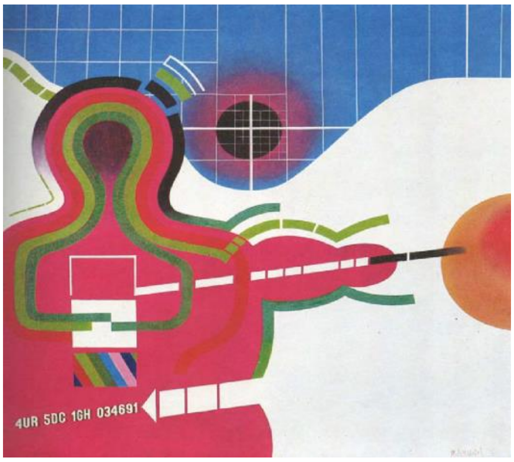

Figure 8: "The Red Cosmonaut Conquers the Left Side of the Sun", oil on canvas, 110x110 cm, 1973 (left).

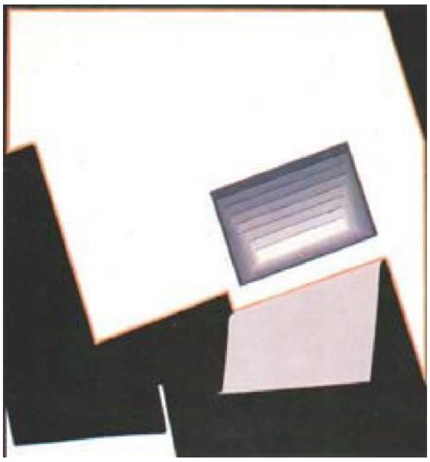

Figure 9: "The Polis Which Would Not Admit Defeat", tempera on canvas, 110x110 cm, 1977.

5. CONCLUSIONS

The overall result, seen through the applied art work and the theoretical pedagogical work of Miodrag Miša Nedeljković, is difficult to grasp, therefore even more difficult to comprehend. It is precisely in the synthesis of these two domains that one cannot clearly discern whether the practice of designer and inspired artist developed from theoretical and ontological reflection, or whether epistemological knowledge was based on constant circulation from concept to realization.

Nedeljković had 27 solo exhibitions in Yugoslavia and 20 group exhibitions abroad[7]. As an author, he was constant in the perception of the actual, which was reflected in practical interpretation, as well as in introjection through visual rhetoric. Nedeljković's clear principles exude with human and sincere presence, hence they endure until today. His principles are reflected in his art and design works, could be read in his notes and books, and finally, but most importantly, they are recognized in the individuals he educated.

6. ACKNOWLEDGMENTS

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[7] Nedeljković frequently participated in numerous Delegations and Working Groups at international gatherings and bilateral meetings.

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PRINTING ADDED VALUE

https://doi.org/10.24867/GRID-2022-p80 Preliminary report

PRELIMINARY REPORT ON PROPERTIES AND INTERACTION OF LAYERS IN "BOARD-BIODEGRADABLE PRIMER-PRINTING INK" SCREEN-PRINTED SYSTEM

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Abstract: *Surface phenomena in printing are extremely important for understanding and optimizing the interaction of materials involved in the process of graphic reproduction. In order to protect absorbent printing substrates from moisture penetration, to strengthen mechanical properties or to ensure better adhesion of the printing ink to the substrate, the substrates are often coated with protective coatings (primers) before printing. The adhesion parameters between the coating and the printing ink then become extremely important for assessing the durability, but also the quality of the print. In this research, biodegradable primers (polycaprolactone and polylactic acid) were applied on a board substrate with the primary aim of reducing the permeability to water vapour in combination with printed ink layers. Two types of water-based screen printing inks were printed on the primed substrates: ink prepared using the transparent base, and the ink prepared using the opaque white base. Two meshes with different screen count were used (32 l/cm and 60 l/cm). The research focused on the possibility of reducing the water vapour transmission rate using the inks and biodegradable primers, and at the same time analysing the interaction of biodegradable primers and printing inks by determining the surface and interfacial properties in the "printing substrate-primer-printing ink" system. The results of the research have contributed to the optimization of the screen-print quality on the primed absorbent and porous substrates.*

Key words: biodegradable primer, PCL, PLA, screen printing

1. BACKGROUND AND MOTIVATION FOR THE RESEARCH

The development of biodegradable and functional materials for the application in graphic and other industries have led to the modification of the conventional printed products (Anselmann, 2001; Khwaldia, Arab-Tehrany & Desobry, 2010). In packaging, printed products need to protect their content and be visually appealing to the potential customer (Kovačević, Brozović & Itrić Ivanda, 2019; Sharma et al., 2017). In order to improve the properties, quality and visual appeal of the printed product, primers are often applied on the board substrates before the printing. Primers can be applied during the board production, or just before the printing. Some board coatings are intended for the products that will not be printed (Tang et al., 2012; Rastogi & Samyn, 2015) - however, if a board substrate with the applied primer is undergoing the printing process, printability is of crucial importance. The properties of the board primer and its interaction with that particular printing substrate greatly influence the suitability of the primed board for the graphic reproduction when using specific printing techniques and inks (Hudika et al., 2020).

Board primers can improve the visual properties of the substrate such as gloss, but they often improve the mechanical and other properties, as well. In some cases, they serve as a barrier to the gas and liquid substances. In addition to the protective purposes and improvement of the print quality, primer can also enable the increase of the printing speed, easier and faster further processing of the print, and add value to the printed product (Lavoine et al., 2016).

For more than a hundred years, polymers have been indispensable in almost every segment of the practical application of materials. Polymers obtained from renewable sources and biodegradable polymers are attracting more and more attention, and one of the main reasons is primarily the care for the environment. The application of biodegradable materials became widespread because they can be utilized in different industries, given their wide range of properties.

In order to facilitate the recycling process of the board substrate, biodegradable polymers were used as board primers in this research: poly(ε-caprolactone) (PCL) and poly(lactic acid) (PLA). PLA is one of the most widely applied biodegradable polymers today. It is classified as thermoplastic polyester. It can be obtained from lactic acid by the process of fermentation of agricultural crops. Melting temperature of PLA is 170 °C and the glass transition temperature is 60 ° (Priselac et al., 2017). PCL is a biodegradable

polymer of synthetic origin with hydrophobic and a semi-crystalline structural property. It has a melting point of 60 °C, and the glass transition temperature of −60 °C.
There is a wide range of applications for PLA. Some of the most common applications include plastic foils, bottles, and biodegradable medical devices (e.g., screws, needles, rods, and plates that are expected to degrade within 6-12 months). PLA shrinks under heat and is therefore suitable for use as a wrapping material. In addition, the ease with which PLA melts allows for some interesting applications in 3D printing. On the other hand, its low glass transition temperature makes many types of PLA (for example, plastic cups) unsuitable for holding hot liquid (Ilyas et al., 2022).
PCL is often used in the production of food packaging and due to its excellent biocompatibility has been researched as a building material in tissue engineering (tissue regeneration and stem cell transplantation). In order to improve its mechanical and thermal properties, it can be mixed with other polymers, such as cellulose acetate, butyrate and polylactic acid. Pure PCL requires two to four years to completely disintegrate, depending on the molecular weight of the polymer (Woodruff & Hutmacher, 2010; Priselac et al., 2017).
Previous research on PCL and PLA as primers on paper substrates proved them as suitable solution for the improvement of print properties in offset printing technique (Hudika *et al.*, 2020). Furthermore, PCL/PLA composites have been successfully applied as the materials for relief printing plate production (Poljaček et al., 2021; Priselac et al., 2022).
PLA and PCL were used in this research as primers on the board substrate, with the motivation of having beneficial effect on reducing the permeability to water vapour, and possibly improving the characteristics of the print such as the edge of the printed motive and adhesion parameters between layers on the print.
The research hypotheses were as follows:

1. The adhesion parameters between biodegradable primers and prepared printing inks will differ depending on the type of materials, but will indicate the optimal acceptance of printing inks on primed printing substrates.
2. Biodegradable primers and printed ink layers will reduce the permeability of the board printing substrate to water vapour.
3. Biodegradable primers will not diminish the definition of the edges of printed elements.

2. RESEARCH METHODOLOGY AND FINDINGS

2.1 Methodology

In this research, the interaction of screen printing inks based on opaque and transparent base, and biodegradable primers applied to the board printing substrates, was analysed. Used printing inks were water-based. Uncoated offset board Sappi Tauro was used as a printing substrate. Uncoated board was chosen specifically because of the application of the PCL and PLA primers prior to the printing process. Polymer/solvent solutions were prepared by stirring the mixtures using magnetic stirrer in air-tight container for 120 minutes to obtain the homogeneous solution. The primers were applied using K202 Control Coater in controlled conditions defined by the ISO 187:1990 standard and using rod number 4. Printing process was performed using a screen-printing machine by Bochonow (Drucktisch 2000 50/70). Printed samples were air-dried for 48 h at a temperature of 25 ± 2 °C after the printing process.
Basic properties of the materials used in this research are given in Table 1.

Table 1: Properties of the printing substrate, primers and inks

Printing substrate	Primers	Printing inks
• Sappi Tauro • grammage: 300 g/m^2 • uncoated offset board	• PLA by InegoTM, 3251D (10% weight, dissolved in ethyl-acetate) • PCL 6800 Capa (10% weight, dissolved in chloroform)	• water-based • TBI: 5 g of black process K print pigment + 95 g Midrol Transparente transparent base • WBI: 5 g of black process K print pigment + 95 g Midrol Bianco white opaque base

In order to analyse the interaction of biodegradable primers and screen printing ink, after the selection of the screens with optimal mesh counts (32 l/cm and 60 l/cm) applicable for the full-tone prints on the given printing substrate, coating the substrate with biodegradable coatings and printing on the coated substrate using two types of screen printing inks was performed. After that, the following methods of measurement and analysis were performed:

- measurement of the roughness of printing substrate, primed printing substrate and the prints;
- calculation of water vapour transmission rates;
- measurements of the contact angles of the referent liquids on all samples in order to calculate the surface free energy (SFE) components of the printing substrate, primed printing substrates and the prints;
- from the SFE values, the adhesion parameters in the system "printing substrate-biodegradable primer-printing ink" were calculated;
- 2D microscopy of the prints.

Surface roughness of the substrate, primed substrates and prints was measured to define the influence of the primers and mesh count on the surface topography of the prints. The profiling method was defined by ISO 11562, DIN 4777, and DIN 4762 standards. Ra and Rz parameters were displayed for all measured samples. The device MarSurf PS 10 with the stylus method was used for the roughness measurements. The diameter of a stylus was 2 µm and measuring force was 0.00075 N. Measurement was performed ten times on each sample.

Thickness of the printed ink layers was measured using SaluTron D4-Fe device. SaluTron D4-Fe works on the principle of magnetic induction and can measure the thickness of layers on non-magnetic surfaces. The results of the printed ink layers' thickness obtained using different inks and printed on different primers were used as an indication of the decrease of the substrate's absorptiveness after the application of the primers.

Water vapour transmission rate was calculated using the cup method. Distilled water (50 ml) was poured into the container. The opening at the lid had a diameter of 35 mm. The samples fixed onto containers were placed in a desiccator in which (50 ± 5)% of relative humidity was set. The surrounding temperature was (23 ± 1) ◦C. The container with the lid and the sample was weighed before putting it into the desiccator. The weighing of the samples was performed after 24 and 48 h. The measured weights were included in Equation (1) to obtain the water vapour transmission rate (WVTR).

$$WVTR = \frac{\Delta m}{\Delta t * A}, \tag{1}$$

where Δm is the difference in sample mass (in grams), Δt is the time period (in days) and A is the area of lid opening (in m^2). The calculated coefficient WVTR presents the weight of water vapour that passed through an area of 1 m^2 in one day (unit of measurement is $g/day \cdot m^2$) (Cigula, Hudika & Tomašegović, 2021). Obtained values for all samples were presented as relative percentages, where the percentage of 100% was allocated to the WVTR of the board.

Surface free energy (SFE) of unprimed and primed board, as well as of the prints, was calculated using the OWRK method. Water, glycerol and diiodomethane were used for calculation of SFE. The conductivity of water was γ = 2,0 μScm^{-1}, the dispersive component of the water's surface tension γ_l^D = 21.80 mJm^{-2}, the polar component of the surface tension γ_l^P = 51.00 mJm^{-2} and the total surface tension of the water was γ_l = 72.80 mJm^{-2}. Glycerol has equal amount of polar and dispersive surface tension components (γ_l^P = 34.0 mJm^{-2}, γ_l^D = 30.0 mJm^{-2}) and total surface tension γ_l = 64.0 mJm^{-2} and diiodomethane is a dispersive liquid with total surface tension, $\gamma_l = \gamma_l^D$ = 50.8 mJm^{-2} ('Future Fibres: Coir', n.d.; Tomašegović *et al.*, 2021). Sessile drop method was used for the contact angle measurement, and the volume of the drops was 1 µl. All measurements of the contact angle on the samples were performed at the same moment after the droplet touched the sample surface (with a delay of 10 frames) and the average value of ten measurements was calculated. The measurements were performed using goniometer Data Physics OCA 30. Adhesion parameters (thermodynamic work of adhesion, interfacial tension and wetting coefficient) were calculated from the obtained total, dispersive and polar components of SFE (Priselac *et al.*, 2022).

Microscopy of the edges of printed elements was used to visually assess the influence of the primers on the line edge of the printed motives. Microscope Olympus BX 51 was used, and magnification was set to 50x.

2.2 Overview of the results

Tables 2 and 3 present the results of the Ra and Rz parameters, and the thickness of the printed ink layers on unprimed and primed substrates in micrometers, respectively.
PLA and PCL layers on the board without additional printed ink layer do not have a significant effect on the roughness of the substrate since they are partially absorbed into the board (Table 2). The lowest values of Ra and Rz were measured on a WBI print obtained using the screen of 60 l/cm on unprimed substrate, while the highest values of Ra and Rz were measured on unprimed substrate with TBI print, obtained using a screen of 32 l/cm.

Table 2: Ra and Rz roughness parameters of the surfaces

Board	Ra = 2.34 ± 0.18, Rz = 14.56 ± 0.99			
PLA on board	Ra = 2.24 ± 0.12, Rz = 14.62 ± 0.84			
PCL on board	Ra = 2.50 ± 0.09, Rz = 14.98 ± 0.65			
	32 l/cm		60 l/cm	
	Ra (µm)	Rz (µm)	Ra (µm)	Rz (µm)
TBI	3.02 ± 0.21	16.85 ± 1.65	2.80 ± 0.34	15.29 ± 1.70
TBI on PLA	2.55 ± 0.19	13.98 ± 1.12	2.17 ± 0.15	12.98 ± 0.85
TBI on PCL	2.34 ± 0.22	13.44 ± 1.36	2.10 ±0 0.17	12.35 ± 1.48
WBI	1.94 ± 0.18	9.67 ± 0.98	1.50 ± 0.19	8.55 ± 0.82
WBI on PLA	1.67 ± 0.16	10.02 ± 1.25	1.56 ± 0.15	8.90 ± 0.58
WBI on PCL	1.71 ± 0.24	10.15 ± 1.21	1.62 ± 0.23	8.66 ± 1.55

It is observable that both PLA and PCL primers cause the increase of the printed ink layer thickness compared to the prints on the unprimed board.

Table 3: Thickness of the ink layers on unprimed and primed substrates (µm)

	TBI	TBI on PLA	TBI on PCL	WBI	WBI on PLA	WBI on PCL
32 l/cm mesh	24.75 ± 3.20	37.00 ± 2.94	32.10 ± 2.10	30.60 ± 2.30	37.25 ± 2.50	35.80 ± 2.17
60 l/cm mesh	13.20 ± 1.71	15.60 ± 2.04	14.00 ± 3.74	15.40 ± 3.21	22.80 ± 3.11	23.40 ± 2.88

Table 4 shows the relative water vapour transmission rates in relation to the rates of the board itself, for which the value of WVTR was set to 100%. It can be seen that TBI as a layer on the substrate has the most expressed property of reducing the WVTR compared to other layers. Therefore, TBI obviously has the most pronounced water vapour barrier properties. On the other hand, PCL, WBI, and WBI on PLA have displayed the highest WVTR percentages and thus contribute the least to the desired effect of reducing WVTR.

Table 4: Water vapour transmission rates (WVTR) of the primed or/and printed substrates, expressed in (%)

<table>
<tr><th></th><th>PLA</th><th>PCL</th><th>TBI</th><th>TBI on PLA</th><th>TBI on PCL</th><th>WBI</th><th>WBI on PLA</th><th>WBI on PCL</th></tr>
<tr><td>32 l/cm mesh</td><td rowspan="2">81.4</td><td rowspan="2">71.1</td><td>43.17</td><td>42.03</td><td>39.77</td><td>60.44</td><td>72.98</td><td>50.98</td></tr>
<tr><td>60 l/cm mesh</td><td>36.9</td><td>57.80</td><td>56.47</td><td>77.00</td><td>62.36</td><td>55.32</td></tr>
</table>

Surface free energy results were used to calculate the adhesion parameters between the unprimed/primed board and the printed ink layers.

From the obtained results of the calculated adhesion parameters, it was possible to conclude that the adhesion between PLA and WBI, compared to other combination of the interfaces, had the most optimal interfacial tension (0.04 mN/m), very good thermodynamic work of adhesion (60.22 mN/m) and wetting with the coefficient closest to zero (-0.27 mN/m) regardless of the negative coefficient. Interfacial tension was highest between PCL and TBI (4.88 mN/m). As far as the thermodynamic work of adhesion is concerned, it was highest between PCL and WBI (72.94 mN/m). It was concluded that the adhesion parameters between biodegradable primers and prepared printing inks differ significantly depending on the types of used materials.
Furthermore, after the analysis of two-dimensional microscopic images, it was concluded that the primers did not affect the appearance of the line edge printed using TBI. When WBI and 32 l/cm screen were used, and the ink was printed on the PLA-primed board, the disappearance of the gradient present on the edge of the line printed with the same ink and screen on the unprimed board, was observed.

3. CONCLUSION

After the performed research and obtained results, hypotheses of the research were partially of completely confirmed:

1. The adhesion parameters between biodegradable primers and prepared printing inks will differ depending on the type of materials, but will indicate the optimal acceptance of printing inks on primed printing substrates.
   The first hypothesis has been partially confirmed. Research has shown that the adhesion parameters are most optimal between PLA and WBI, but not when using PLA in combination with TBI. On the other hand, due to the extremely negative wetting coefficient, PCL is not recommended as a board coating for either WBI or TBI but should be tested for the application when printing with other types of inks (solvent-based or UV-curable).
2. Biodegradable primers and printed ink layers will reduce the permeability of the board printing substrate to water vapour.
   The second hypothesis was confirmed. Specifically, it was established that PLA, as a primer on a board substrate, has the least effect on the reduction of water vapour permeability. The mentioned permeability of board with a PLA layer was about 80%. The similar was true for PCL primer, with a value of about 70% WVTR. Significant reduction in WVTR occurred when the biodegradable primers were combined with TBI, because it apparently contained the most favourable water vapour barrier properties.
3. Biodegradable primers will not diminish the definition of the edges of printed elements.
   This hypothesis was confirmed – the biodegradable primers did not decrease the quality of the printed line edge but have caused the decrease in the appearance of the gradient on the line edge present on the unprimed substrate due to the ink absorption into the board.

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PRODUCTION AND PRINTING OF SOLVENT-BASED FLUORESCENT INK FOR USING IN ANTI-COUNTERFEITING DOCUMENTS

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Abstract: *Security inks are used in areas such as money, expensive products, identity cards, passports. Generally, they are more expensive than conventional inks. A good security ink is expected to be fairly inexpensive and non-replicable. Pigments used in security ink are usually produced from rare earth elements. It is very difficult to produce ink from rare earth elements and high performance ink carrier systems are needed. There is no need for special carrier systems to produce ink from organic fluorescent pigments, and they allow cheaper ink production while reducing reproducibility. In this study, it is aimed to produce ink using organic-based fluorescent pigment. For this purpose, solvent-based ink formulations containing commercial solvent based organic fluorescent blue pigment in different ratios were prepared with polyurethane resin. The prepared inks were printed on the paper surface with the inkjet printing system. The colour properties of the prints obtained were determined under daylight and UV light. In addition, the gloss, adhesion, abrasion resistance, light fastness and drying times of the prints were determined. As a result, it has been determined that the ink produced is transparent in daylight, has a blue glow in UV light and can be used as a security ink in valuable documents.*

Keywords: security ink, fluorescent, anti-counterfeiting, printability.

1. INTRODUCTION

Due to the fact that counterfeiting creates economic problems in our age, security inks appear in many areas, both in government institutions and in the private sector (Kumar et al., 2014). Security inks are used in tamperable counterfeit products such as money, checks, stocks, passports, special drugs. Security inks are an additional security parameter used to prevent the duplication of valuable documents, packaging, labels or end products and to protect them against counterfeiting (Muthamma et al., 2021). Many security inks can be produced depending on the printing technique, the product to be used, the security level and the purpose of use. Due to the reasons such as the pandemic in recent years, increasing internet and technology use, the security printing market, which is growing day by day, is becoming more diverse every day to meet the needs (Schell, 1988).
When security printers are considered, two basic raw materials emerge. These; substrates and inks (Chambers et al., 2015). When examined in terms of printing materials, the most widely used products are papers, polymeric materials and cardboard (Warner & Adams, 2016). New and different features can be added to some substrates as safety parameters. Most countries moneys are made of heavy paper from cotton fibres, in some cases flax or specially coloured or forensic fibres are added to the paper to give it individuality and protect against counterfeiting. In some countries, extra security parameter is gained by adding money polymeric small frames (Spiridonov et al., 2018).

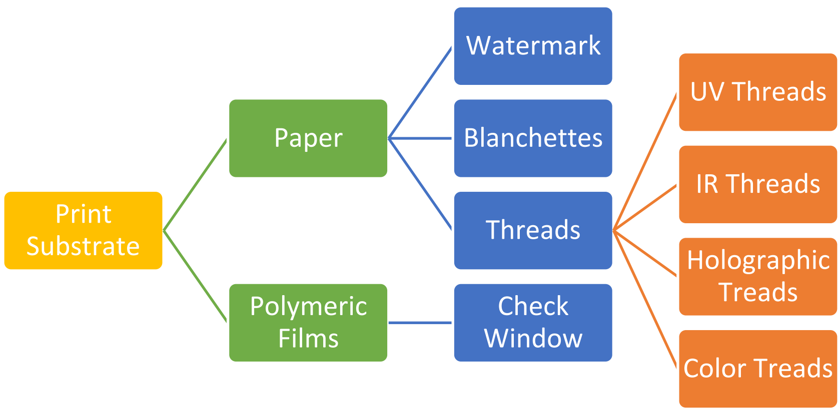


Figure 1: Substrates used in security printing

Another material used in security printing is inks and top-varnishes. Security inks are used in many areas where it is desired to prevent counterfeiting, from labels to money, from the pharmaceutical industry to packaging. In addition to security inks, it directs the studies in this field in top-coat varnishes. Many different types of security inks are produced to meet market needs. Although inks that do not make visible radiation to the visible region but become visible in the UV region are most commonly used, there are many security inks such as hologramic, thermochromic, photochromic, magnetic, etc. that glow in the IR region (Reardon, 2008).

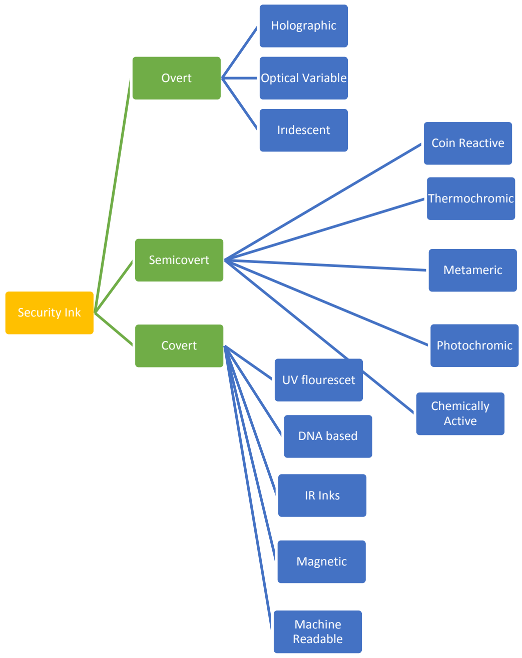


Figure 2: Inks used in security printing

Microtext, Guilloches patterns, Void pantographs, Prismatic colour, Digital watermarks, Fake watermarks are used during the design to try to prevent counterfeiting (Bozhkova et al., 2017). There is a wide variety of technologies used to ensure the security of printing materials. The main industrial printing processes are offset lithographic printing, flexography, intaglio printing and screen printing.

Traditional anti-counterfeiting Technologies and materials are expensive, complex and can be easily copied. Hence, it is a significant challenge to develop a kind of anticounterfeiting label that is cost-effective and hard to duplicate (Feng et al., 2022). Stimulus-reactive fluorescent materials from security materials are frequently used in counterfeiting due to their unique backscattering properties. Organic materials with fluorescent properties absorb light of lower wavelengths and backscatter at higher wavelengths. These can be used alone in inks or mixed with various pigments to produce inks (Ramanna et al., 2017).

In this study, it is planned to prepare and print inkjet ink using solvent based fluorescent blue pigment. Thus, we aimed to determine the quality parameters in order to produce anti-counterfeiting security ink and to use it in different areas.

2. METHODS

2.1 Materials

The colorant used in the study, which emits blue in the UV region, was obtained from Tüver Pigment (Istanbul-Turkey). Solvent-based polyurethane resin suitable for ink was obtained from İldeş Kimya AŞ (Gebze-Turkey). With the produced inks, prints were made on 80 g/m^2 white office paper. The technical specifications of the paper are given in Table 1.

Table 1: Technical specifications of 80 g/m^2 white office paper

	Standard	Paper
Grammage (g/m^2)	ISO 536	80
Thickness (µm)	TAPPI T411	189
Whiteness (D65/10) (%)	ASTM E313	97
Gloss (75°)	ISO 8254-1	5.7
Yellowness	ASTM E313	0.08

2.2 Ink production

Polyurethane binder and isopropyl alcohol solvent inkjet printing inks were produced in the formulations shown in Table 2. Before the ink is produced, the polyurethane-isopropyl alcohol-dispersant mixture is prepared as the ink dispersant phase. Different amounts of commercial UV-radiating colorant were added to the mixture obtained. It was mixed with a butterfly type high-speed mixer at 750 rpm for 10 min, and isopropyl alcohol was added slowly until the viscosity was adjusted for 20 sec. As soon as the created inks were prepared, they were directly printed (Ozcan & Kandirmaz, 2020).

Table 2: Inkjet ink formulation

Ingredients	Purpose of usage	Quantity %
UV irradiating colorant	Effect substance	F1: 0.5 F2: 1 F3: 2.5
Polyurethane resin	Forming the dispersant phase for the colorant and giving it physicochemical properties	15
Dispersant	Stabilizing the colorant in the resin	2.5
Isopropyl alcohol	Adjusting the viscosity	Balance to 100
	Total	100

2.3 Printing of obtained ink

The obtained inks were printed on the 80 g/m^2 office paper surface as a background with the BENTSAI BTHH 6105 handheld thermal inkjet printing machine. The colours of the prints obtained were measured by X-Rite eXact portable spectrophotometer, gloss measurements were measured with BYK Gardner gloss measuring device at an angle of 60° according to ISO 8254-1. Colour differences were calculated according to the CIELab (1994) technique. The prints were subjected to the light fastness test to determine how the colour would change over time in the ground prints. In the light fastness test, all prints made with a blue wool scale were kept in a UV light cabinet for 192 hours, the initial and final CIELab values were measured and how much the colour changed according to BS4321.

3. RESULTS

Inkjet printing security inks were successfully produced with using different ratio radiant in the UV region dyestuff, polyurethane binder and isopropyl alcohol. The produced three inks were printed on the paper surface as a solid tone with inkjet printing. The colours of the prints were measured by X-Rite eXact portable spectrophotometer. Table 3 shows the CIELab values, gloss and visual samples of the prints under daylight.

Table 3: Colour characteristics and glosses of security prints under daylight

	L	a	b	ΔE	Gloss	Image
Base paper	95.46	2.41	-9.32		5.8	
F1 Ink's Print	97.28	2.67	-9.45	1.31	12.6	
F2 Ink's Print	96.83	2.84	-9.43	0.98	12.3	
F3 Ink's Print	96.27	2.96	-9.40	0.88	12.1	

When the colour measurements made under daylight are examined, it has been observed that the L value has increased slightly in inks containing UV-radiating dyestuff, which is the safety parameter in the ink formulations prepared when the base paper without dyestuff is taken as reference. This is due to the ink resin. However, as the amount of active substance in the content increases, there is a slight decrease in the L value, which is due to the fact that the solid UV-radiating substance in the ink creates a slight roughness on the surface. Similar results are supported by brightness measurements. In addition, when ΔE colour differences are examined in Table 3, it is seen that the colour differences of all inks are below the visible limit. In addition, the slight blue shift caused by the ink binder was tolerated by the increased UV active substance, thus decreasing the ΔE. The colour and gloss characteristics of the prints obtained were measured under UV light and the results are given in Table 4.

Table 4: Colour characteristics and glosses of security prints under UV light

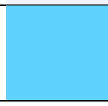
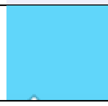
	L	a	b	Gloss	Image
Base paper	95.46	2.41	-9.32	5.8	
F1 Ink's Print	87.59	-21.02	-22.39	15.49	
F2 Ink's Print	83.21	-25.10	-27.85	15.20	
F3 Ink's Print	78.09	-33.39	-34.17	14.86	

When the prints were placed under UV light and the colour properties were examined, it was seen that the colour changed completely and took on a blue colour. All of the L, a, and b values have changed in the negative direction. When the colour was examined, the colour became darker as the amount of UV active substance increased. Gloss, on the other hand, increased according to its values under daylight. This is due to the optical banishing effect. As in the measurements under daylight, there was a small decrease in the gloss as the UV active substance increased.

Prints made with ink with the highest concentration of dyestuff were selected from the obtained inks, and the adhesion, abrasion resistance, light fastness and drying times of the prints were determined.

Lightfastness test was applied to print according to BS4321 and colour differences were calculated. ΔE values are given in Table 5.

Table 5: Color changes of UV reflective prints with lightfastness test

	ΔE	Blue wool scale color change	Image before light fastness test	Image after light fastness test
F3 Ink's print under daylight	3.04	7		
F3 Ink's print under UV light	1.2	8		

When the light fastness results are examined, it is seen that the colour changes slightly under daylight, and the change is towards yellow. This can be explained by the formation of yellowing due to the breakage of the double bonds in the ink by daylight. When examined under UV light, it is seen that the color difference decreases. It has been determined that the UV active pigment already has open double bonds, so the color changes less. It has been concluded that the ink is suitable for the application and has high color stability according to BS4321 under both lights.

Table 6: Quality control tests of inks

	F3 Ink's Print
Abrasion resistance	1
Adhesion	5
Drying times	5 sec

Abrasion resistance test (weight: 920 g load, 30 cycle) 1 = excellent, 2 = good, 3 = bad, 4 = very bad.*

To test for the effect of adhesion, ink was prepared and print onto paper substrates and allowed to dry thoroughly overnight. The tape adhesion test was then carried out, the results of which can be seen in Table 6. A visual assessment of the adhesion was made. Zero indicates that all ink has left the surface (poor adhesion) and 5 indicates no separation (excellent adhesion). When examined in ultraviolet and daylight on the band, it was determined that there was no ink residue, so the adhesion result was given as 5. that is, the ink adheres to the surface quite well. When drying times were examined, it was determined that drying took less than 5 seconds. this is an expected result. The absorbent paper helped the ink dry quickly, while the solvent of the ink was quickly removed. Thermal inkjet inks dry in approximately 2-10 sec, so the ink easily meets this quality parameter. The evaluation made using the abrasion resistance test 30 oscillations and a weight of 920 grams was evaluated visually. The tests of the prints were examined under both daylight and UV light. It was evaluated as 1 because there was no deformation even after 30 oscillations. In other words, ink with high friction resistance has been produced. This is due to the strength of the resin of the ink.

4. CONCLUSIONS

As a result, the ink, which cannot be seen under daylight, has been successfully prepared by using polyurethane resin and radiating in the UV region. Thermal inkjet prints can be made easily with the prepared inks. Properties such as colour and brightness of the prints were determined. It was determined that the ink, which is transparent at room conditions, radiates blue in the UV region and a stable print is created. It has been determined that the prints made with the obtained ink have high light fastness, high adhesion and abrasion resistance and dry for a short time. It can be suggested that the obtained ink can be used in areas such as packaging, valuable documents, money, as a security parameter.

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READABILITY OF 2D CODES CONSIDERING THE ACTIVATION TEMPERATURE OF THERMOCHROMIC PRINTING INKS IN SMART TAGS

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Abstract: *Many advantages and applications of 2D codes and functional printing inks have led to the development of Smart Tags. Interactive 2D codes provide the ability to store a large number of various information on a relatively small area and are easy to use. Combined with temperature sensitive thermochromic inks, 2D codes can provide a possibility for making Smart Tags, which could be used in smart packaging applications. In this study, Smart Tag is a temperature – dependent system sensitive to surrounding temperature, which provides information in the form of 2D codes and hidden messages. By combining the information provided by the Smart Tag, it is possible to monitor the temperature conditions of a particular product, create anti – counterfeit elements, and high – temperature warning systems. In this paper, 2D codes will be printed using thermochromic (TC) inks with different activation temperatures (T_A) in screen printing technique. Printed 2D codes will be exposed to the defined temperature range around T_A, to determine readability of the codes by mobile code scanning. Colorimetric properties of TC inks will also be measured within the defined temperature range. The aim of this paper is to determine which temperature range of a particular TC ink provides readability of 2D codes. The results could help in design and development of 2D code - Smart Tags using functional inks. These kinds of Smart Tags could provide higher level of consumer protection, temperature monitoring of pharmaceutical and cosmetics products, as well as burn – hazard warning systems.*

Key words: 2D codes, thermochromic inks, Smart Tag

1. INTRODUCTION

The development of 2D symbology was motivated by the need to place more information in a relatively small area. 2D codes can encode numeric, alphanumeric, binary, and Kanji characters, but also website URLs, documents, and multimedia files (Rizwan, 2016). QR (Quick Response) 2D codes are quickly and easily decoded using smartphones, thus providing a link to a digital media and additional information (Hakola & Linna, 2005). 2D codes can be printed on many different types of substrates, using regular printing inks and process. Error correction feature ensures readability of QR codes even if the code is damaged, distorted, or dirty, by up to 30% (Rizwan, 2016).

2D codes can be combined with environmentally sensing materials for a cost-effective tag that can be attached to product packages (Hakola, Vehmas & Smolander, 2021). This kind of functional Smart Tags can be printed with commercially available thermochromic (TC) printing inks, which changes its coloration according to surrounding temperature (Jakovljević et al., 2017). 2D codes printed with this type of functional inks creates temperature-sensing system in which the results of code-scanning dynamically change, depending on temperature conditions of a certain product. The specifications of mentioned functional materials must be well known and adjusted in detail, for usable and useful applications. Smart Tags based on QR codes and TC inks can provide information which is dynamically approached and can be combined with hidden messages. These types of Smart Tags can be used in intelligent packaging designed for food, pharmaceutics, and cosmetics products. By combining the dynamic information provided by the Smart Tag, it is possible to monitor the temperature conditions of a particular product, create anti-counterfeit elements, and high-temperature warning systems.

This research aims to determine which temperature range of a particular TC ink provides readability of 2D codes. The complete function of this application is possible only if all the elements that affect the functional properties of Smart Tag system are examined and adjusted in detail. The results of this research could help in better understanding of 2D code-Smart Tags using functional inks and influence in future improvement of this system. These kinds of Smart Tags could provide higher level of consumer protection, temperature monitoring of pharmaceutical and cosmetics products, as well as burn-hazard warning systems.

2. MATERIALS AND METHODS

2.1. Materials

In this research, 2D codes were printed using reversible thermochromic (TC) inks with different activation temperatures (T_A); blue, T_A=15°C – denoted as TC 15; black, T_A=31°C – denoted as TC 31, and red T_A=47°C – denoted as TC 47. All three TC inks are water-based and change from colored to uncolored state at the defined activation temperature. TC inks were mixed with binder (50:50) provided by the producer (SFXC, United Kingdom), to prepare useful screen-printing ink formulation.
2D QR codes were printed on four types of uncoated paper substrates: N 160 – Navigator, 160 g/m^2; FC 250 – Favini Crush, 250 g/m^2; EPR 80 - Evercoply plus, recycled, 80 g/m^2; and PRW 70 - Paperzone Reciclingpapier Weissegrad, 70 g/m^2. EPR 80 and PRV 70 are both specified as recycled papers, while N 160 does not contain recycled fibers. FC 250 is labeled as eco-friendly paper, made by replacing 15 % of virgin tree pulp with by-products from citrus fruits. Selected paper substates differ in their composition, basic, surface, and optical properties.

2.2. Printing process

Before the printing process, TC inks were mixed with binder and the printing paper substrates were conditioned at a temperature of 24 ± 1 °C and 50-55 % relative humidity. Two types of designs were prepared for the printing process. For printing solid images, a full-tone square image was prepared and for printing 2D codes, a digitally created 2D code was transferred to the film. The films were used for exposure of the printing plates using the standard plate-making procedure [5]. Two types of printing plates were used. A printing plate with a mesh density of 43 lines cm^{-1} (SEFAR® PET 1500 43/110-80 PW) was made for printing a solid image and a plate with a mesh density of 77 lines cm^{-1} (SEFAR® PET 1500 77/195-55 PW) was made for printing 2D QR codes. The prints were made with a manual screen printing machine by Bochonow (Drucktisch 2000 50/70) and the printed samples were air-dried for 48 h at a temperature of 25 ± 2 °C after the printing process.

2.3. Measuring methods

Optical properties of paper substrates were measured using Techkon (Techkon GmbH, Germany); opacity and whiteness were measured. Caliper was determined with a micrometer DGTB001 Thickness Gauge (Enrico Toniolo, S.r.l., Milano, Italy). Microscopic images of paper samples were performed by means of an Olympus BX51 microscope (Tokyo, Japan).
Surface roughness of paper substrates was measured to determine the differences in the surface structures of observed papers. An electromechanical stylus instrument MarSurf PS 10 (Mahr GmbH, Germany) was used for measurement. The diameter of the stylus was 2 µm and the measuring force was 0.00075 N. The measurement was performed ten times on each sample in the fiber direction and in the opposite direction, and the results of a mean value were presented. The roughness parameters determined and used in this research are compliant to the standards for geometric product specifications (ISO 4287: 1997). Three roughness parameters were defined: R_a - average surface roughness; R_z (ISO) - mean height of unevenness in ten points, numerically the difference in mean height between the five highest peaks and the five lowest peaks within the reference length; R_{max} - maximum roughness height (ISO 4288: 1996).
Temperature-dependent optical properties of TC prints were measured 5 °C below and 5 °C above the activation temperature of each TC ink. Spectral reflectance of the samples was measured between 400 and 800 nm, in 1 nm steps, using fibre – based USB 2000+ portable spectrometer (Ocean Optics, USA) with 30 mm wide integrating sphere (ISP-30-6-R), (8°:di) measuring geometry and a 6 mm sampling port diameter. Ocean View 2.0.7. software by Ocean Optics was used to calculate the CIELAB L^*, a^* and b^* values taking into account the D50 illuminant and 2° standard observer. The printed samples were temperature controlled using the surface of a water block (Ek Water Blocks; EKWB d.o.o., Slovenia) (Jakovljević et al., 2017; Kulčaret al., 2010; Mahović Poljaček et al., 2021).
2D codes printed with TC inks were exposed to the defined temperature range around T_A, to determine readability of the codes by mobile code scanning. The mobile app used for code scanning were: QR & Barcode Scanner (QR & BS), QR skener (QR) and Qr Barcode Scanner (QR BS).

3. RESULTS AND DISCUSSION

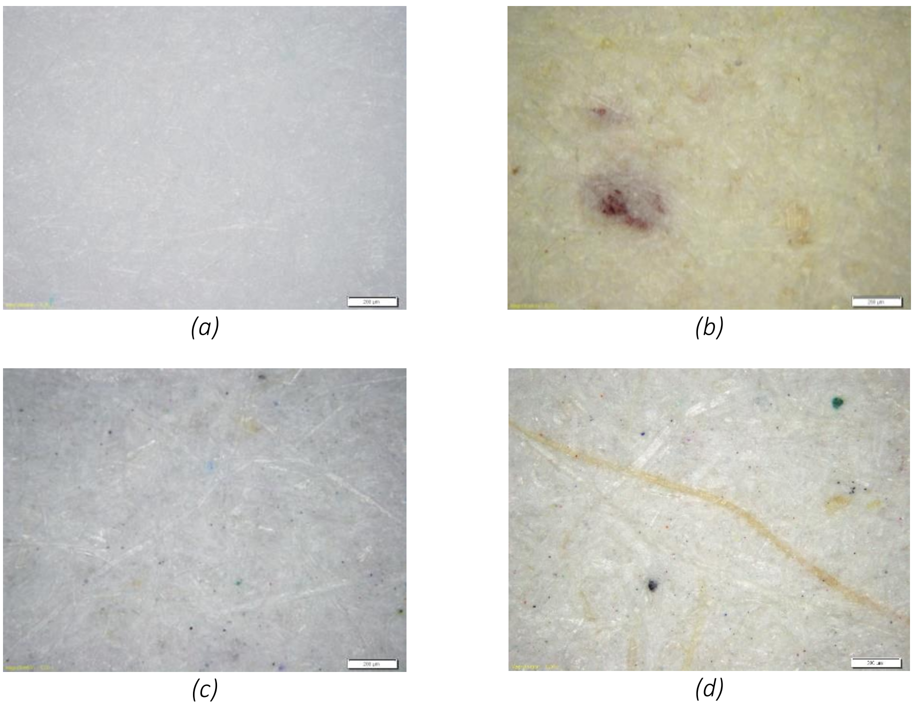
3.1. Characterization of paper substates

The results of measured caliper, bulk, opacity, and whiteness of all paper substates are shown in Table 1. FC 250 has the highest caliper of all samples, followed by N 160 and EPR 80, while PRW 70 results in the lowest value. These results are consistent with the values of basis weight for all samples. Substrate PRW 70 has the highest bulk of 1.351 cm^3/g, which means it has the lowest density. Substrates FC 250 and EPR 80 have the bulk values of 1.3 cm^3/g in the middle, while N 160 has the lowest bulk of 1.063 cm^3/g. Sample FC 250 has the highest opacity of 99.6 %, followed by N 160 – 97.58 % and PRW 70 – 97.02 %. EPR 80 has the lowest opacity of 93.22 %. The results of whiteness show very high result for N 160 – 151.35 %, which indicates the presence of optical brighteners. EPR 80 results in whiteness of 90.62 %, PRW 70 61.11 %, and FC 250 35.43 %.

Table 1: The results of measured caliper, bulk, opacity, and whiteness of paper substrates

Paper substrate	Caliper (µm)	Bulk (cm^3/g)	Opacity (%)	Whiteness (%)
N 160	170	1.063	97.58	151.35
FC 250	325	1.3	99.6	35.43
EPR 80	104	1.3	93.22	90.62
PRW 70	94	1.351	97.02	61.11

Figure 1 presents microscopic images of paper substrates N 160, FC 250, EPR 80 and PRW 70 under magnification of 5×. The surface of the paper substrate N 160 presented in Figure 1a is uniform, homogeneous, the fibers are thin and evenly distributed over the surface, without any visual irregularities. Figure 1b presents a FC 250 substrate. One can see that the structure of the paper is inhomogeneous, the particles of the organic residues are visible and interspersed with primary cellulose fibers. One can see that recycled papers (Figures 1c and 1d) have similar surface structure with intertwined fibers arranged in different directions forming a complex surface morphology. The particles of recycled material is slightly larger in size (up to 50 µm) on PRW 70 paper in comparison to EPR 80 but they are evenly distributed in the surface structure of the both papers.



(a) (b)

(c) (d)

Figure 1: Microscopic images of the paper substrates: N 160 (a), FC 250 (b), EPR 80 (c) and PRW 70 (d) (mag. 5×)

Table 2 presents the results of measured R_a, R_z and R_{max} roughness parameters. It is visible that all three parameters have the highest values on paper FC 250 which means that FC 250 has the roughest surface structure. Substrate with the smallest surface roughness is paper N 160; recycled papers EPR 80 and PRW 70) have similar roughness values. One can see that paper PRW 70 has average surface roughness slightly smaller than EPR 80 paper. These results correspond to the microscopic images of the papers, where the differences in the surface structure of the paper substrates are clearly visible.

Table 2: Roughness parameters measured on paper substrates.

Paper substrate	Roughness parameters (µm)					
	R_a	SD	R_z	SD	R_{max}	SD
N 160	1.552	0.109	10.472	1.004	13.323	2.371
FC 250	3.122	0.103	18.549	1.201	23.740	2.487
EPR 80	2.714	0.309	15.842	1.476	18.905	1.922
PRW 70	2.088	0.182	13.220	1.338	18.609	1.744

Spectral reflectance of substates used in this research differ from each other, mainly because of the optical properties of paper, such as whiteness, brightness, and opacity, but also because the presence of optical brighteners. The latter is most likely the reason for the highest reflectance spectra of N 160 substrate, especially between 420 and 520 nm (Figure 2). Substrate PRW 70 has the lowest reflectance spectra, which could be related to the lowest density of the paper. Sample EPR 80 has very similar trend as PRW 70, higher by about 10 % in reflectance between 420 and 500 nm. The specific yellowish tone of the FC 250 substrate results in spectral reflectance which partially follows the curve of the substrate N 160, between 555 and 800 nm.

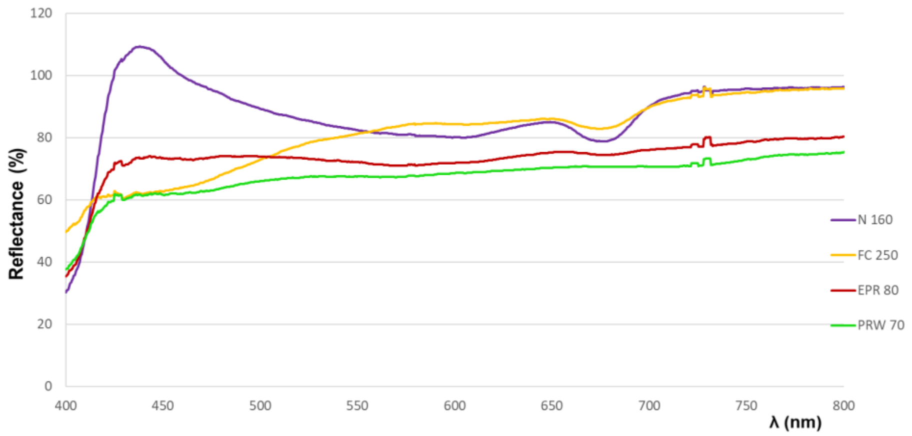
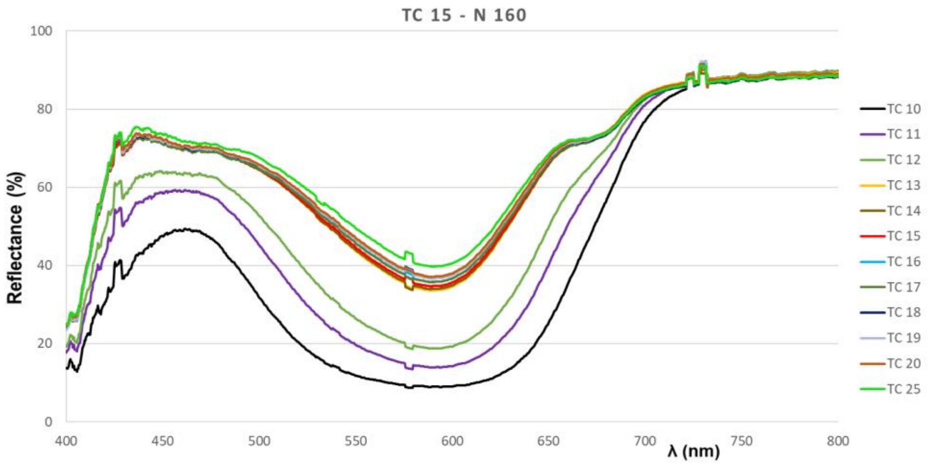


Figure 2: Spectral reflectance of substrates used in the research

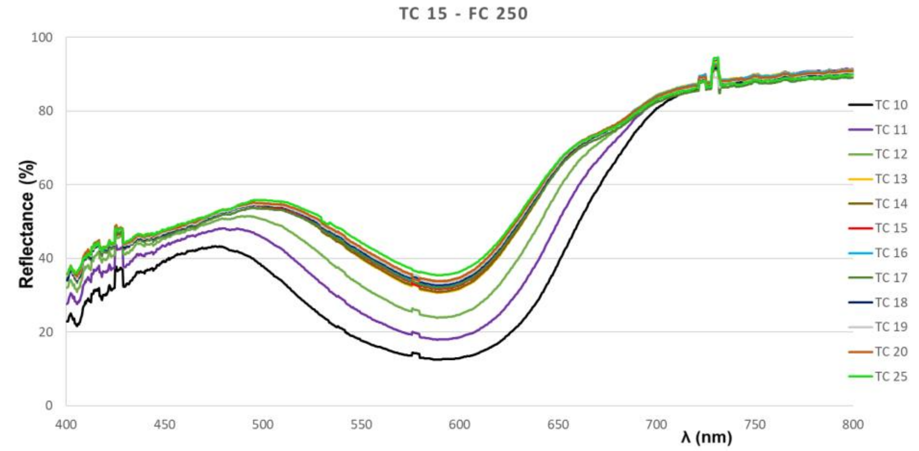
3.2. Spectral reflectance of prints

The results of reflectance spectra of printed TC inks on all paper substrates are shown in Figures 3 – 5. In each individual diagram, each reflection spectrum is measured at the defined temperature, at temperature range from 5 °C bellow, and 5 °C above T_A of each TC ink. The reflection spectra of the printed samples measured at T_A are marked red in each diagram. The results show similar trend of the measured samples as the temperature rises, resulting in higher reflection spectrums and increasing lightness. These dynamic changes of the TC ink affect the readability of QR codes printed with them, which is explained in the section 3.5.
Spectral reflectance of TC 15 printed on all paper substrates (Figure 3) show greater mutual distinction between the samples measured at lower temperatures – 10, 11 and 12 °C, while other temperatures result in rather narrow area of measured reflectance spectra, overlapping with T_A of the samples for all substrates. Similar effect can be noticed for TC 31 printed on EPR 80 and PRW 70 (Figure 4c and 4d), where reflection spectrum of the samples measured at 26, 27 and 28 °C are more separated from the rest of the samples, overlapping the narrow range. Samples printed with TC 31 on N 160 and FC 250 show relatively even distribution of reflection spectra, but T_A is almost completely overlapping with adjacent

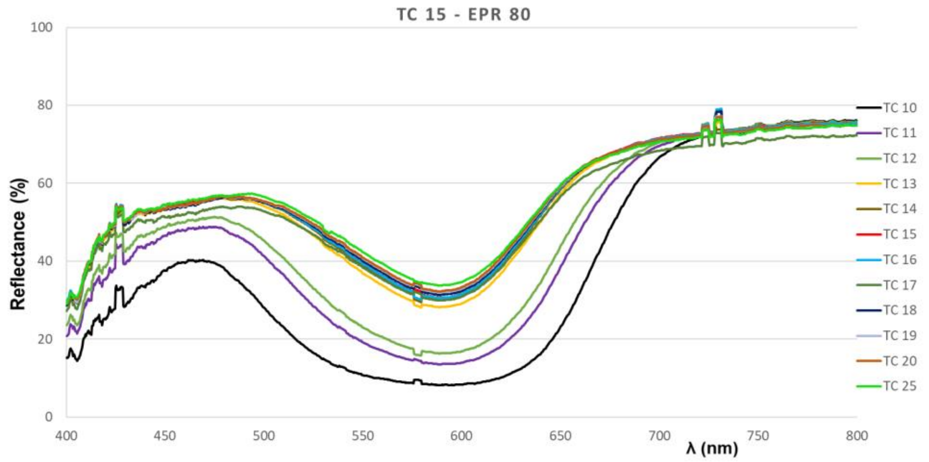
temperatures. The clearest mutual differences between the samples measured inside defined temperature range are shown in Figure 5, for the samples printed with TC 47, with the minor exception of the substrate EPR 80. These results are closely related to the readability of QR codes printed with TC inks, which is explained in the next section.



(a)

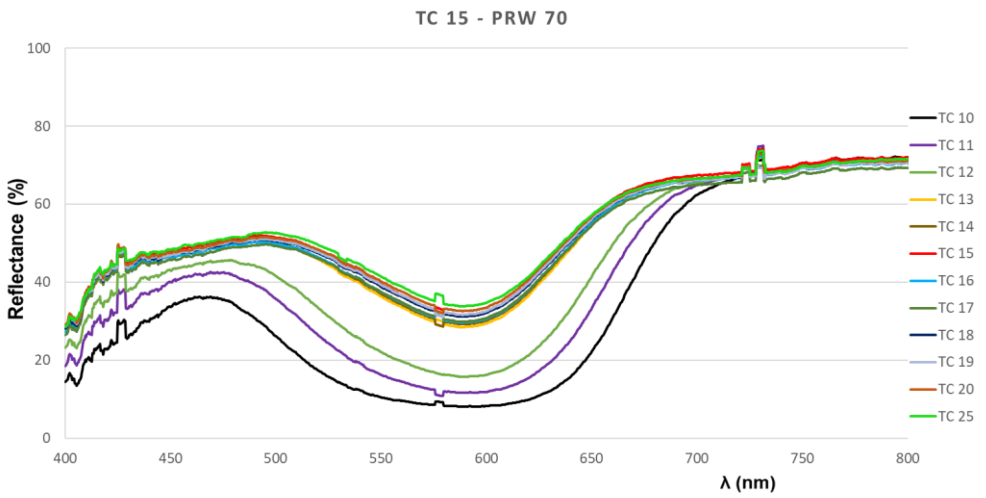


(b)



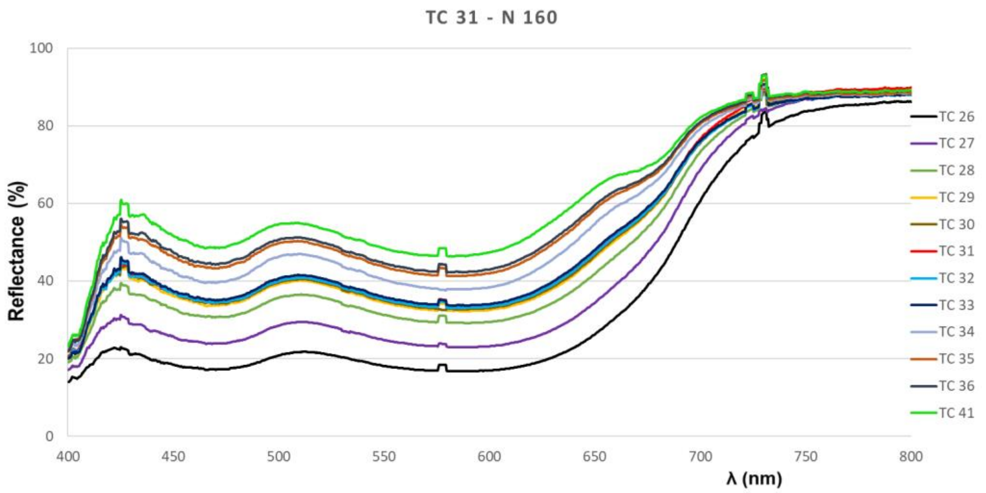
(c)

Figure 3 (part 1): Spectral reflectance of TC 15 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)

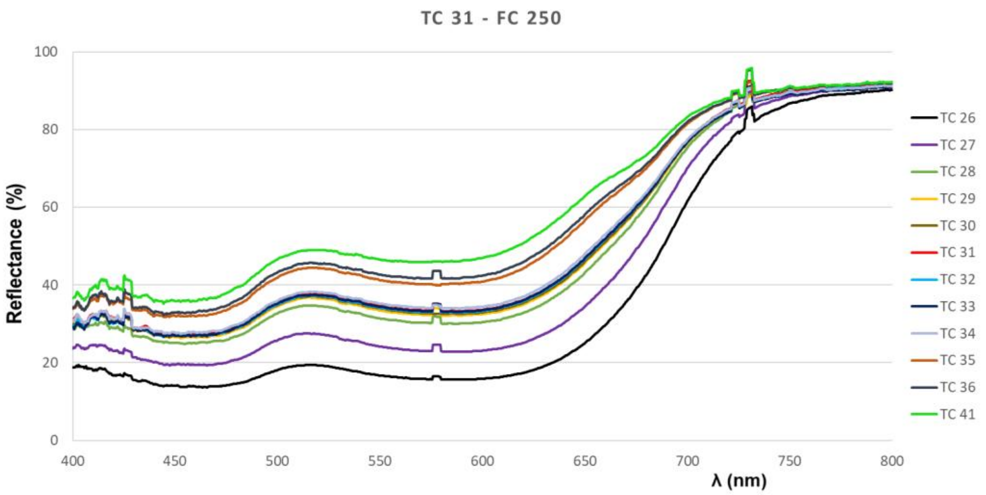


(d)

Figure 3 (part 2): Spectral reflectance of TC 15 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)

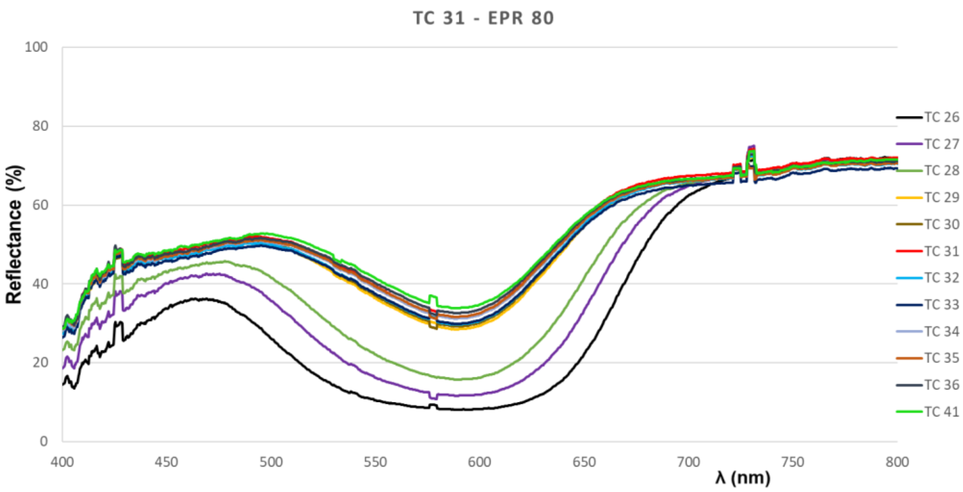


(a)

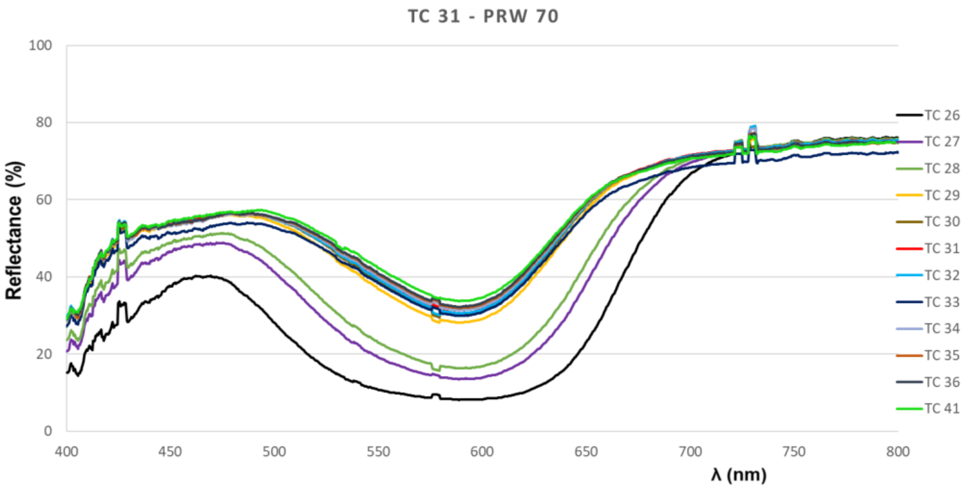


(b)

Figure 4 (part 1): Spectral reflectance of TC 31 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)

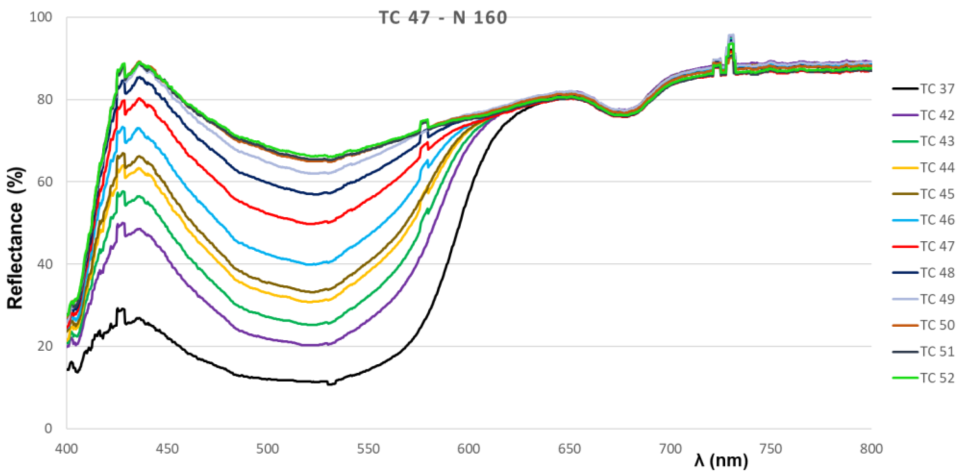


(c)



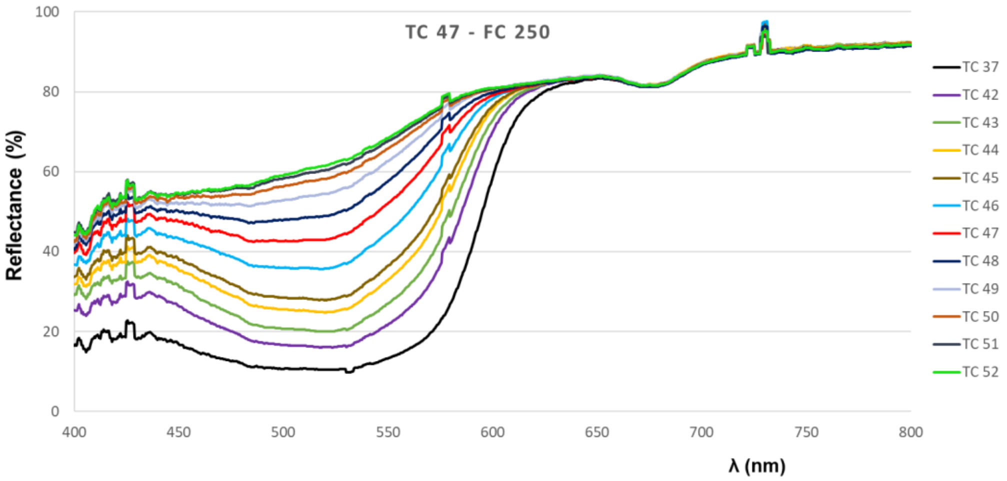
(d)

Figure 4 (part 2): Spectral reflectance of TC 31 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)

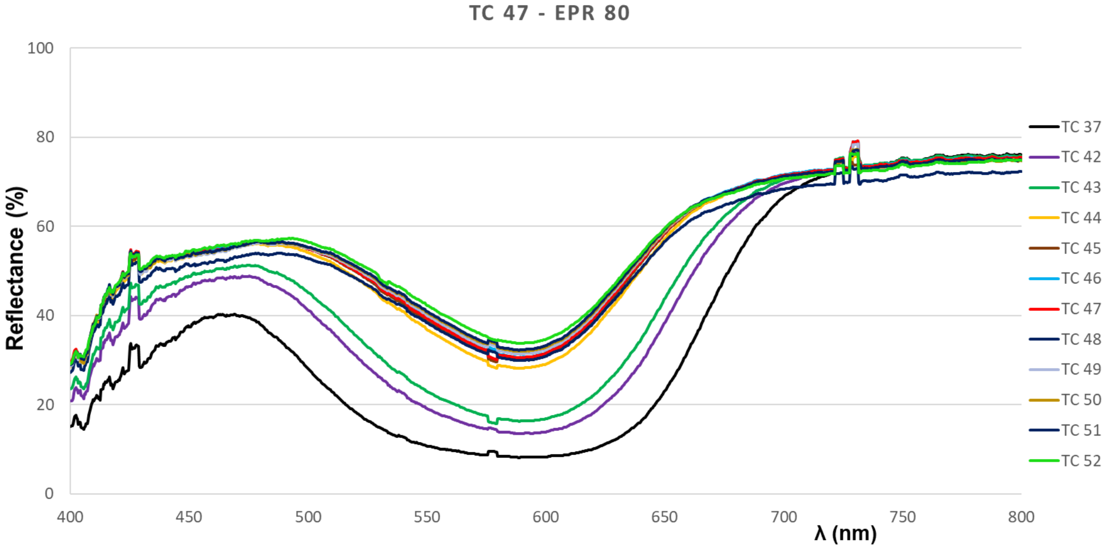


(a)

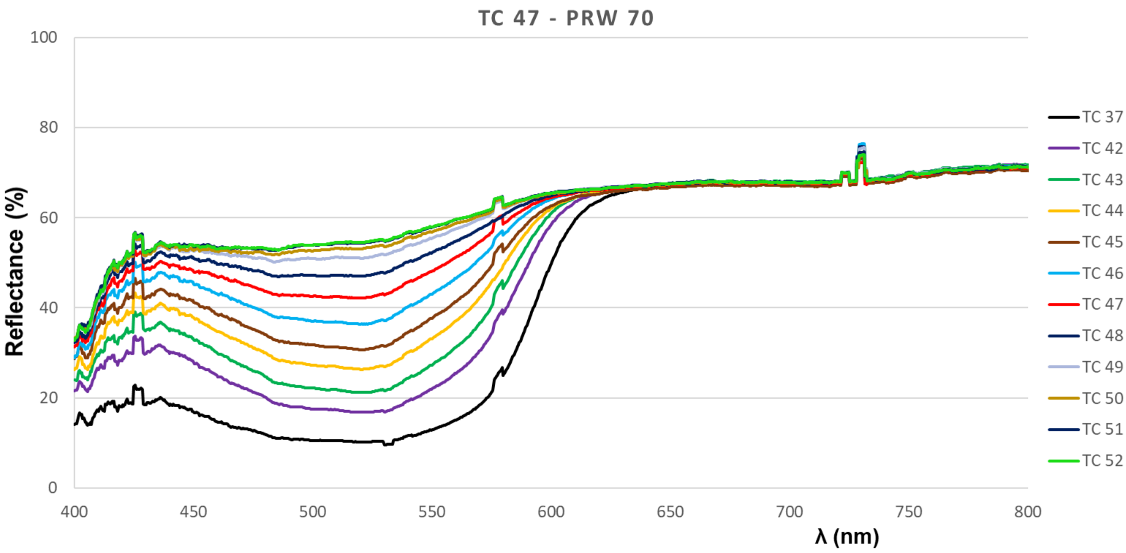
Figure 5 (part 1): Spectral reflectance of TC 47 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)



(b)



(c)



(d)

Figure 5 (part 2): Spectral reflectance of TC 47 ink printed on substrate N 160 (a), FC 250 (b), EPR 80 (c), and PRW 70 (d)

3.5. Readability of 2D codes at the defined temperatures

The results of readability of 2D codes at the defined temperatures are shown in Table 3 – 5. The readability of the QR codes printed with TC inks on all four paper substrates was checked using three different commercially available 2D code scanners/readers. The readability of printed QR codes at the T_A of each TC ink is marked in light blue. The producer of the TC ink defines T_A as the temperature at which TC inks changes their coloration from colored to uncolored state. This means the readability of the printed QR codes should be compromised at this temperature. However, the samples printed with TC 15 show inconsistency in readability of QR codes, considering the type of mobile reader and used substrate (Table 3). The codes are readable at T_A in the case of all used substrates when QR skener (QR) is used, despite the fact the TC ink should fade at this point, i.e., become translucent. Inside the defined temperature range, every single QR code is readable if QR skener is used. The results of code scanning with QR & Barcode Scanner (QR & BS) and Qr Barcode Scanner (QR BS) show loss of readability from 11 or 12 °C to the upper limit of temperature range at 20 °C. Ideally, printed QR codes should be readable at the temperatures below T_A, and gradually lose their tone and function with the rising temperature, i.e. become unreadable.

Table 3: Readability of 2D codes printed with TC 15 ink on different paper printing substrates

		T(°C)										
	QR code scanner	10	11	12	13	14	15 (T_A)	16	17	18	19	20
N 160	QR & BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
FC 250	QR & BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
EPR 80	QR & BS	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
PRW 70	QR & BS	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓*	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Samples printed with TC 31 (Table 4) show a complete absence of functional properties of TC ink inside the defined temperature range. Besides a few isolated samples, all QR codes show complete readability on all printing substrates, making temperature monitoring according to inks specifications impossible. Most of the samples printed with TC 47 (Table 5) resulted in unreadable codes, even on temperatures below T_A. The exception from these results are samples printed on N 160 and EPR 80, where QR codes are readable at temperatures between 42 and 47 °C, and unreadable above T_A. Substrate PRW 70 resulted in readability only on temperatures of 43, 44 and 45 °C. These results are also followed by the photographs of QR codes printed with TC inks, at the defined temperatures (Figure 6 – 8) on substrate EPR 80.

Table 4: Readability of 2D codes printed with TC 31 ink on different paper printing substrates

		T(°C)										
	QR code scanner	26	27	28	29	30	31 (T_A)	32	33	34	35	36
N 160	QR & BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
FC 250	QR & BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EPR 80	QR & BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✗	✓	✓	✗	✓	✓	✗	✓	✓	✗
PRW 70	QR & BS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	QR BS	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✗

Table 5: Readability of 2D codes printed with TC 47 ink on different paper printing substrates

		T(°C)										
	QR code scanner	42	43	44	45	46	47 (T_A)	48	49	50	51	52
N 160	QR & BS	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
	QR BS	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
FC 250	QR & BS	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
	QR BS	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
EPR 80	QR & BS	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✓	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗
	QR BS	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
PRW 70	QR & BS	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
	QR	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
	QR BS	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗

(a) (b) (c)

Figure 6: 2D code printed with TC 15 ink on EPR 80 substrate, photographed at 10 °C (a), 15 °C (b) and 20 °C (c)

(a) (b) (c)

Figure 7: 2D code printed with TC 31 ink on EPR 80 substrate, photographed at 26 °C (a), 31 °C (b) and 36 °C (c)

(a) (b) (c)

Figure 8: 2D code printed with TC 47 ink on EPR 80 substrate, photographed at 42 °C (a), 47 °C (b) and 52 °C (c)

4. CONCLUSIONS

The aim of this research was to determine which temperature range of a particular TC ink provides readability of 2D codes in proposed Smart Tags. The results show dysfunctionality of the application for QR codes printed with TC 15 and TC 31 printing inks. The component of the Smart Tag system through TC inks did not satisfy the criterium of the change in coloration inside the defined temperature range, which affected the readability of the QR codes. TC 47 partially met the criteria of functional printing ink, in the case of N 160 and EPR 80 substrates and QR skener. Further research should be based on TC inks with functional properties investigated and adjusted in detail and aim to examine all printing parameters. All the elements that affect functional properties of Smart Tag system must be known, predictable and repeatable, so they can fulfil its purpose. In addition, the influence of the room temperature on the functional application must also be considered, along with the temperature of the packed product. The thickness of the printing substrate and eventual barrier properties of the packaging with this kind of Smart Tags should also be considered. Detail adjustment and investigation of all elements creating Smart

Tags are necessary for their complete function. Such knowledge and understanding of functional properties could put Smart Tags into more frequent commercial use. The quality of the mobile's camera and the application for scanning the code also had an influence on the readability of the information provided by the Smart Tag, and also should be considered in future research.

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ENHANCEMENT OF MACRO-UNIFORMITY OF COPPER(I) OXIDE PRINTED LINEN FABRICS BY ADDITION OF *PINUS SYLVESTRIS* L. PLANT EXTRACT

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Abstract: *High surface texture of textile materials is rougher than other printing substrates which can cause excessive macro non-uniformity. Adding metal oxides into the ink to enhance material properties usually add to surface roughness and increase print mottle. In this paper copper(I)oxide particles and different amounts of Pinus sylvestris L. plant extract were added to modified alginate paste (CHT-NV) prior to printing. The aim of this paper is to inspect the influence of added metal oxide and plant extract on the print quality of linen based material via surface macro non-uniformity GLCM determination method. In the pattern recognition phase, the co-occurrence matrix is applied to calculate the texture characteristics, such as contrast, correlation, energy, entropy and homogeneity. The research results indicated that the metal oxide particles have had a negative influence on macro uniformity of printed linen. Increasing of the concentration of extract leads to a dilution of the printing paste, and thus to a greater penetration of copper ions between the threads of the fabric, as well as into the yarn itself.*

Key words: Macro non-uniformity; Printing fabrics; *Pinus sylvestris* L.; Copper(I) oxide; GLCM method

1. INTRODUCTION

Screen printing of textile materials using alginate paste modified with pigments from plants and different types of mordants, while respecting ecological principles, is gaining more and more importance today. Natural colors represent an emerging trend in the textile industry and eco-fashion due to the growing awareness of the concept of sustainability that must be applied to the environment. Natural materials are the basis of sustainable clothing production today. Some of the natural materials used in the production of clothing are cotton, silk, wool and linen. Linen is a versatile and highly durable fabric that is twice as strong as cotton and offers similar comfort to clothing. Medicinal elements found in the fibrous shell of flaxseed are plant lignans. Lignans are precursors of phytohormones that exhibit immunostimulating and antibacterial, antifungal and antiviral effects. *Pinus sylvestris* L. (white pine) is a tree up to about 40 m tall, with a trunk up to 1 m wide. The needles are in tufts, 4 to 7 cm long and 2 mm wide. Hoai et al. (2015) found that *Pinus sylvestris* L. needle extract inhibited the growth of several cancer cell lines. Essential oils, isolated from white pine needles, have much better antimicrobial effects, as well as effects on inhibiting the growth of cancerous cells (Czerwinska & Szparaga, 2015; Hoai et al., 2015). The most important components of the essential oil extracted from white pine needles have antiseptic, anti-allergic, anti-inflammatory and deodorizing properties, as well as an effect on faster wound healing (Kumar et al., 2010).

Copper has strong anti-fungal and anti-bacterial properties. Copper is also an essential trace element, vital for the normal function of many tissues and necessary for the creation of new capillaries and skin. Human skin is not sensitive to copper and the risk of side effects due to dermal exposure to copper is extremely low (Borkow, Zatcoff & Gabbay, 2009). Copper-impregnated products possess a wide range of antimicrobial and anti-fungal properties, without causing hypersensitivity or skin irritation (Borkow & Gabbay, 2004; Gabbay et al., 2006). Cupric oxide-impregnated nonwoven fabric has been safely used in adult diapers and antimicrobial wound dressings for years (Borkow et al., 2010a; Weinberg et al., 2013). Their safety in respiratory face masks has also been proven (Borkow et al., 2010b). Copper(I) oxide as a mordant shows great promise for biomedical applications due to its unique potential to combine antibacterial effects with multiple other functionalities. Wang, Yonghong & Liu (2017) analyzed the antibacterial activities of different forms of Cu_2O and found that Cu_2O, even after being coated with various surfactants, still showed activity (Wang, Yonghong & Liu, 2017).

In textile screen printing, many parameters affect the evenness of the print application and the macro-uniformity of the print surface. Previous research has shown that textile material printed by screen printing has high macro non-uniformity, caused by the texture of the material (Stančić, 2016; Vujčić & Ružičić, 2017). The quality of printing, mostly, is tested by testing the quality of color reproduction, but this is often not enough. In a series of experiments (Fedorovskaya, Blommaert & de Ridder, 1993), (de

Ridder, 1996) and (Fedorovskaya, de Ridder & Blommaert, 1997) it was proved that print quality is not only a function of color and color-related features. Parameters such as contrast, sharpness, uniformity of image elements, etc., are not directly related to tone and color, but affect the overall quality. Surface pattern is a term that refers to optical heterogeneity, non-uniformity of optical density and brightness. It appears on fields of full tonal value and is a non-uniform reflection of light from the print. It usually appears in the form of systematically structured patterns that are easily perceived by the human eye due to its perfect response to pattern detection (Petersson, 2005). The larger the surface pattern, the greater the non-uniformity, and based on this, it can be concluded how much influence the non-uniformity has on the sharpness of the print and on the overall quality of the print. In their research, Gebeješ et al. (2012) concluded that a higher entropy value suggests a stronger textural pattern that is easier to perceive with the naked eye. Textures are present on textile materials due to the very structure of the substrate. The assessment of full-tone print uniformity in this research was conducted with the help of GLCM (Grey Level Co-occurrence matrix) image processing methods. GLCM, also known as a gray level spatial dependency matrix, is a table that tracks how often they are different combinations, pairs of pixel intensities (gray level values), occur in a certain spatial relationship and distance in the analyzed image (Hladnik & Lazar, 2011).

2. METHODS

Alginate paste (CHT-NV) was prepared by adding 92 ml of distilled water at room temperature in 8 g of modified alginate. A homogeneous mixture is obtained by continuous mixing. This paste is used as a base for screen printing. After creating a homogeneous paste 20 ml, 40 ml and then 60 ml of *Pinus sylvestris* L. alcoholic extract was gradually added with mixing. Then, an additional 0.2 g of copper(I) oxide was added individually to each mixture. All samples are listed in Table 1.

Table 1: Sample overview

Sample name	Sample modification
E1	Printed with alginate paste + 20 ml *Pinus sylvestris* L. extract
E2	Printed with alginate paste + 40 ml *Pinus sylvestris* L. extract
E3	Printed with alginate paste + 60 ml *Pinus sylvestris* L. extract
Cu	Printed with alginate paste + 0,2 g Cu_2O
E1-Cu	Printed with alginate paste + 0,2 g Cu_2O + 20 ml *Pinus sylvestris* L. extract
E2-Cu	Printed with alginate paste + 0,2 g Cu_2O + 40 ml *Pinus sylvestris* L. extract
E3-Cu	Printed with alginate paste + 0,2 g Cu_2O + 60 ml *Pinus sylvestris* L. extract

A semi-automatic Screenprinter S300 screen printing system was used to print the material. Each sample of linen fabrics previously bleached with hydrogen peroxide (H_2O_2) was printed in two passes at a speed of 0.08 m/s on a 15 threads/cm screen. Fabrics characteristics are listed in Table 2.

Table 2: Fabrics characteristics

Sample	Fiber fineness [tex]	Surface mass [g/m^2]	Density [m^{-1}]	
			Warp	Weft
LINEN	42,386	199,37	22,7	20,5
	METHODS:	ISO 3801	ISO 7211-2	

The fabrics are cut to a size of 50 x 50 cm, and a 40 x 30 cm patch was printed on each sample. After drying, the samples were scanned with a Mustek 1200 ub plus flatbed scanner. The resolution used is 1200 spi, and image was generated using the Adobe Photoshop software. When scanning, all options for automatic image adjustment are turned off. The scan setup is the same for all samples. The samples were photographed with a Velleman digital microscope and the Xploview software application. The GLCM image processing method was applied to scanned printed samples using MATLAB software and a plugin proposed by Uppuluri (2008). This plugin provides information on 22 parameters, the most relevant of which are used in the literature, as well as in this research, are contrast, correlation, entropy, energy and homogeneity (Hladnik & Lazar, 2011; Chen, 1998). It was found that the parameters of these five parameters can be used to assess the uniformity of print (Hladnik & Lazar, 2011; Fahlcrantz, 2005). Low contrast, low correlation, low entropy, high energy and high homogeneity correspond even distribution of gray levels, that is, they indicate a uniform, smooth surface (Hladnik & Lazar, 2011; Chen, 1998).

3. RESULTS

The results are shown in Figure 1.

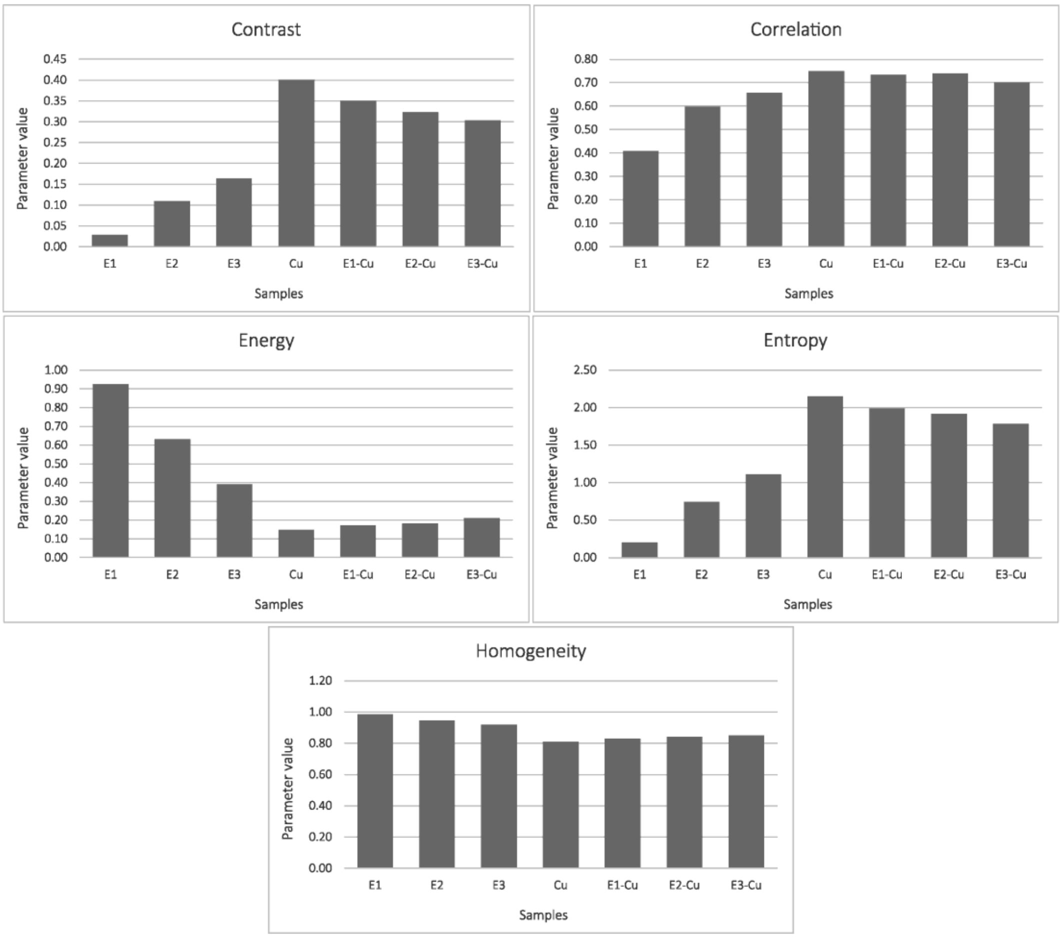

Figure 1: Macro non-uniformity parameters

By visual analysis of the samples, as on Figure 2., small copper particles were observed in the yarn of the printed linen fabrics on the 600x enlarged sample.

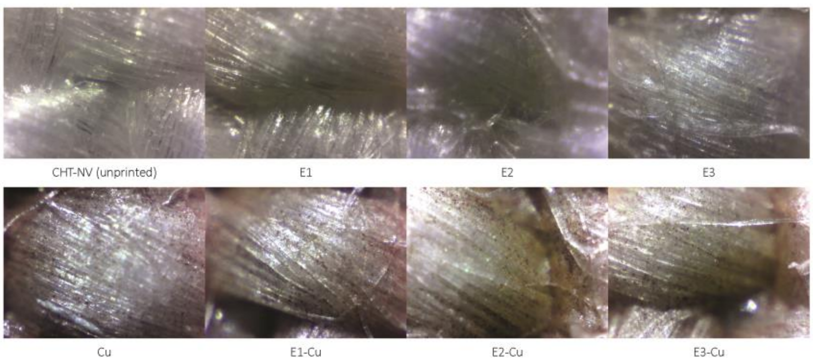

Figure 2: Enlarged images of samples

4. DISCUSSION

Observing all parameters of surface non-uniformity, it can be concluded that the sample E1 has the most favorable parameters and the highest uniformity during printing, and this uniformity is decreased by increasing the concentration of the extract. This could be caused by the accumulation of extract in the weaves of the fabric, which becomes more pronounced as the concentration of the extract increases. This can also be attributed to the structure of the linen fabric by looking at the entropy parameter that best correlates with the human perception of texture. We see that, where the entropy value is high, a certain texture becomes more visible and noticeable. On samples with added copper(I) oxide (sample Cu) it can be concluded that Cu_2O significantly disrupt the uniformity of the printed surface, however, by adding the extract, particles of copper ions penetrate deeper into the yarn and the macro non-uniformity decreases.

5. CONCLUSIONS

The addition of Cu_2O to the printing ink has an effect on the macrouniformity of the printed fabric, which is confirmed by all parameters of surface non-uniformity. It has been shown that the samples with added copper(I) oxide significantly impair the uniformity of the printed surface, however, by adding the extract, the copper ion particles penetrate deeper into the yarn and macro non-uniformity is reduced.

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DYNAMICS OF THERMOCHROMIC COLOR CHANGE OF PRESSURE SENSITIVE LABELS FACESTOCK MADE FROM ENVIRONMENTALLY FRIENDLY MATERIALS

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Abstract: *To maintain a circular economy and better sustainability, it is important to minimize the use of synthetic polymers. Nowadays, agricultural and industrial wastes or by-products are increasingly being used as raw materials in industrial processes. It has been determined that agro-industrial wastes have a high potential of cellulose fibers, which makes them an excellent resource for paper production. Recently, potential resources from non-wood raw materials for paper production, as well as cheap raw materials, have become the interest of various researchers. Since our main focus is on the study of thermochromic inks (TC) and the influence of substrate characteristics on their dynamic color change, this paper will examine the possibilities of a commercially available offset TC ink printed on several environmental friendly pressure sensitive labels (PSL) facestock compared to commonly use in PSL production. For the purpose of this study, a commercially available TC ink with an activation temperature (TA) of 29°C was used. The effect of color change, from blue to colorless, was measured through one heating and cooling cycle at several selected temperatures at six different PSL materials. Three fiber-based facestock of PSL used in this research are produced with 15% agroindustrial byproducts, 40% post-consumer recycled paper and 45% virgin wood pulp to form a high-quality natural paper. In addition, one material made from biogenic polymers facestock and two materials commonly used in labels production were used as well. The results of this research show that TC ink printed on alternative materials has a similar trend of color change and may be a good choice. Also, the influence of the color of fiber-based paper substrates on the change of TC color was noticed, which indicates the importance of colorimetric analysis of paper and TC ink before their printing.*

Key words: pressure sensitive labels, facestock, thermochromic inks, eco-friendly materials, spectrophotometric measuremets

1. INTRODUCTION

Pressure sensitive labels (PSL), also known as self-adhesive labels, have gained great popularity due to their simplicity and user-friendly role (Medeiros et al., 2019). As AWA predict globally, PSL label material industry is expected to grow (Labels&Labeling, 2021). The PSL is an integrated part of the product packaging. It is very important that the label and the product packaging are made of the same materials and have the same structure. Such mono-material packaging enables recycling and reuse. Paper as a substrate for the production of labels represents more than 50%, and 20% is the siliconized part (PP and PE). When choosing an appropriate label material, it is important to choose an adhesive that will not adversely affect the recycling or reuse process of the product in any way (Huhtamaki, 2020). Each PSL from a roll consists of three basic parts: facestock (paper, foil), adhesive and liner. The paper used as facestock can be coated, uncoated, white, colored, smooth, structured and may contain some special characteristics such as security fibers. The correct selection of each part of the label is defined by various parameters. Some of the parameters are where the label will be placed and used and general information about its use such as application surface, application speed, room temperature of use and the temperature of the product itself, humidity, etc. The most common printing techniques for PSL are UV flexo printing, UV offset, UV letterpress, digital UV inkjet and electrophotography (Marošević Dolovski, 2016; Tesařová et al., 2020).

The PSL can also provide additional value by using interesting structures, designed by a hot or cold stamping process, spot varnishes etc. It is also possible to insert RFID tags or NFC and use labels for security purposes. The life cycle of a label is defined by several conditions such as printing, handling, use and deciding whether the label is to be recycled or treated as waste. All materials from which the label is made depend on various external influences such as weather and storage conditions, methods and

conditions of application, type of printing, etc. When printing, the surface of the substrate or the top layer of the label must have the appropriate quality. Print quality can be affected by surface structure, paper dust or discoloration of materials based on paper fibers. Optimum printing methods and techniques, appropriate inks and other auxiliary devices must be used to achieve the best appearance and purpose of the label (Marošević Dolovski, 2016).
This paper aims to test the functionality of one offset TC ink on the most commonly used labels and those made of biologically acceptable materials for environmental protection. Also, the influence of the shade of the facestock surface on the dynamic changes of the TC color will be examined and analyzed with spectrophotometric measurement and presentation in the CIELAB color space.

2. EXPERIMENTAL

For this research, six types of different PSL were used. Figure 1 shows the spectral reflectance curves of all tested PSLs in this paper before printing while Table 1 shows their characteristics as provided by the manufacturer. Three types were made of agroindustrial by products, one is a bio-based polymer and the other two are most often used as PSL, wood-free coated on a cellulose basis. The eco-friendly labels based on agroindustrial byproducts are made from barley (B), citrus (C) and grapes (G). To produce B, C and G, the upper layer of the label, CO_2 emissions were reduced by 20%. The fibers that make up the upper layer of the labels are made from 15% agro-industrial bio products, i.e., barley, citrus, and grapes, containing 40% recycled paper and 45% virgin wood pulp to obtain high-quality natural paper. Grape fibers are obtained from the rest of the grapes used to make wine, citrus fibers are obtained from the remains of fruit and juice products, and barley fibers are collected from barley used in the production of beer and whiskey malt. The wood-free coated papers used are MC and TT and a bio-based polymer, polyethylene white (PEW-B). MC is a white, wood-free, semi-glossy paper containing an acrylic-based adhesive. PEW-B is polymer-based, made mainly from sugarcane ethanol, with a rubber-based adhesive. TT is a thermosensitive wood-free paper made from chemical pulp. The top layer is thermally coated, and below it is a black thermosensitive layer that provides good resistance to moisture, fats, oils and alcohols (AveryDennison, 2022a, 2022b; Vukoje et al., 2021) .

Table 1: Properties of used PSL given by the producer

Substrate	Abbreviation	Facestock		Liner		Total Laminate
		Basis Weight ISO 536, g/m^2	Caliper ISO 534, mm	Basis Weight ISO 536, g/m^2	Caliper ISO 534, mm	Caliper ISO 534, mm
Fasson®rCrush Barley	B	90	110	70	61	190 ± 10%
Fasson®rCrush Grape	G	90	114	70	61	192 ± 10%
Fasson®rCrush Citrus	C	100	130	70	61	210 ± 10%
Fasson®MC FSC	MC	77	66	54	47	124 ± 10%
Fasson®Thermal	TT	76	82	54	47	141 ± 10%
Fasson®PE85-BIOB White	PEW-B	82	82	59	53	152 ± 10%

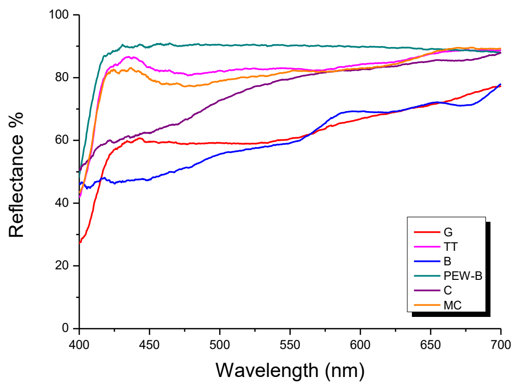

Figure 1: Spectral reflection curves of all used unprinted PSL samples

The reversible thermochromic (TC) ink used is a commercially available leuco dye-based offset printing ink with an activation temperature (T_A) of 29°C. Before reaching the T_A, the TC color is blue. By heating up and reaching the T_A, the TC ink changes to a colorless state.
Prints were printed in a printing press under standard conditions and dried using a UV drying unit of an offset printing machine.
Spectral reflectance was measured by Ocean Optics USB2000+ spectrometer using 30 mm wide integrating sphere under (8: di) measuring geometry. The printed samples were heated/cooled on the full-cover water block (EK Water Blocks, EKWB d.o.o. Slovenia). The measurements were performed in the steps of 1 nm for the spectral region from 430 to 750 nm. Ocean Optics SpectraSuite software was used for the calculation of the CIELAB values from measured reflectance. The total colour difference between *between printed PSL samples at 15°C and those at 45°C* was calculated using the formula CIEDE2000 (International Commission of Illumination, 2004).

3. RESULTS AND DISCUSSION

To examine the influence of the characteristics of the upper layer of the label and its color on the visual appearance, hue and the effect of changing the printed TC ink, the changes were monitored through CIE *a*b** graph, *L**T graph and spectral reflectance curves.

The dependence of the lightness *L** on the temperature T of the printed TC ink on B, C, G, MC, PEW-B and TT labels is shown in Figure 2. These are the characteristic hysteresis curves of thermochromic colors. It is evident from the graphs that during heating there is an increase in *L** because the TC changes from blue to colorless, i.e. the color of the upper layer of the label is visible on the sample. The increase in brightness occurs up to the T_A of 29°C, after which the change slowly stops and the graph becomes more continuous. During the cooling process, a sudden change occurs after crossing the activation temperature. It can be read from the graph that the curves do not have the same path of change, they do not overlap.

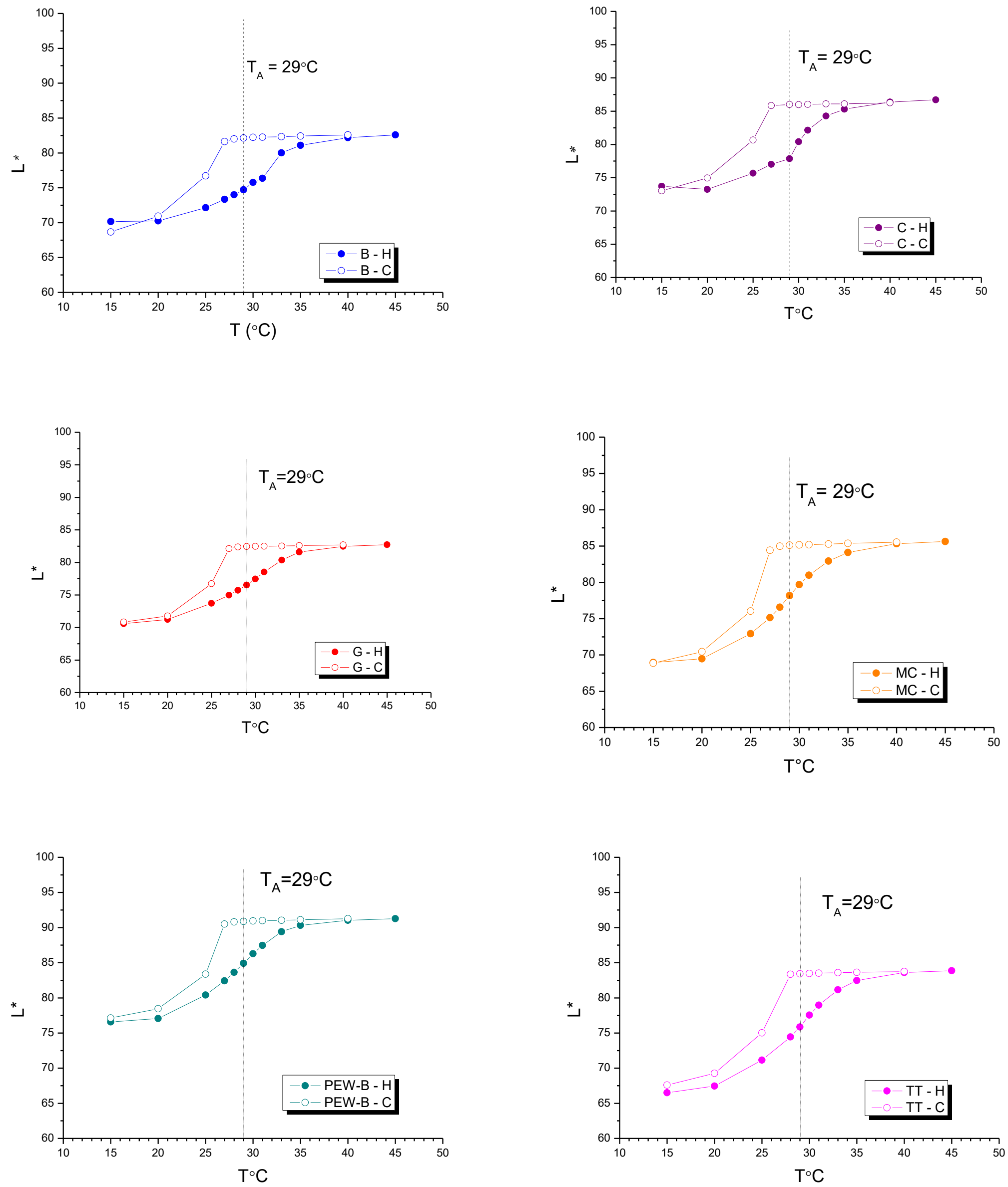

Figure 2: Hysteresis loops of all printed PSL samples during heating (closed signs) and cooling (open signs)

Based on these graphical representations, it can be concluded that during heating and then cooling, there are no equal changes in the lightness of the tested TC ink and that the reversible process is not ideal. The shape of the hysteresis for all tested samples is the same, only some small differences are observed at the hysteresis opening, i.e. at the temperature where the measurement cycle starts and ends.

hysteresis opening, i.e. at the temperature where the measurement cycle starts and ends.

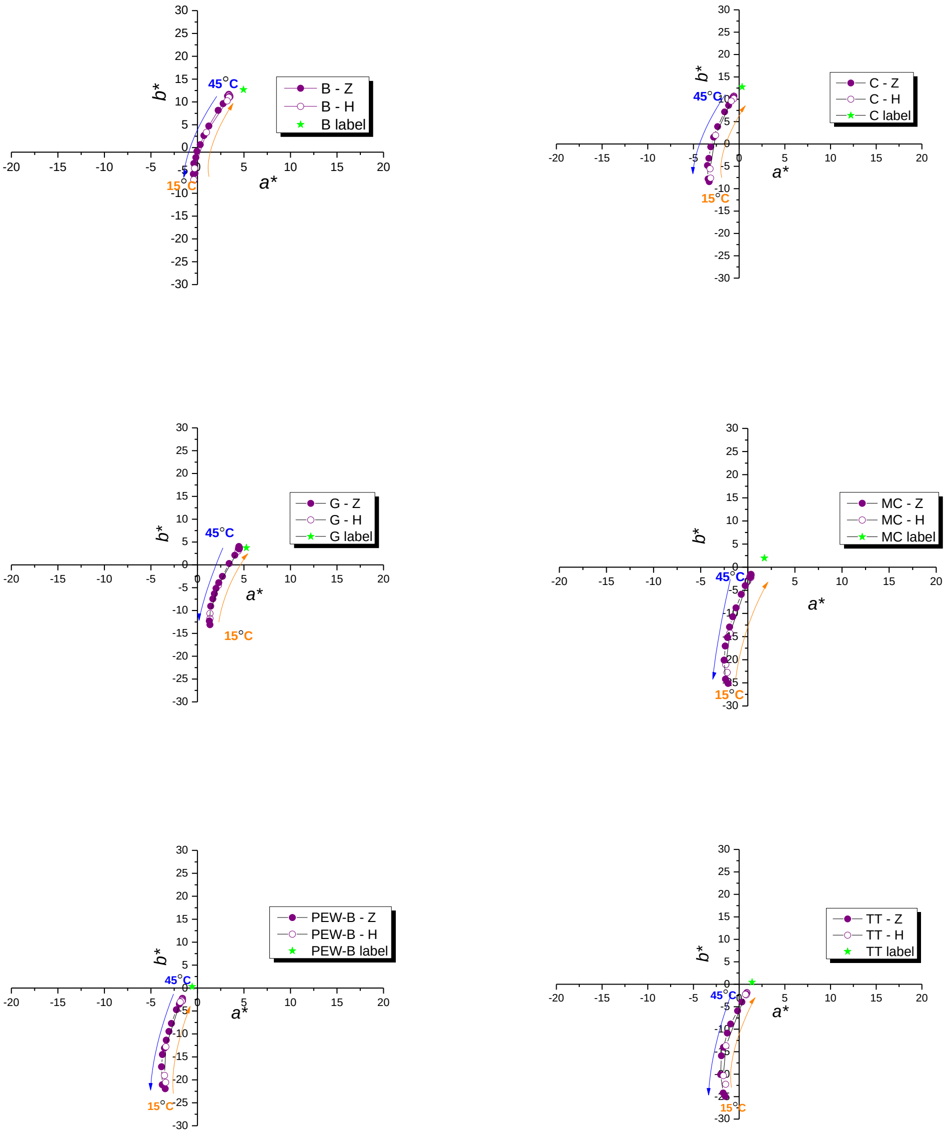

*Figure 3: TC color change path on CIE a*b* graphs during the heating and cooling process on all PSL labels*

The CIE *a*b** graph (Figure 3) shows the color change path of a TC ink through the entire heating and cooling cycle. The color of the top layer B of the label is within the yellow part of the CIELAB color space. One of the reasons for this is that the top layer of that sample has a yellow shade. When heating (minimum temperature is 15°C), the curve takes the direction from the blue part to the yellow part of the CIELAB color space. The curve of print on the B label is mostly on the right side of the graph, where red-yellow, warmer hues predominate. With cooling (the maximum temperature is 45°C), the curve takes a direction from the yellow area towards the white, achromatic center of the graph and slightly enters the light blue area. Unlike the B label, the print on the C label is mostly within the blue area although the top layer of the label also has a yellowish shade. From this, it can be concluded that the hiding power of the TC ink on the C label is better than the B label. The curves of prints on the C label are located on the left side of the graph, green–blue part. During heating, the curve takes the direction from the blue part to the yellow part of the CIELAB color space. With cooling, the curve takes a direction from the yellow area to the blue. The color of the top layer of the G label is within the red part of the CIELAB color space.

The curves of the printed G label are located on the right part of the graph where red-blue, warmer tones predominate. Unlike the B and C labels, the G label is mostly inside the blue part, and the reason for this is probably the color of the top layer of the G label itself. During heating, the curve takes the direction from the blue part to the red part of the CIELAB color space. With cooling, the curve takes a direction

from the red area to the blue. The color of the top layer of the MC label is within the central, white, achromatic part of the CIELAB color space, which is also visible on the MC label, which is white. The curve of the MC label is located on the left side of the graph where blue predominates. Unlike the previous graphs, here the hiding power of the TC ink is the best because the curve is entirely within the blue part of the CIELAB space. The top layer of the label itself, which is coated and smooth contributes to such good hiding power. During heating, the curve takes the direction from the blue part towards the central part of the graph. With cooling, the curve takes the direction from the central part towards the blue.
The color of the top layer of the PEW-B label lies within the very central, white, achromatic part of the CIELAB color space. Compared to the MC label, the color of the top layer of the PEW-B label is closer to the center, which means it is whiter. The curves of prints on the PEW-B label are on the left side of the graph, where blue predominates. As with the curves of the MC label, the hiding power of the TC color of the PEW-B label is very good, because the entire part of the curve is inside the blue part of the CIELAB space. The top layer of the label itself, which is smooth, uniform and white, contributes to such good hiding power.
The color of the top layer of the TT label is within the central, white, achromatic part of the CIELAB color space, which is also visible on the MC and PEW-B labels, which are white. The curves of the printed TT label are located on the left side of the graph where blue, cold hues predominate. As with the previous graph, the covering power is very good, and the reason for this is the top layer of the label itself, which is smooth, uniform and white. During heating, the curve takes the direction from the blue part towards the central part of the graph. With cooling, the curve takes the direction from the central part towards the blue. These graphs show that the shade of the top layer of the labels has an effect of TC color. Also, it shows that the reversible process is not ideal because the heating and cooling curves do not exactly match.

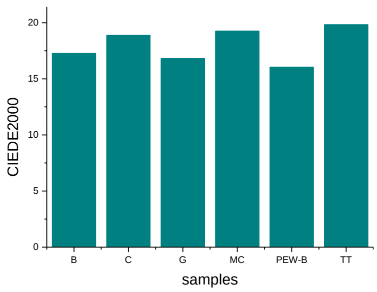

Figure 4: CIEDE2000 color difference between printed PSL samples at 15°C and those at 45°C

The bar graph (Figure 4) shows the CIEDE2000 color differences between all TC ink samples during the heating process at 15°C and 45°C, which is the so-called total color contrast. It is evident from the graph that there is a large noticeable difference in the thermochromic color for each sample when it is at 15°C and when it reaches a temperature of 45°C. Large color changes are the result of discoloration of the TC ink by the heating process, which results in a stronger and more noticeable TC effect. The smallest color difference is achieved by the printed pattern on the PEW-B label and the largest color difference is achieved by the pattern on the TT label.

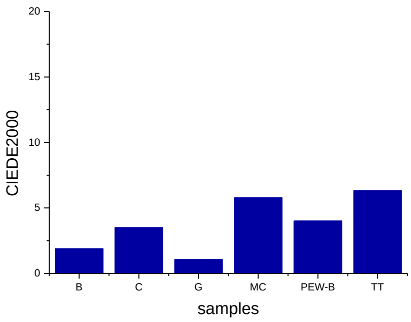

Figure 5: CIEDE2000 color difference between unprinted PSL and printed PSL with TC color and measured at 45°C

Figure 5 shows that there are larger and smaller visual differences in color. Eco-friendly samples have small color differences, unlike bio-based polymers and wood-free samples, which have visible color differences. Of the ecological samples, the print on the C label has the biggest difference in color, and the G sample has the smallest color difference. The TT wood-free sample has the largest change in color difference, and the PEW-B label has the smallest. From the results in Figure 6, it can be concluded that B and C samples with rough surfaces have the smallest color difference. They have the smallest hiding power with TC ink, which is probably why the visual difference isn't that obvious. MC and TT labels with smooth surfaces have the greatest visual difference in color and have the best hiding power with TC ink. The reason for the lower hiding power of rough samples is that they are structured and more absorbent and the dye penetrates more into the structure of the paper in contrast to smooth samples.

4. CONCLUSIONS

Based on this research, it was confirmed that the characteristics of the upper layer of the label and its color have a significant impact on the visual appearance, color shade and the effect of TC color change. Eco-friendly labels have a weaker TC effect compared to bio-based polymer and wood-free labels. Due to their rough surface structure, TC color have low hiding power on eco-friendly labels, which is also reflected in lower CIEDE2000 color difference values compared to smoothly structured papers with large color difference values. However, the TC effect is still clearly visible on these substrates. It has been proven that the reversible process of TC ink is not ideal for any of the tested materials. Analyzing the results of the spectrophotometric curves, it was determined that the discoloration of the TC color is not complete in any of the tested samples and that all the tested samples have a yellowish undertone. The reason for this could be different scattering or absorption that occurs due to different optical properties of the capsule in its discolored state and the binder, i.e. as a result of incomplete transparency of the TC composite inside the capsule itself at high temperatures. This test, among other things, showed the possibilities of offset TC ink, which, despite its poor hiding power still has a significant TC effect that is visible. This is the most important factor for the thermochromic indicators on the packaging to fulfill their functional role that gives the product itself additional value.

5. ACKNOWLEDGMENTS

The authors are grateful for the financial support of the University of Zagreb.

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ECOLOGY

https://doi.org/10.24867/GRID-2022-p85 Original scientific paper

INVESTIGATION OF RECYCLING PERFORMANCE OF DIFFERENT TYPES OF PAPER PRINTED WITH UV INKS

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Abstract: *Waste paper is an important raw material for the paper industry and pulp due to its low cost and sustainability. However, the majority of waste paper contains high volumes of printed paper, which is difficult to deink and limits their application. One of them is printed papers using UV ink. In the study; Papers of different surface structures were printed with LED-UV curable inks. Printed papers were recycled using the INGEDE method 11p. CIEL*a*b* values of the resulting paper sheets were measured; and then compared with those of the base paper. The handsheets obtained via recycling process were viewed with a microscope and the particle sizes were shown. It has been determined that it is very difficult to remove the polymerized UV cured inks from the pulp.*

Key words: Paper recycling, LED–UV ink, deinking

1. INTRODUCTION

Printed or used waste paper has become a promising raw material for the pulp and paper industry due to its low cost and conductivity to sustainable development. However, the majority of waste paper contains high volumes of printed paper, which is difficult to deink and restricts their application. (Yang et al., 2022)
Recycling waste paper requires removing printing ink from the paper through a process called deinking. (Tutak, 2018) Deinking is an important stage in secondary fiber recycling. (Meng et al., 2013) Deinking of secondary fibers involves removing ink particles from fiber surfaces and separating dispersed ink from fiber suspensions by washing or flotation.
In the deinking flotation process, the printing system used, ink, temperature, pH, bubble size, ink thickness, size of ink particles and age of printed products are the main factor of the recycling process. (Yang et al., 2022) In addition, the flotation deinking process plays an important role in the product quality and processing costs of waste paper recycling. (Yang et al., 2022)
Many difficulties are encountered in the flotation processes. One of the most important of these is the ink particle size in the flotation process. For example; the small pigment particles such as digital printing, or the difficulty of disintegration of polymerized inks in the recycling process.
Printing inks generally consist of a carrier (water, oil or solvent), colorant (pigment or dyestuff) and a binder (resin). The substrate to be used and the printing system play a decisive role in the content of the inks. (Aydemir et al., 2018) UV-curable offset printing inks have a similar structure. UV-curable inks generally consist of four main components: monomers, oligomers, photoinitiators and pigments. (Liu et al., 2020) UV-curable inks consist of monomers that are crosslinked with oligomers using UV irradiation. Monomers act as reactive dilutants and oligomers essentially replace the resinous binder (Hakeim et al., 2018) The biggest feature that distinguishes UV inks from standard offset printing inks is that they are quickly dried by a UV dryer.
UV-curable inks have a number of advantages over standard printing inks, such as high printing speeds, low VOC emissions, and good adhesion to non-absorbent surfaces. (Robert et al., 2019) In addition, the use of low energy consuming LED lamps used in recent years is also important in terms of energy saving and high productivity. (Salleh et al., 2002)
However, although the drying of the ink on the printing by polymerization provides good quality and visual advantage in printing, it causes some difficulties in the recycling process.
In this study, the effects on the recycling of coated and uncoated papers printed with UV LED ink were investigated.

2. METHODS

In this study, 140 g/m2 uncoated and 170 g/m2 coated glossy paper was used to examine the recycling performance of coated and uncoated papers. These papers were printed with UV-LED curable offset printing ink. The printed papers were prepared according to the INGEDE method 11p and the recycling process was applied. Table 1 shows the chemicals used for the recycling process.

Table 1: Standard INGEDE 11p solution formula for preparing pulp

Chemical	Rate (Dry Fiber Base)
NaOH	0.6% (100%)
Sodium Silicate	1.8% (1.3-1.4 g/cm3)
H_2O_2	0.7% (100%)
Oleic acid	0.8% (extra Pure)

Air permeability, surface roughness and CIE L*a*b* values, which will affect the recycling processes of printed and unprinted papers were measured before the recycling process. The measured values are listed in Table 2.

Table 2: Paper properties

	Base Uncoated	Base Coated
Grammage g/m^2	140	170
L*	93.15	94.88
a*	2.75	0,97
b*	-9.87	-4.48
Air permeability (ml/min)	658	0,3
Surface Roughness (ml/min)	74	0

3. RESULTS AND DISCUSSIONS

Prints were made with printing ink cured by UV-LED lamps on coated and uncoated papers. Handsheets were obtained by subjecting the printed papers to the recycling process. The measurement results on these handsheets are shown below.

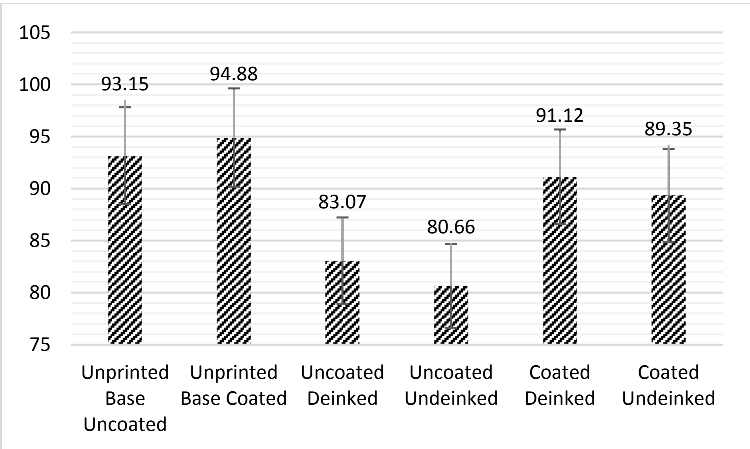

Figure 1: Comparisons of CIE L values of handsheets*

When the CIE - L* values of the obtained handsheets are compared, it is seen that the CIE - L* value of the deinked handsheets obtained from the recycling of coated papers is quite close to the base paper values. It has been determined that the CIE - L* value of the handsheets obtained from the uncoated papers is quite low compared to the base papers.

Figure 2 and Figure 3 show the CIE a* and CIE b* values. Looking at these values, it can be observed that both CIE a* and CIE b* values are quite low compared to base paper values. While the CIE a* value for the uncoated handsheets was nearly 1/5 compared to the base paper values, this ratio was determined as 1/3 for the coated papers.

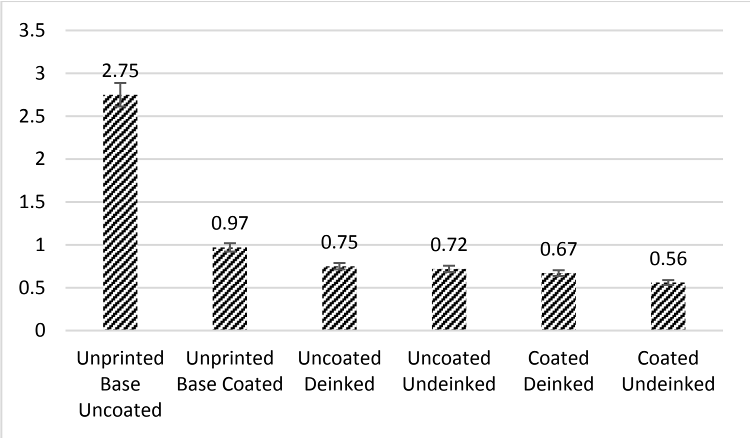

Figure 2: Comparisons of CIE a values of handsheets*

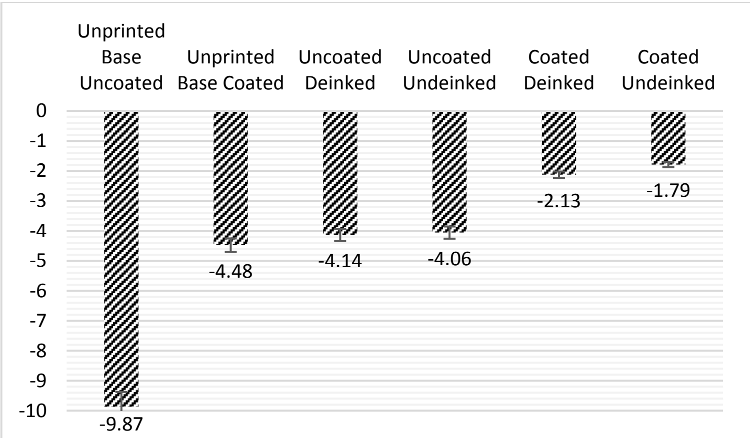

Figure 3: Comparisons of CIE b values of handsheets*

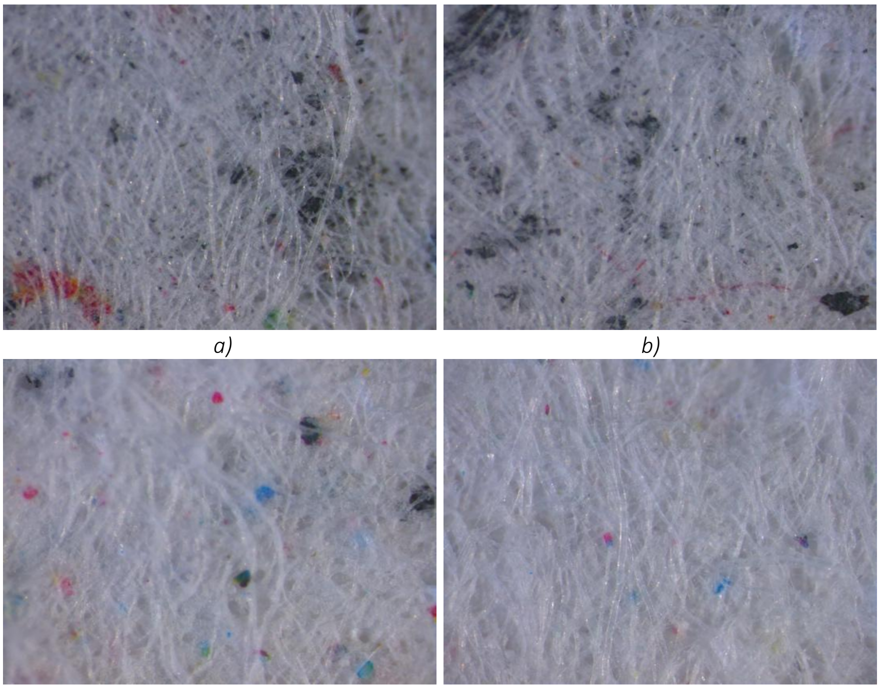

Figure 4: 3X microscope view of surface a) uncoated undeinked, b) uncoated deinked, c) coated undeinked, d) coated deinked

One of the main components of UV ink is acrylic resin. After curing with UV, this resin forms a hard coating layer on the surface of the substrate. It is very difficult to break up this layer, because of unacceptable speckle contamination of pulp formed after deinking. For this reason, printed products using UV ink have been seen as raw materials to be avoided in the recycling process. (Koizumi et al., 2022) In Figure 4, this situation is shown in the handsheets taken with the microscope.

4. CONCLUSIONS

Studies have shown that the printing system and the type of ink used are very important in the recycling processes of papers. Ultraviolet inks form a hard polymer layer on the substrate. This hard polymer layer formed is very difficult to break down while preparing the pulp. The dimensions of the fragmented ink particles are quite large and it is very difficult to remove them by flotation. (Bolanča & Bolanča, 2004) This situation has become more difficult in uncoated papers as the ink penetrates more into the paper. Inks that could not be removed during the flotation process caused the CIE L*, CIE a* and CIE b* values of the handsheets to be low.

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https://doi.org/10.24867/GRID-2022-p86 Original scientific paper

FLUORESCENCE SPECTROSCOPIC ANALYSIS OF BIODEGRADED PRESSURE-SENSITIVE LABELS MADE FROM AGRO-INDUSTRIAL AND POST-CONSUMER WASTE

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Abstract: *Today, more than ever, sustainability is at its highest peak of daily interest for all business sectors, especially involving label and packaging industries. Usage of paper products made from alternative fiber sources is a very important topic that directly supports circular economy in everyday life. Although paper products should be recycled or re-used as secondary source of raw - material, a vast volume of products end their life at landfill, especially still in our region, causing excessive accumulation in the environment. For the purpose of this research, fluorescence intensity was measured on three different biodegraded pressure sensitive label material samples (PSL), made from agro-industrial and post-consumer waste. PSL materials utilized in this research are widely used for labelling various products, for example, wine, luxury products, food etc. and are compiled of 3 parts: facestock, adhesive and liner. PSL materials are enriched with optical brighteners to give the final product the desired optical properties. Fluorescence spectroscopy is a direct measure of optical brightener concentration within the substrate. Biodegradation was performed by usage of soil burial test under aerobic conditions. Laboratory soil burial experiments were conducted at room temperature (25±2°C) by placing the unprinted label paper substrates; facestock and adhesive (delaminated from the liner) horizontally in field soils in 2L laboratory glass containers, orientated adhesive down. The water content of the soil was adjusted to 40 % of its maximum water retention capacity. Substrates were buried for a period of 2, 4, 7, 10 and 13 days. Sample's fluorescence intensity was measured before and after incubation in the soil containers. The samples were dug out after designated time, rinsed with distilled water to remove soil particles from the surface, air dried and measured. Fluorescence intensity was measured by using Ocean Optics USB2000+ spectrometer using a 30 mm wide integrating sphere under (8:di) measuring geometry with the addition of LSM Series LED light source at 365 nm. LED light source is operated via a smart controller during the measurement. A constant current of 0.140 A was kept stable in order to maintain a constant excitation light source with the aim to excite fluorescence whitening agents within the samples. As previously research shows the presence of optical brighteners in composition of fibre based PSL, fluorescence spectroscopy of biodegraded samples indicates decomposition of optical brighteners.*

Key words: pressure sensitive labels; fluorescence spectroscopy, sustainable self-adhesive labelling materials, biodegradation

1. INTRODUCTION

In everyday life sustainability is, particularly by the wide public, narrowed down solely into its environmental dimension. Well known fact is that in the paper industry, the main raw material for paper production is wooden fibres, either virgin or recycled. Due to rising demand of paper industry raw material in general (including paper – cellulose-based product that are not directly related to graphic printing industry), we witness an obvious trend towards sustainable fibre sourcing and sustainable and controlled forestry, especially lately as European countries ban various plastic packaging and promote methods of reducing usage of plastic (Labels&Labeling, 2021).
If the example of citrus crush paper is considered, which is produced in Italy, we can see that a large proportion of the 600,000 tons of bio-waste from juice production in the form of citrus mesh in the country is used for its production. Some ratio of the citrus mash is used to produce essential oils, biofuels, and candied fruit, but a large share is still accessible for paper production and thus saved from landfill. The process remains the same as for other kinds of paper, but less energy is used and no additional chemicals. In the production of these paper types 20% drop in CO_2 emission is achieved in comparison to standard label papers.

Crush paper includes by-products from citrus fruits, coconut, cocoa, grapes, cherries, lavender, corn, olives, coffee, kiwi fruits, hazelnuts, and almonds. These natural raw materials are saved from landfill and used to make these distinctive and vivid papers.

Also, there is a tendency of using renewable non-tree biomass like seaweed and algae for paper production. The possibility of upcycling, meaning using discarded materials in such a way as to create a product of higher quality or value than the origin is also increasingly present. For example, discarded leather residue from the manufacturing process can be used to replace almost 25% of wood pulp in the paper production process. It is noteworthy that all of these papers are recyclable and biodegradable.

All pressure sensitive materials, also known as self-adhesive materials, comprise of three functional parts: facestock, adhesive and liner. The importance of pressure-sensitive label industry is proven by its constant business and consumption growth. As various market researchers show, the global self-adhesive labels market size is projected to grow from USD 47.9 billion in 2021 to USD 62.3 billion by 2026, at a CAGR of 5.4% from 2021 to 2026. With the increasing demand for convenience and quality food products, people are opting for packaged food products, where the product information and other product details need to be clearly presented to the consumer (Research and Markets, 2022).

One of the ways of making fibre based labels facestock whiter is by bleaching the pulp and incorporating fluorescence whitening agents (FWAs) in the paper pulp during it's production (Pauler, 2012). Role of the FWAs is to absorb excitation light in the UV part of the spectrum because that energy is needed for excitation from ground state. Molecules remain briefly in the excited state and emit energy at higher wavelengths during emission. Since part of the energy is consumed or converted into another form, the emitted energy is lower and is reflected in the spectrum as a shift (Brand & Johnson, 2008; Itaqaki, 2000).

It is convenient to measure fluorescence using integrating sphere (Shaw & Li, 2008; Zwinkels, 2010; Zwinkels et al., 2014). Fluorescence spectroscopy measures power of the radiation absorbed by the molecule. Biodegradation by burial testing is a way of examining the decomposition ability of organic substrates with the help of microorganisms and different abiotic components (Vukoje et al., 2017). Possibility of composting paper and it's forms is previously studied by various authors (Alvarez et al., 2009; Tomšič et al., 2007; Venelampi et al., 2003). FWAs as a paper component can be decompose by prolonged exposure to microorganisms in the soil. The decrease in FWA concentration can be confirmed with the drop in fluorescence intensity of the sample under study.

2. MATERIALS AND METHODS

2.1 Characteristics of the pressure-sensitive labels made from agro-industrial and post-consumer waste used in the study

Avery Dennison is a world leading producer of PSLs from agro-industrial and post-consumer waste. Natural by-products of citrus fruits, grapes, cherries, lavender, corn, barley, olives, coffee, kiwi fruits, hazelnuts and almonds are micronized and then combined with virgin tree and recycled fibers together with other necessary additives to produce Crush paper. In this research thee PSLs from the Crush series, citrus fruits, grapes, and barley, were selected. After the production of citrus juice there is 60 % leftover in the form of citrus mash. Depectinized mash is further micronized and reused for the production of Crush Citrus facestock paper (Avery Dennison Corporation, 2021).

Table 1: Properties of the used PSLs given by the manufacturer (Avery Dennison Corporation, 2021)

Sample name	Fasson ® rCRUSH CITRUS FSC S2030-BG45WH FSC	Fasson ® rCRUSH BARLEY FSC S2030-BG45WH FSC	Fasson ® rCRUSH GRAPE FSC S2047N-BG45WH IMP FSC
Designation	C	B	G
Basis weight ISO 536/g·m² (facestock)	100	90	90
Basis weight ISO 536/g·m² (liner)	70	70	70
Caliper ISO 534/ µm (facestock)	130	110	114
Caliper ISO 534/ µm (liner)	61	61	61

Similar production is for barley based facestock. Following the use of malted barley in brewing and whiskey production the by-product of the fermentation process (exhausted barley malt) is micronized and reused for the production of Crush Barley facestock (Avery Dennison Corporation, 2021). Similarly, the residue from the grape pressing process (marc) after the distillation process is dried further micronized. The resulting flour is then mixed with water and natural fibres to produce a unique ecological paper: Crush Grape (Avery Dennison Corporation, 2021).

Favini's sustainable Crush paper is paired with an Avery Dennison adhesive to match the application. Adhesives are chosen to maintain the integrity of the facestock, including the tactility, visual aesthetic, and printability, while ensuring the finished pressure-sensitive label can withstand the demands of production, use, and recyclability.

2.2 Soil burial test under aerobic conditions

Biodegradation was performed by usage of soil burial test under aerobic conditions. Laboratory soil burial experiments were conducted at room temperature (25±2) °C by placing the unprinted label paper substrates size 30 x 30 mm (Vukoje et al., 2017). Facestock and adhesive (delaminated from the liner) were placed horizontally in field soils in 2L laboratory glass containers, orientated adhesive down. The water content of the soil was adjusted to 40 % of its maximum water retention capacity. Substrates were buried for a period of 2, 4, 7, 10 and 13 days. Sample's fluorescence intensity was measured before and after incubation in the soil containers. The samples were dug out after designated time, rinsed with distilled water to remove soil particles from the surface, air dried and measured.

2.3 Visual evaluation

Visual evaluation process can be used as a first indicator of degradation process, when visible changes of the surface structure, for example: defragmentation, change in colour and/or formation etc. can be seen. However, these changes without usage of other quantifying methods do not prove the existence of degradation process in terms of microbial activity (Shah et al., 2008; Vukoje et al., 2017). Photos of paper samples were taken from the containers in sampling times in order to visually evaluate the facestock degradation over time. Samples were visually observed in lighting booth X-rite Judge II for the purpose of evaluation of structural, colour and surface change of the tested facestock and the presence of optical brighteners, as well as their performance after soil burial test under aerobic conditions. Two types of illuminants, D50 and UV, were used for the observation of the samples. The Canon EOS D450 camera with 50 mm, 1/30 s at f5.6, ISO 400 (Japan) was used for the imaging of the samples.

2.4 Fluorescence spectroscopy

Fluorescence spectroscopy measurements were done using USB 2000+ spectrometer (Ocean Optics), 30 mm integrating sphere with (8:di) geometry, and 365 nm LED light source (Ocean Insight-LSM Series). Stability of the excitation light was obtained using smart controller. Fluorescence intensity data were processed with OcenView software and the results will be presented in the spectral range between 350 and 600 nm. The method proved to be reliable in our previous research (Vukoje et al., 2021).

3. RESULTS

3.1. Visual evaluation

Figure 1 shows the images used for visual evaluation of PSL facestocks before and after soil burial test. All samples show differences in colour and structure change, especially after 13 days of biodegradation, which proves the presence of significant degradation process. PSL samples based on barley and citrus residue show similar biodegradation result after 13 days of aerobic exposure, while grape based PSL (facestock and adhesive) dissolve almost completely.

Regarding the images obtained under UV light, it is evident that grape based PSL facestock has the highest ratio of FWA which disintegrates proportionately and symmetrically during exposure to the burial testing. Citrus based PSL shows the lowest concentration of FWA based on the visual evaluation.

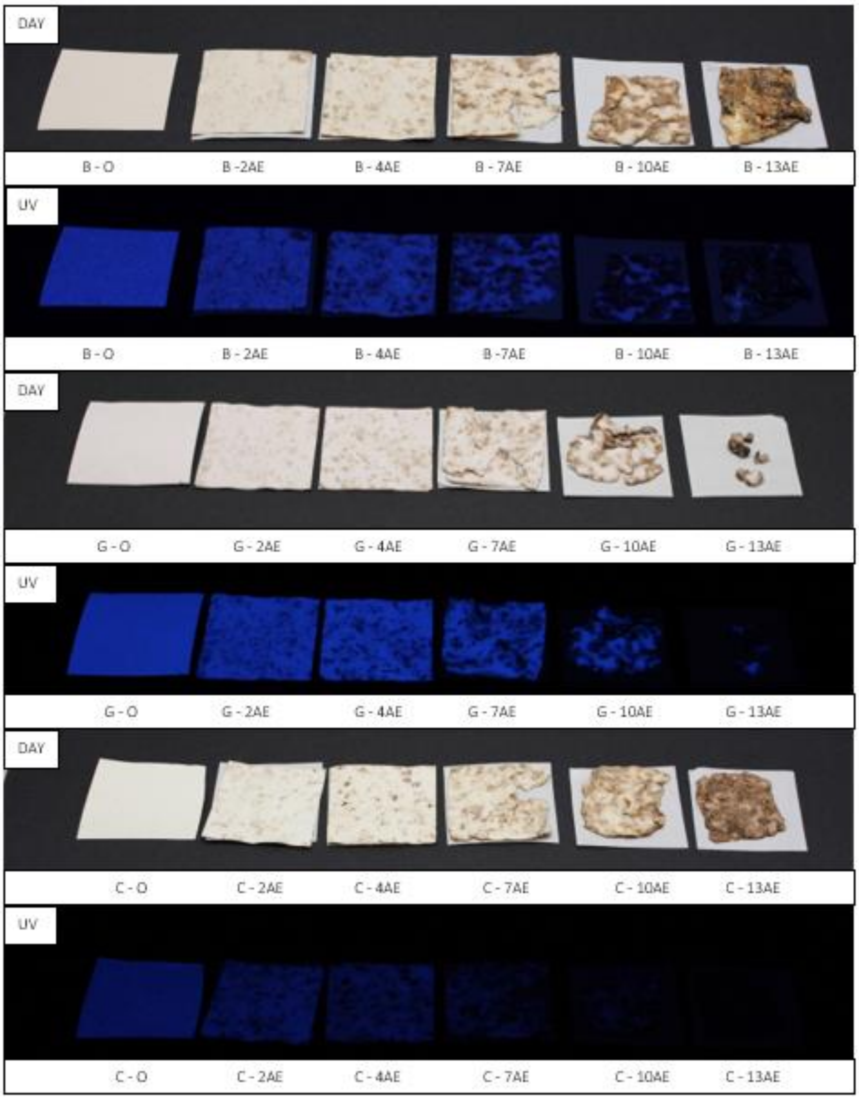

Figure 1: Visual evaluation of fibre based pressure sensitive facestock under illuminant D50 (DAY) and illuminant UV (UV); original before and after 2, 4, 7, 10, 13 days of soil burial test

3.2. Fluorescence spectroscopy

Fluorescent whitening agents used in paper industry are active in the area from 390 to 600 nm, while they absorb light in the UV part of the spectrum (Mercer, 1990; Shakespeare & Shakespeare, 2009). Fluorescence intensity in the excitation area can give significant information regarding the activity of FWAs, namely inactive FWAs reflect high amount of incident light. Excitation fluorescence intensity is much higher than the emission fluorescence intensity due to numerous interactions of light with the different types of PSL facestock constituents. Processed fluorescence intensity spectra of all samples before and after burial test in the period of 2, 4, 7, 10 and 13 days is showed in Figures 1-3. Fluorescence intensity emission spectra of all PSL facestocks made from agro-industrial and post-consumer waste correspond to the emission of the OBAs in the blue part of the spectrum with two characteristic peaks at 441 nm and 478 nm for all PSL facestocks and additionally peak at 414 nm for citrus and barley based PSL facestock (Coppel, 2010; Coppel, 2013; Pauler, 2012; Vukoje et al., 2021). Amount of FWAs in the any paper, including PSL facestock is proportional to the area of fluorescence intensity summed over all wavelengths in the visible part of the spectrum (Zwinkels et al., 2014). From the look of the emission fluorescence intensity diagram, more precisely the area under the curve, of all original samples it is obvious that different PSL facestocks have different ratios of fluorescence whitening agents which highly influences the proportion of absorbed light at excitation wavelength. Thus, fluorescence intensity of grape based PSL facestock (Figure 2) shows the highest absorption level at 365 nm, while for citrus (Figure 1) and barley (Figure 3) based PSL facestock this value is three, i.e. 3.5 times lower.

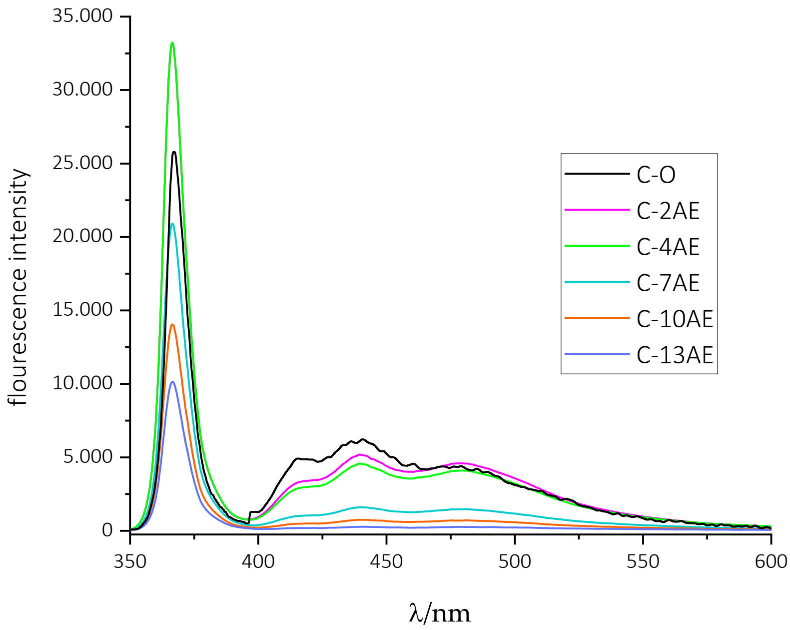

Figure 2: Fluorescence intensity spectra of original citrus fibre based PSL samples and citrus fibre based PSL samples after 2, 4, 7, 10, 13 days of soil burial test

After two days of burial there are no major differences in the mentioned values. After 4 days of burial test the absorption values decrease for citrus and grape based PSL facestocks, while the absorption for barley slightly increases.

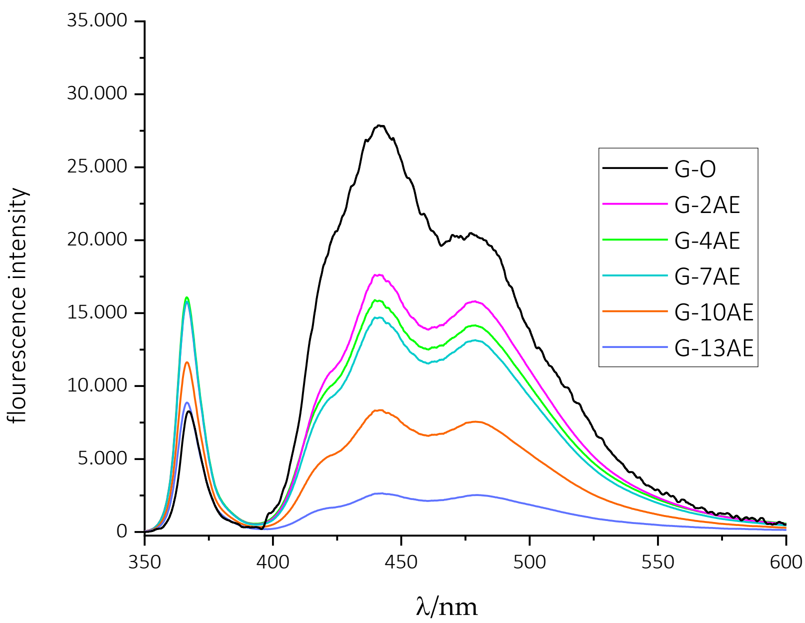

Figure 3: Fluorescence intensity spectra of original grape fibre based PSL samples and grape fibre based PSL samples after 2, 4, 7, 10, 13 days of soil burial test

Seven days burial test stands out as a turning point where all three PSL facestocks show the increase in absorption at 365 nm wavelength, which follows same regularity for next two intervals, 10 days, and thirteen days. After 13 days of aerobic degradation all samples have similar absorption values at the excitation wavelength.

Emission part of the spectrum, 400-600 nm, can explain the behaviour of the incident light. Fluorescence intensity spectra of citrus based PSL facestock decreases in the are between 400 and 450 nm, while the peek at 471 nm remains unchanged after first two intervals of burial test. Significant decrease in the emission intensity spectrum can be seen after seven days of burial tests, which is manifested by the loss of characteristic bands and the general disappearance of the emission spectrum (Figure 1). This behaviour corresponds to the absorption result in the emission part of the spectrum Namely, burial test, cause decomposition of florescence whitening agents within the PSL facestock among ardor components. Decomposition of FWAs causes less active material for absorbing UV light. After seven days of decomposition most of the FWAs were decomposed making room for other PSL facestock ingredients to absorb UV light.

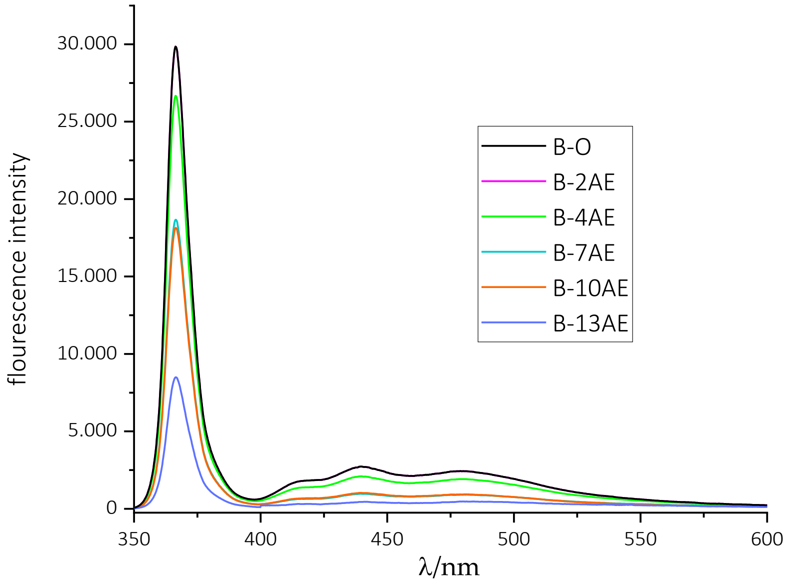

Figure 4: Fluorescence intensity spectra of original barley fibre based PSL samples and barley fibre based PSL samples after 2, 4, 7, 10, 13 days of soil burial test

Grape based PSL facestock has the highest level of FWAs (Figure 2). First three cycles of burial test reduced the fluorescence intensity in the emission part of the spectrum, but the characteristic peaks remained at the same place (Figure 2). Significant change can be seen after ten days of aerobic degradation where the overall spectrum dropped to 30% of its initial value. Likewise, broadening of peaks at 441 nm and 491 nm is observed. Last burial test interval, thirteen days resulted in significant decomposition of FWAs which is confirmed by the flattening of the spectrum, i.e. further expansion of the characteristic bands. Again, fluorescence intensity spectra in the emission part of the spectrum correspond to the excitation part values. With the more pronounced decomposition of FWAs in PSL facestock absorption of the UV light decreases. After that, due to the further decomposition of the FWAs and the papers surface structure, the incident UV light is significantly scattered and absorbed in the interior of the paper.

For barley we can say that it has the lowest level of FWA according to the appearance of the fluorescence intensity spectrum in the visible part of the EM (Figure 3). With exposure of samples to aerobic degradation the fluorescence intensity spectrum tends towards zero. In order for FWAs to be effective they have to be combined with non-lignin pulp since lignin is known for it's high absorbance in the UV part of the spectrum, same as FWA (Pauler, 2012). It was found that grape fibres residue from wine making processes contains as high as 30 % cellulose, 21 % hemicellulose and 17 % lignin (Amedola et al., 2012; Prozil et al., 2012). At the same time, citrus fibres collected from juice production contains significantly lower ratios of cellulose (16 %) and hemicellulose (10 %) (Lundberg et al., 2014). Barely fibres resulting from whiskey production and brewing beer contain 17% cellulose and 28% lignin (Mussatto et al., 2006). Due to this, and from the fluorescence spectroscopy measurement, it can be concluded that most of the lignin from the grape marc after the distillation process is chemically removed to enable FWAs.

4. CONCLUSION

High growth of self-adhesive labels market is mainly a result of increase rapid urbanization, demand for pharmaceutical supplies, increasing consumer awareness, and growth of the e-commerce industry (Research and Markets, 2022).

When using alternative fibre sources, the paper making process in its core remains the same, as for other kinds of paper, but less energy is used and no additional chemicals. In the production of papers utilized in this research, manufacturers state that 20% drop in CO_2 emission is achieved in comparison to standard label papers.

Sustainable fibre-based products have their usage status proven and justified by everyday greater demand, increasing consumption and constant product development.

In this research, the rate of decomposition of FWAs in three types of pressure sensitive labels made from agro-industrial and post-consumer waste (grape march, citrus juice residue and exhausted barley malt) by means of burial testing were examined. Samples were buried for periods of 2, 4, 7, 10 and 13 days. The presence of FWAs in the substrate was tracked by means of fluorescence spectroscopy. Critical point, regarding the FWA activity is 7 days, at which point there was a major drop in fluorescence intensity for all samples. After thirteen days of exposure to aerobic soil testing, FWAs are completely decomposed. Further research will evaluate the decomposition rate of other substrate characteristics by means of weight loss, FT-IR spectroscopy, scanning electron microscopy and so on.

Also, subsequent research will be dedicated to biodegradation processes of alternative fibre labels applied on various types of cardboard, both in unprinted and printed versions, simulating real market usage and today less appropriate, but unfortunately realistic products' end of life, especially in our region.

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PHYSICO-CHEMICAL EVALUATION AND KINETIC STUDY OF COLOURED PRINTING WASTEWATER PRIOR AND POST- FENTON TREATMENT

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Abstract: *The paper reports removal of organic Black (Key) dye from real printing wastewater using nano zero valent iron particles as a catalyst in Fenton-like treatment. The degradation efficiency of Black diazo dye via Fenton-like treatment is reported to be 61% under established optimal process conditions: [Fe^{2+}] = 0.75 mgL^{-1}, pH = 2, [H_2O_2] = 1 mM, within a reaction time of 75 min. The absorption spectra of Black dye clearly indicate that dye degradation is a slow process with difficult decomposition of aromatic structures, due to the cleavage of diazo bonds by hydroxyl radicals. The physico-chemical characterizations (measurements of pH, electrical conductivity, temperature, turbidity, chemical oxygen demand, biochemical oxygen demand, total organic carbon, anionic surface-active substances and phosphorus content) as well as toxicity study (Vibrio fischeri bacteria) revealed the complex nature of printing effluent. Increased conductivity and biochemical oxygen demand content after Fenton treatment imply the formation of various byproducts and intermediates, formed in a solution during dye degradation. The mineralization percentage of Black dye of 58% is followed with 47% of chemical oxygen demand reduction. Results of toxicity test on Vibrio fischeri bacteria indicate that both untreated and treated printing effluents belong to moderate toxic samples with 58% and 67% of toxicity inhibition, respectively. Among three evaluated kinetic models (the first-order, the second-order, and Behnajady–Modirshahla–Ghanbary), experimental results fitted very well to the Behnajady - Modirshahla - Ghanbary model, indicating high initial rate of Black dye degradation.*

Key words: Fenton-like treatment, Black dye removal, physico-chemical characterization, kinetic models, toxicity evaluation

1. INTRODUCTION

The printing industry is considered one of the largest consumers of synthetic dyes and wastewaters from this industry might be overloading water systems with organic and inorganic pollution if not adequately treated (Natarajan, Bajaj & Tayade, 2018; Zhu et al., 2018). Due to extremely complex structure, their removal represents a major challenge in the field of wastewater treatments. Synthetic printing dyes (azo and phthalocyanine), belong to the group of aromatic and heterocyclic compounds which are hardly biodegradable, with a tendency to show carcinogenic and toxic effect (Kale & Kane, 2019; Namgoong et al., 2018). The high consumption of dyes leads to the creation of a large amount of colored effluents that are discharged into water bodies (Karimifard & Moghaddam, 2018; Katheresan, Kasedo & Lau, 2018). The presence of these dyes in effluents, even in very low concentrations, represents a potential problem for ecological systems (Bulgariu et al., 2019). Dyes, in addition to affecting the aesthetic properties and transparency of water bodies, also affect the absorption and solubility of gases, creating very unfavourable anaerobic conditions for photosynthesis and biological activity (Bulgariu et al., 2019; Dojčinović, 2011; Karimifard & Moghaddam, 2018; Natarajan, Bajaj & Tayade, 2018). And to emphasize, the creation of by-products with pronounced negative effects is very much possible during the degradation of dyes (Natarajan, Bajaj & Tayade, 2018).

Achieving complete mineralization and degradation of printing dyes to carbon(IV)-oxide, water and inorganics is very difficult (Karimifard & Moghaddam, 2018; Pavithra et al., 2019). Application of conventional biological treatments is not efficient due to diazo groups in the form of chromophores (Collivignarelli et al., 2019; Xu et al., 2018) Possible solution to treatment of this wastewaters might be advanced oxidation processes (AOPs), i.e. Fenton-like process, which are based on *in-situ* production of highly reactive hydroxyl radicals in the presence of peroxides and ferrous ions (Mirzaei et al., 2017), which have the ability to degrade difficult biodegradable compounds, such as printing dyes are.

Nanomaterials have attracted the attention of many researchers primarily due to their large specific surface area, which makes nanoparticles achieve numerous advantages in the field of chemical catalysis, such as low resistance to diffusion, easy access to reactants, a large number of free active sites and fast development of chemical reactions (Wang et al., 2016). The use of nano zero valent iron (nZVI) particles in AOPs processes achieved certain advantages compared to conventional methods and solved their practical disadvantages, such as the need for the application of a high concentration of iron, the generation of sludge from metal hydroxides after the treatment and, at the same time, the formation of secondary pollution, operation in a narrow pH range, as well as regeneration of the catalyst and the impossibility of its reuse. Thanks to the properties and surface of nanomaterials, numerous studies have proven the success of using nZVI particles as Fenton catalysts (Mukherjee et al., 2016; Pirsaheb et al., 2019). The high efficiency of dye degradation in the presence of nZVI particles is based on electron exchange, since nZVI particles are good electron donors and dye molecules are excellent electron acceptors. The mechanism of dye degradation using the nZVI/H_2O_2 system is based on the generation of hydroxyl radicals through typical Fenton reactions that will attack the chromophore of the dye molecule and cause the cleavage of the bond in the chromophore group. The whole process is accompanied by the decomposition of the auxochromic group, and in the ideal case, complete degradation and mineralization (Raman & Kanmani, 2016).
The current investigation describes the efficiency of Black printing dye removal from real effluent using a Fenton-like treatment under previously established optimal process conditions (iron concentration, pH value and hydrogen peroxide concentration). In order to consider mineralization degree of treated effluents, physico-chemical characterization was carried out by determining the following parameters: pH, electrical conductivity, temperature, turbidity, chemical oxygen demand, biochemical oxygen demand, total organic carbon, anionic surface-active substances and phosphorus content. Three relevant kinetic models were studied to demonstrate the improved performance of the Fenton-like process for dye removal.

2. MATERIALS AND METHODS

2.1 Experimental procedure

Sample of printing wastewater was obtained from one flexographic printing facility in Novi Sad. In the present study, Fenton-like treatment of real printing effluent was carried out according to the procedure described in our previous work (Gvoić et al., 2020), under determined optimal process conditions (iron concentration, pH and H_2O_2 concentration). To assess the Fenton-like efficiency, nZVI (0.75 mgL^{-1}) and H_2O_2 (1 mM) were added to an aqueous solution containing 250 mL printing wastewater, whereby pH value (2) was adjusted using 0.1 M ccH_2SO_4. Reaction system was mixed on a JAR apparatus (FC6S Velp Scientific, Italy) at 120 rpm and constant temperature of 23 °C. Thereafter, aliquots of supernatant were analysed at different time intervals (0 - 180 min) using UV/VIS spectrophotometry (UV-1800 PG Instruments Ltd T80+ UV/VIS, Japan). The residual dye concentration was established immediately by measuring the absorbance of the aqueous solutions at 613 nm and decolourization efficiency of printing wastewater was calculated according to Equation (1):

$$E(\%) = A_0 - A/A_0 * 100 \tag{1}$$

where: A_0 is the initial absorbance of the aqueous solution sample before Fenton treatment and A is the absorbance of the aqueous solution sample after Fenton treatment.

2.2 Physico-chemical characterization of printing effluent

The physico-chemical characterization of printing effluent before and after Fenton-like treatment included measurement of pH, electrical conductivity, temperature, turbidity, determination of chemical oxygen demand (COD), biological oxygen demand (BOD), total organic carbon content (TOC), anionic surface-active substances (dodecylbenzene sulfonate - DBS) and phosphorus content. pH value, electrical conductivity and temperature were measured with AD110 Adwa instrument. Turbidity was determined by using the instrument Turb 430 IR WTW. The concentration of organic matter in printing wastewater is determined by measuring COD quantification and TOC according to the standard potassium dichromate volumetric method - SRPS ISO 6060: 1994 and SRPS ISO 8245:2007 method, respectively. Determination of BOD after 5 days at 20 °C was performed with manometric method - H1.002, by using the instrument

Velp Scientifica Italia, Lowibond and WTW. Determination of DBS was measured by the index of methylene blue MBAS spectrophotometric method based on SRPS EN 903:2009. The phosphorus content was determined with spectrophotometric method with ammonium- molybdate according to the SRPS EN ISO 6878:2008. In order to investigate the toxicity of printing effluent and to establish the negative impact on living organisms, standard ISO 11348 method (Water quality - determination of the inhibition effect of water samples on the *Vibrio fischeri* light emission (luminescent bacterial testing)) was applied. Inhibition of *Vibrio fischeri* luminescence is determined by a series of tests, combining the specific volume of the test sample or dilution sample with luminescent bacteria suspension, by using a LUMIStox 300 instrument (Dr Lange GmbH, Germany) and LUMISsoft IV software. The inhibitory effect was measured in water samples, during 30-minute exposure to bacteria at 15 °C, and expressed in %.

2.3 Kinetic experiments

The first-order, second-order and Behnajady - Modirshahla - Ghanbary (BMG) kinetic models were applied to fit the dynamic process of the Fenton-like treatment, which were expressed as Equations (2-4), respectively:

$$\frac{dA_t}{dt} = -k_1 A_t \tag{2}$$

$$\frac{dA_t}{dt} = -k_2 (A_t)^2 \tag{3}$$

$$\frac{A_t}{A_0} = 1 - \left(\frac{t}{m+bt}\right) \tag{4}$$

where: A_0 and A_t are the initial dye absorbance, i.e. the dye absorbance in a certain time period t, k_1 and k_2 are the rate constants of the first- and second-order, whereas b and m are the BMG model constants related to the reaction kinetics and oxidation capacity, respectively.

The parameters of the kinetic models for the removal of Black dye under optimal process conditions were calculated using the linear forms of the first- and second-order kinetic models, as well as the BMG model (Equations 5 - 7):

$$A_t = A_0 * e^{-k_1 t} \tag{5}$$

$$\frac{1}{A_t} = \frac{1}{A_0} + k_2 t \tag{6}$$

$$\frac{t}{1-\frac{A_t}{A_0}} = m + bt \tag{7}$$

Calculated kinetic parameters were further used to interpret the kinetics of the observed reactions by plotting the linear graph of ln (A_0/A_t) versus time for the first-order model, ($1/A_t$) versus time for the second-order model and t/1 - (A_t/A_0) versus of time for the BMG model.

3. RESULTS AND DISCUSSIONS

3.1. Optimized Fenton-like treatment of printing wastewater

Decolourization efficiency of Black dye from printing wastewater by the applied Fenton-like process under optimal process conditions is presented in Figure 1a. The maximum treatment efficiency of 60.63% was achieved after 75 minutes. Figure 1b presents the UV/VIS spectrum of printing effluent, as a change of peak intensity, in a function of applied Fenton treatment under optimized process conditions.

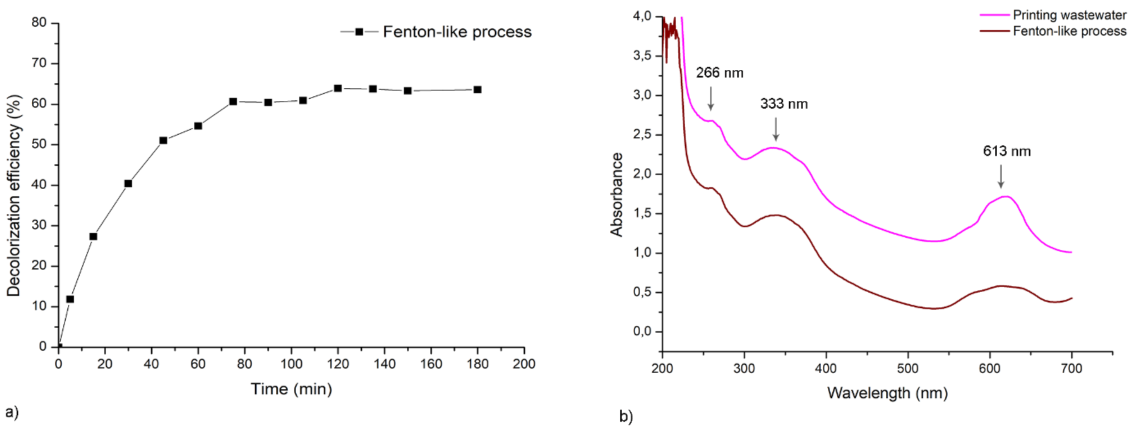

Figure 1: a) Decolorization efficiency of treated printing wastewater; b) UV/VIS spectrum of printing wastewater before and after Fenton-like process

Different structural units and functional groups in the molecule of Black dye have different absorption peaks. Three peaks are observed on the absorption spectrum of printing effluent: one main peak at 613 nm in the visible region and two smaller peaks in the ultraviolet region at 333 nm and 266 nm. It is assumed that the absorption peak at 613 nm corresponds to a conjugated functional azo group connected to aromatic substituents due to the n → π* transition, while the remaining two peaks in the UV region correspond to the benzene and naphthalene rings due to the π → π* transition, whereby the naphthalene ring occurs at a longer wavelength. It is observed that the absorption peak at 613 nm decreases, but does not disappear completely, which means that a slow degradation of Black dye has been achieved, which is in accordance with the results of the decolourization efficiency shown in Figure 1a. The intensity of the absorption peaks in the UV region also decreases, indicating the decomposition of the benzene and naphthalene rings to simpler aliphatic structures. Based on the obtained results, it can be concluded that degradation of Black printing dye is a slow process with a difficult decomposition of aromatic structures. This behaviour occurs most likely as a consequence of the n → π* electronic transition within the azo group, where the hydroxyl radicals first attack the azo group and cleave the -N=N- bonds, destroying the long conjugated π-systems, causing degradation and removal of the Black dye from of the treated sample.

3.2. Characterization of printing wastewater

Physico-chemical characterization of treated effluent was performed in order to determine the mineralization degree of printing dye, and the results are presented in Table 1. The obtained values of physico-chemical parameters for the printing effluent indicate that only tap water is used for the cleaning process of dye chambers and rotating cylinders with flexible rubber relief plates, since the content of detergents and phosphates is low. Therefore, the cleaning process of water-based dyes does not require additional application of solvents or abrasives, which makes them environmentally friendly and easy to use, unlike easily volatile, quick-drying solvent-based dyes. Furthermore, results of physico-chemical characterization indicated a conductivity increment after applied Fenton-like treatment, which may be in accordance with the formation of numerous degradation products and the release of certain inorganic ions. The increase of BOD value after Fenton process pointed out to the formation of degradation products, confirming the assumption that dye degradation does not necessarily imply its complete oxidation to CO_2 and H_2O. Also, a fragmentation of highly complex structure of dye molecule into smaller compounds and mineralization of treated effluent was confirmed with TOC and COD reduction. The mineralization degree resulted with 58% TOC and 47% COD reduction. Based on the obtained results, it is assumed that the formation of large number of aliphatic compounds is achieved.

Table 1: Physico-chemical characterization of printing wastewater

Parameter	Before Fenton-like treatment	After Fenton-like treatment
pH	7.87	1.98
Conductivity ($\mu S\ cm^{-1}$)	590	1158
Temperature (°C)	22.60	22.50
Turbidity (NTU)	57.10	32.90
COD ($mgO_2\ L^{-1}$)	466.50	249.30
BOD ($mgO_2\ L^{-1}$)	0	18
TOC ($mgC\ L^{-1}$)	106.55	45.25
DBS ($mg\ L^{-1}$)	0.31	<0.10
Total phosphorous ($mgP\ L^{-1}$)	<0.011	<0.011
Toxicity inhibition (%)	57.92	66.58

Based on the results of toxicity test on *Vibrio Fischeri* bacteria, it was established that printing effluent belongs to the group of moderate toxic samples, due to the toxicity inhibition of 58%. A slight toxicity increase of 66.58% is observed after the implemented Fenton-like treatment, probably due to the formation of degradation products that are more toxic than the dye molecule, classifying the treated effluent in moderately toxic samples, but again with the impossibility of safe discharge into the recipient. Based on the obtained results, it is concluded that the Fenton-like catalyst, nZVI, achieved a high catalytic activity from the aspect of Black dye removal, but entails solving the problem of the toxic and acidic effluent in the recipient.

3.3. Kinetic studies

To determine the degradation kinetic of Black dye using nZVI in Fenton-like process, the first-order, the second-order and BMG kinetic models were evaluated. Obtained kinetic parameters and correlation coefficients for all three models are presented in Table 2.

Table 2: First-order, second-order and Behnajady–Modirshahla–Ghanbary kinetic model constants and regression coefficients for decolourization of Black dye

Model	First-order		Second-order		[a]BMG model			
	K_1 (min^{-1})	R^2	K_2 ($L\ mg^{-1} min^{-1}$)	R^2	b	m	1/m	R^2
Fenton-like process	0.0127	0.755	0.0127	0.815	1.359	30.111	0.0332	0.996

[a]Behnajady - Modirshahla - Ghanbary model

The kinetic data of Black degradation showed that correlation coefficient values of BMG model are generally greater than those of the first-order and the second-order models. Thus, all experimental data are fitted well by BMG model (Figure 2).

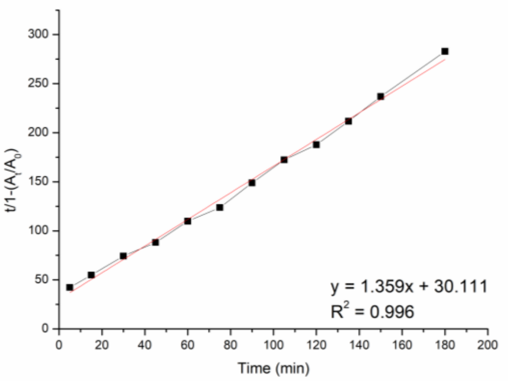

Figure 2: Decolourization kinetic of printing effluent under optimal process conditions (BMG model): $[Fe^{2+}]$ = 0.75 mgL^{-1}, $[H_2O_2]$ = 1 mM, pH = 2

Low values of the parameter 1/m indicate that the effective removal of Black dye from the printing wastewater requires a longer reaction time to achieve high efficiency primarily due to the complexity of the treated matrix.

4. CONCLUSIONS

A highly efficient Fenton-like catalyst, nano zero valent iron, was applied to remove Black dye form printing wastewater. Efficient treatment of real printing effluent under previously optimized experimental conditions ($[Fe^{2+}]$ = 0.75 mgL^{-1}, $[H_2O_2]$ = 1 mM, pH = 2) was obtained: 61% of dye removal was achieved after 75 min of reaction. Decreased intensity of three absorption peaks on UV/VIS spectrum (wavelength: 613 nm, 333 nm and 266 nm) of treated sample indicated $n \rightarrow \pi^*$ and $\pi \rightarrow \pi^*$ electron transition within the azo group, as well as decomposition of the benzene and naphthalene rings to simpler aliphatic structures. Under the optimal operating conditions, 58% TOC and 47% COD removals were attained by the Fenton-like process. The enhanced removals of TOC and COD contributed to the fragmentation of highly complex dye molecule structure into a large number of simpler aliphatic and aromatic fragments. The results are confirmed within BOD and toxicity increase, assuming that dye degradation does not necessarily imply its complete oxidation to CO_2 and H_2O, but forming smaller compounds that could be even toxic than original dye molecule. Three kinetic models (the first-order, the second-order, and Behnajady–Modirshahla–Ghanbary) were evaluated and the Behnajady–Modirshahla–Ghanbary kinetic model was found to be the best model representing the experimental kinetic data of Black dye removal. The obtained results implied that Fenton-like process, as environmentally friendly treatment, can be used for printing dye removal from real printing wastewater. However, this study can be extended by considering various options how to overcome the well-known challenges of Fenton process, such as the acidic pH as an optimal reaction condition and high toxicity of treated printing wastewater.

5. ACKNOWLEDGEMENTS

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CONTRIBUTION OF FLEXOGRAPHIC PRINTING PROCESS TO GROUND-LEVEL OZONE CONCENTRATIONS

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Abstract: *The concentration levels of ground-level ozone in the flexographic printing plant were determined in two campaigns during five working days. The first campaign was conducted in the middle, and the second at the end of the eight-hour working time. In the second campaign, the mean ozone values per day (3.81, 3.60, 4.25, 4.71, and 3.18 µg/m^3) were almost two times higher than in the first. Still, they were 32 to 47 times lower than the emission limit value prescribed by the Regulation of the Republic of Serbia.*

Keywords: flexographic printing process, ground-level ozone, emission limit value

1. INTRODUCTION

The ozone layer is a band of natural gas called ozone (O_3). It is found in the stratosphere 15 to 30 kilometers above the Earth and is a shield against the sun's harmful ultraviolet B (UVB) radiation. When stratospheric ozone is found in the lower layers of the atmosphere, it is considered a pollutant (Morales-Méendez & Silva-Rodríguez, 2018).

Printing materials, such as printing inks and solvent-based cleaners used in the machine cleaning process, cause the release of ozone and volatile organic compounds (VOCs) and contribute to air pollution (Aydemir & Özsoy, 2020). Experimental data suggest that the solvents typically used in printing inks will photo-degrade rapidly in the atmosphere into water and carbon dioxide and are not significant contributors to lower atmospheric ozone. The emission of solvents from the printing industry is such that their contribution is minimal compared to road transport and energy generation. Also, the amounts of solvents emitted into the atmosphere during printing are strictly controlled (EuPIA, 2013).

Solvent-based inks are widely used in the flexographic printing process because these inks dry by evaporation. Unfortunately, the flexographic solvents usually contain significant VOCs, which have notable health and safety concerns. Also, VOCs contribute to the formation of ground-level ozone, which causes substantial respiratory and other health problems (USEPA, 2002).

When printing on an absorbing substrate (paper or board), the ink is absorbed into the fibres or pigment coating as it dries and binding to the substrate surface. In contrast, on a non-absorbing substrate (polymeric materials), physical binding is far more limited, and adhesion must rely more on chemical mechanisms, thus demanding chemical compatibility between ink formulation and substrate surface (Rentzhog, 2006). Polymeric materials such as polyolefins are the most common substrates in flexographic printing.

Factors causing poor ink adhesion on untreated polyolefins are: low substrate surface energy, low polar functionality, and potential weak boundary layers. The surface modification, good ink wettability, and adhesion on these surfaces require increasing their very low surface energy. Corona discharge treatment in the air is one of the most widely used methods. In this treatment, the substrate passes through a high-energy electrical discharge zone where the surface is exposed to reactive species in the high-energy plasma (or "corona"). Free radicals created at the polymer surface by hydrogen abstraction form covalent chemical bonds with the mixture of reactive species representative of the local atmosphere. These species include free oxygen in its elemental form, ozone, and activated oxygen in air corona. In addition to oxidation, the free radicals cause crosslinking of polymer molecules at the surface, increasing their molecular weight. The oxidation occurs first in the outermost polymer layer and subsequently penetrates deeper (on the order of nanometres), which increases with treatment energy (Rentzhog, 2006). Therefore, corona discharge treatment contributes to the formation of ground-level ozone.

The quantitative concentration levels of ground-level ozone emitted due to the flexographic printing process are presented in this paper. Also, the obtained ozone concentrations were compared to the emission limit value prescribed by the Regulation of the Republic of Serbia.

2. METHODS

2.1 Flexographic printing plant

Measurements of ground-level ozone concentration were carried out in a flexographic printing plant located on the territory of Novi Sad. The flexographic printing machine, model No: JXG 6750 (manufactured by Shenzhen Fungshengtai Industry CO., LTP, China), was used to print polymer bags.

2.2 Analysis of ground-level ozone in the flexographic printing plant

The potassium-iodide method was used to determine ground-level ozone in the air of a flexographic printing plant (GZZZ, 2002). The air with ground-level ozone was collected with a PRO-EKOS AT-401X sampler with four Drechsel gas washing bottles with filter disks. The air from the printing house was passed through the Drechsel bottles at a speed of 0.5 dm^3/min. Also, the absorption solution for ground-level ozone (10 ml of 1% potassium iodide in 1 M sodium hydroxide) was found in the Drechsel glass washer. After the sampling, an acidified reagent (5 g of sulfamic acid, 84 cm^3 of 85% phosphoric acid, and distilled water up to 200 cm^3) was added to the absorption solution. The prepared solution was well stirred and allowed to cool to room temperature. A stable compound was formed, which could be stored for several days. The analysis was completed in the laboratory by adding a phosphorus-sulfamine reagent, which releases iodine. The absorptions of the yellow-coloured ground-level ozone solutions were determined by UV/VIS spectrophotometer DR 5000 at 352 nm.

The absorptions of ground-level ozone present in the collected samples were determined based on the calibration curve made with standard solutions of potassium iodate concentrations of 0.2, 0.4, 0.8, 1.0, 1.2, 1.6, and 2.0 mg/L (Figure 1).

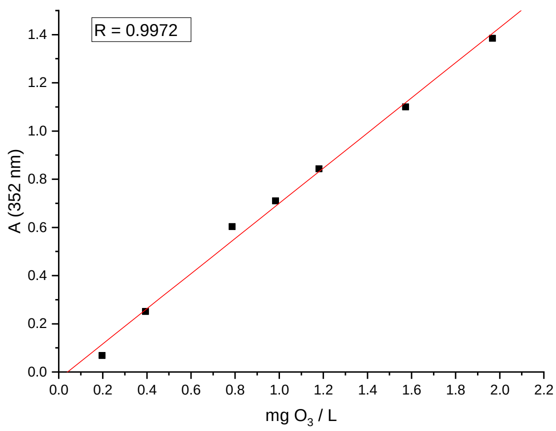

Figure 1: Calibration curve of ozone

Campaigns 1 and 2 were carried out after four and eight hours of working time, respectively. In each campaign, absorption samples of ground-level ozone were collected simultaneously in four Drechsel gas washing bottles.

The concentration (µg/m^3) of ground-level ozone in the flexographic printing plant (in campaigns 1 and 2) was determined according to the formula (1) (GZZZ, 2002):

$$C(O_3) = \frac{(\mu g / 10cm^3 O_3) \cdot 1000}{V_{kor}} \quad (1)$$

Where, V_{kor} is the volume of sampled air corrected to standard conditions (temperature of 25°C and pressure of 101325 Pa), according to formula (2):

$$V_{kor} = \frac{P \cdot V}{T} \cdot \frac{T_K}{P_K} \tag{2}$$

Where V – a volume of sampled air (m^3), P – air pressure, Pa, T – air temperature, °C, T = 25°C, and P_k = 101325 Pa.

3. RESULTS AND DISCUSSION

Concentration levels of ground-level ozone in the flexographic printing plant in campaigns 1 and 2 for four Drechsel gas washing bottles during five days of monitoring are shown in Figure 2.

The obtained results show that in campaign 1, the concentration levels of ground ozone were in the intervals: from 2.20 to 2.75 μg/m^3 (on the 4th day), from 2.35 to 2.65 μg/m^3 (on the 3rd day), from 2.10 to 2.30 μg/m^3 (1st day), from 1.80 to 2.00 μg/m^3 (2nd day), and from 1.60 to 1.80 μg/m^3 (5th day). Therefore, the highest ground ozone concentration was detected on the 4th day (2.75 μg/m^3), and it was 3.6%, 16.4%, 27.3%, and 34.5% higher in comparison to the highest values detected on days 3, 1, 2, and 5 of the monitoring, respectively.

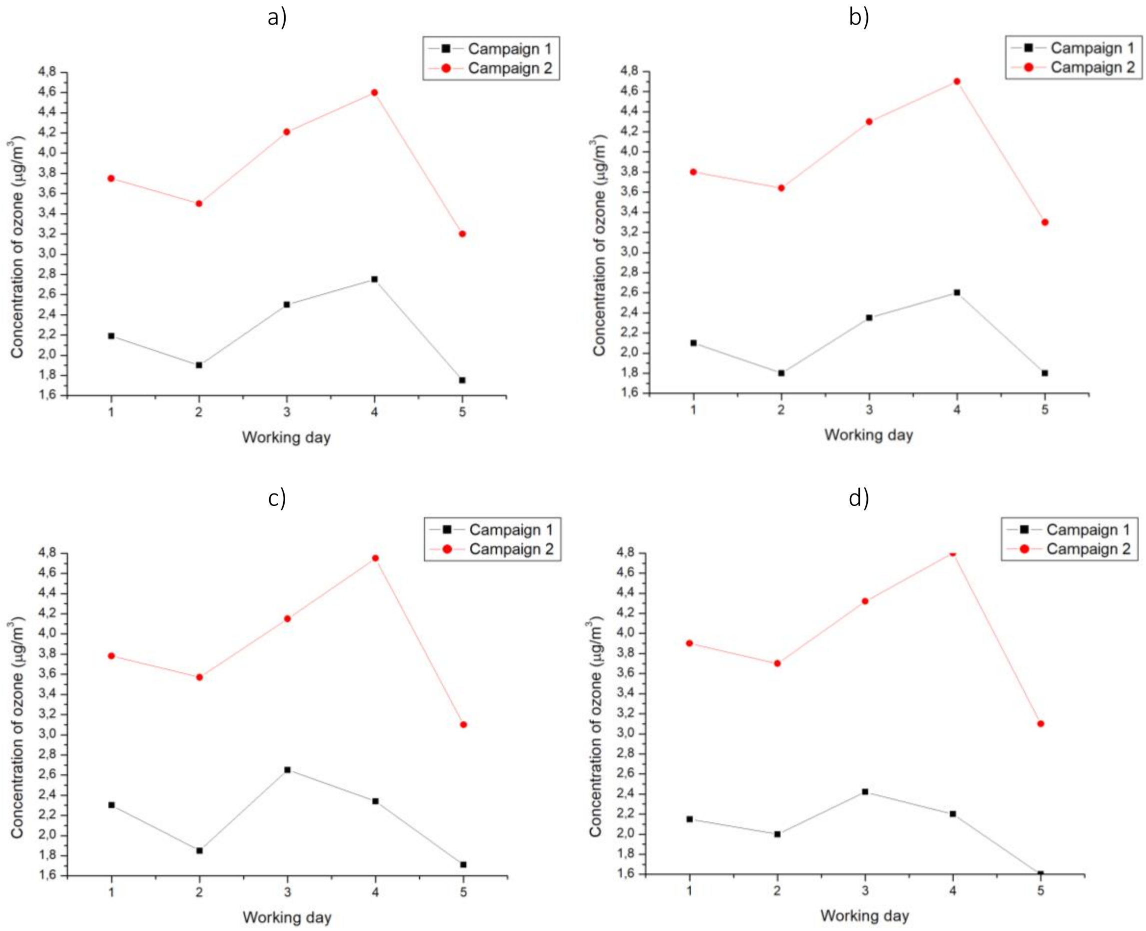

Figure 2: Comparison of ground-level ozone concentrations in the flexographic printing plant in campaigns 1 and 2 for a) the first, b) the second, c) the third, and d) the fourth Drechsel gas washing bottles

In campaign 2, the ground ozone concentration levels decreased from: 4.60 to 4.80, 4.15 to 4.32, 3.75 to 3.90, 3.50 to 3.70, 3.10 to 3.30 μg/m^3 for the 4th, 3rd, 1st, 2nd, and 5th days, respectively. On the other hand, the highest concentration of ground-level ozone was detected on the 4th day (4.80 μg/m^3), and it was 10%, 18.8%, 22.9%, and 31.3% higher in comparison to the highest values detected on days 3, 1, 2, and 5 of the monitoring, respectively.

The mean values of ground-level ozone concentrations from the 1st to the 5th day of monitoring were 2.19, 1.89, 2.48, 2.47, and 1.72 μg/m^3 (campaign 1) and 3.81, 3.60, 4.25, 4.71, and 3.18 μg/m^3 (campaign 2). By comparison, the stated values in campaigns 1 and 2 for the same day increased from 42 to 48%. As

expected, after 8 hours of work and with the increase in the volume of flexographic production, ground-level ozone concentrations are more than 1.7-1.9 times compared to the values after 4 hours.
In the Republic of Serbia, the Regulation on monitoring conditions and air quality requirements (Official Gazette of the RS, 2013) defines the limit value of emission as the highest allowed concentration of pollutants in the air. According to the Regulation mentioned above, the limit value for ground-level ozone is 150 μg/m^3 for 1 hour of monitoring. However, the analysis of ground-level ozone produced by the flexographic printing plant in the middle and at the end of the eight-hour working time during the five-day shows that the highest measured values were from 32 to 47 times lower than the limit value.

4. CONCLUSIONS

The results of the five-day analysis show that the flexographic plant produces ground-level ozone. Based on the measured ground-level ozone concentrations of the flexographic printing plant, the following conclusions were drawn:

• In the campaign conducted in the middle of working hours, ground-level ozone concentrations are from 1.60 to 2.75 μg/m^3. At the end of the eight-hour working time, ground-level ozone concentrations are from 3.10 to 4.80 μg/m^3. In both campaigns, concentration levels during the working week decrease in an order: 4th > 3rd > 1st > 2nd > 5th day of monitoring.
• As expected, ground-level ozone concentrations are increasing with the increase in the volume of flexographic production. Still, they are lower than the emission limit value defined by the Regulation of the Republic of Serbia.

5. ACKNOWLEDGMENTS

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MACHINE LEARNING AS A SUPPORT TOOL IN WASTEWATER TREATMENT SYSTEMS – A SHORT REVIEW

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Abstract: *Machine learning (ML) is a subset of artificial intelligence (AI). It is based on teaching computers how to learn from data and how to improve with experience. This valuable technique has been increasingly supporting different spheres of life. This includes ML application in enhancement and optimisation of many ecological and environmental engineering solutions, such as wastewater treatment systems (WWTS). Complexity of processes triggers challenges in ensuring good effluent quality by adequate response to dynamic process conditions. That is why techniques such as ML which, after being trained, have strong prediction ability, have been applied in WWTS. ML facilitates understanding of correlation between input features and output targets through a data-driven approach. Different ML models have been used for this purpose. Some of the commonly used were artificial neural network (ANN) or deep neural network (DNN) model, support vector machine (SVM) and its variation support vector regression (SVR) model, random forest (RF) model and many others. More often authors apply a few different models in order to obtain the one that most appropriately works for specific problem. In wastewater management those problems are various, and could include modelling of WWT processes, prediction of certain technology performance, optimisation of technology working parameters, optimisation of the production of the materials there are being used in WWT technology etc. For instance, there are several articles which describes ML power in optimisation of material synthesis (e.g., biochar production). Application of ML led to reduction in number of runs which were necessary for obtaining the best results by applied production procedure, which saved time and was also cost-beneficial. Indeed, ML incorporation in solving or avoiding potential problems within WWTS is a promising approach which has gained more attention in recent years due to the exponential technology development and progress in artificial intelligence application.*

Key words: artificial intelligence, machine learning, wastewater treatment technology, prediction and process optimisation

1. INTRODUCTION

In order to more efficiently evaluate complex data and improve traditional types of data processing within the environmental management field, different advanced computer-based techniques could be applied (Corominas et al., 2018). One of the subsets of artificial intelligence which is recognized and more often applied for the mentioned purpose is machine learning (Sundui et al., 2021). Among versatile environmental science and engineering scientific fields, machine learning analytical tool seems to be mostly applied in the field of water management (Zhong et al., 2021). ML algorithms have proven their efficiency in enhancing many segments of wastewater treatment, such as: energy cost modelling (Torregrossa et al., 2018), monitoring programme, anomalie detection, evaluation of wastewater infrastructure, optimization of treatment technologies, detection of process hot spots by life cycle assessment (Zhong et al., 2021), optimization of material synthesis and prediction of material or process behaviour (Li et al., 2019; Paula et al., 2022).
To address complex problems, ML approach is using so called “training data” to build models/algorithms which will be able to make predictions or decisions, without being explicitly programmed for that (Zhong et al., 2021). Among many available ML algorithms, artificial neural network (ANN) or deep neural network (DNN) model, support vector machine (SVM) and its variation support vector regression (SVR) model as well as random forest (RF), were among most frequently used.
This paper provides a short overview of good practice examples in the mentioned field, summarising and reviewing the most frequently used ML models applied to different wastewater management problems.

Furthermore, knowledge gaps and some recommendations for future studies were included and emphasised.

2. MACHINE LEARNING ALGORITHMS AND THEIR APPLICABILITY DOMAIN IN WWT TECHNOLOGY

ML algorithms are based on input data called “independent variables”, which are connected with correlated outputs called “dependent variables”. In order to “train” the ML model and enable it to improve with experience, large datasets are usually used (Zhong et al., 2021). After being “trained” algorithms can make certain predictions. In general, when more “training data” is available the more efficient predictions will be generated by the proposed ML model (Zhong et al., 2021). Fig. 1 shows typical ML model workflow, which depicts the data transformation process from raw data to generation of the best possible solution (Sundui et al., 2021). ML algorithm is consisted of three key components: the structure of the algorithm (e.g., RF, DNN); the goal which is aimed to achieve (e.g., prediction accuracy); and the training method to achieve the goal (e.g., stochastic gradient descent) (Montavon, Orr & Müller, 2012). In this work, the focus is put on the mostly applied ML models in WWT systems: ANN and DNN, RF, SVM and SVR.

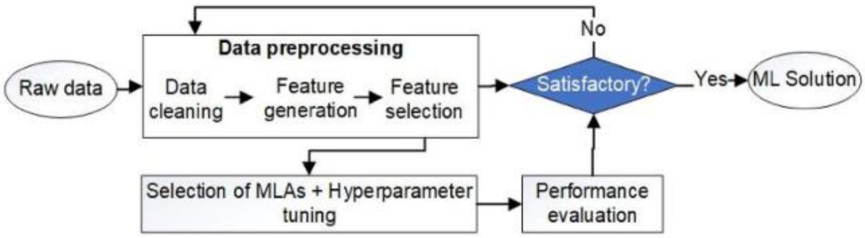

Figure 1: Machine learning model workflow (Sundui et al., 2021)

2.1 ANN models

ANN model consists of set of input, hidden and output processing units (i.e., artificial neurons) which are generating the network of predefined structure. The Type of ANN model is defined by architecture and activation functions (Moreno-Pérez et al., 2018). Single neuron performance is limited to simple calculations. However, their interconnections within hierarchical organizations make them suitable for carrying out complex tasks (El-Din & Smith, 2002). It is very important to test and validate ANN (with new data sets) after training it with previously available data. The performance of the obtained ANN is based on its ability to generalize from the training to the validation data set (El-Din & Smith, 2002). Neural networks with more than two hidden layers are known as deep neural networks (DNN) (Sundui et al., 2021).

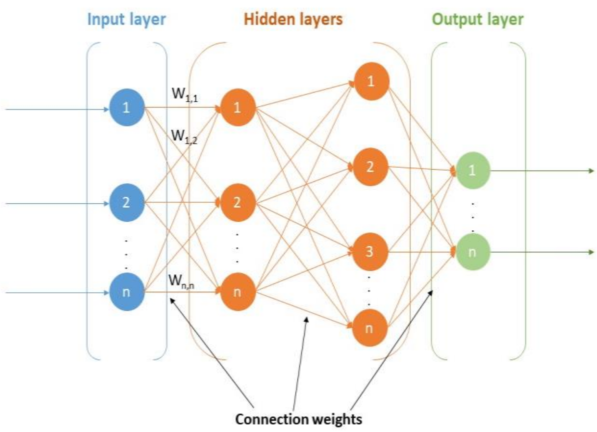

Figure 2: Schematic interpretation of ANN model

2.2 RF model

The Random Forest building process implies generation of new training data sets by applying the bootstrap method on the original data set. Each training data set forms a regression tree which afterwards generates separate prediction. Finally, the general prediction is calculated as the mean value of all separated predictions (Salem et al., 2022). All trees in RF have the same distribution. The generalization error of a RF depends on the strength of the individual trees in the forest and their correlations (Jin et al., 2020). Sometimes another model (e.g. ANN) could be used for the validation of RF model (Wang et al., 2021), however, RF has its advantages over other methods (e.g., importance of every input variable) as the representativeness of training data highly affects model performance (Salem et al., 2022).

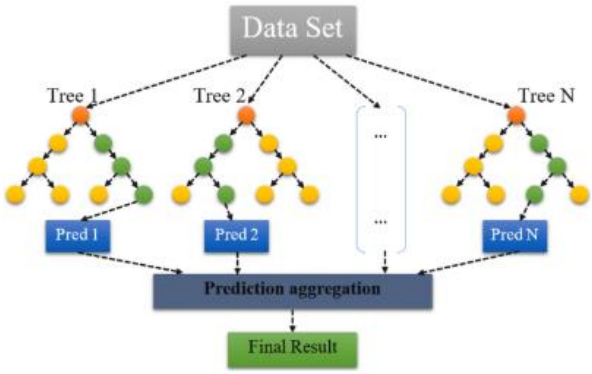

Figure 3: Random forest architecture (Bagherzadeh et al., 2021)

2.3 SVM models

Support vector machine is another powerful algorithm that can be used for addressing a variety of environmental problems (Sundui et al., 2021). While standard, linear SVM presents the fundamental formulation of SVM and is used for classification and regression and, least squares SVM can deal with more different complex problems (Yang, Guergachi & Khan, 2006). General operation of SVM considers observing the end points of data sets, and generating a decision boundary near extreme values, consequently separating classes into two spaces. Basically, the SVM algorithm represents a border between two classes, and the hyperplane that separates the classes is also known as a support vector (Subramaniam & Kaur, 2019). An Important feature of SVM is that it can simultaneously minimize estimation residuals and model dimensions (Foroughi et al., 2020).

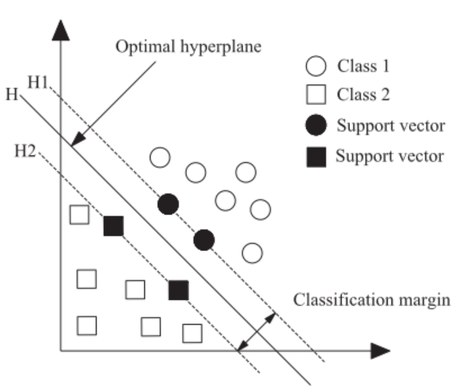

Figure 4: Interpretation of SVM model (Li et al., 2019)

3. EXAMPLES OF GOOD PRACTICE

WWTPs are complex systems which daily receive large quantities of wastewater of dynamic quality. In spite of all variations, WWTPs have to produce an effluent which adheres to the certain standards (Corominas et al., 2018). In order to achieve that, monitoring and control of WWTP performance must be maintained on a high level. In general, as stated by Corominas et al. (2018) there are several driving forces that triggered an intensified development of computer-based approaches for transformation of data into knowledge, namely: control implementation (in order to ensure stability of the process and optimize resource utilization, including energy and chemical consumption) and transformation of data graveyards into data mines (great number of data generated within WWTPs calls for efficient and advanced software processing and transformation into valuable information). Utilization of ML models for mentioned and similar purposes within wastewater treatment management, has especially rapidly increased during the last two decades, which can be seen from the number of published articles within the mentioned field of research. Several examples of good practices are summarized in Table 1.

Table 1: Examples of different ML models utilization within WWT systems

Algorithm	**Application**	**Reference**
ANN and DNN	Improving effluent quality control in WWTP (as validation of RF model used for the same purpose) Generation of energy cost model in WWTPs Prediction of breakthrough curves in adsorption study Modelling and optimization of the extraction process Support of modelling arsenic removal by adsorption process Wastewater inflow prediction Optimization of coagulant dosage by modelling jar-test experiments Prediction of ciprofloxacin adsorption Estimation of phosphorus reduction Generation of support sensors Development of software sensors Optimization of naproxen adsorption by biochar	(Wang et al., 2021) (Torregrossa et al., 2018) (Moreno-Pérez et al., 2018) (Genuino et al., 2017) (Rodríguez-Romero et al., 2020) (El-Din and Smith, 2002) (Haghiri, Daghighi & Moharramzadeh, 2018) (Salawu, Han & Adeleye, 2022) (Kumar & Deswal, 2020) (Dürrenmatt & Gujer, 2012) (Bhattacharya et al., 2021)
RF	Improving effluent quality control in WWTP Generation of energy cost model in WWTPs Prediction of phosphorus content in hydrochar Modelling and evaluation of the performance of a full-scale subsurface constructed wetland plant (prediction of pollutants removal) Wastewater inflow prediction Estimation of phosphorus reduction Monitoring of odor in WWTPs Ozone-membrane process optimization Development of software sensors	(Wang et al., 2021) (Torregrossa et al., 2018) (Djandja et al., 2022) (Salem et al., 2022) (Zhou et al., 2019a) (Kumar & Deswal, 2020) (Cangialosi, Bruno & De Santis, 2021) (Mousavi et al., 2022) (Dürrenmatt & Gujer, 2012)
SVM and SVR	Prediction of an adsorption performance Performance prediction of biological WWTP Nitrogen removal process modelling Optimization and modelling of tetracycline removal from wastewater Wastewater inflow prediction Optimization of flocculation conditions	(Li et al., 2019) (Manu & Thalla, 2017) (Yang, Guergachi & Khan, 2006) (Foroughi et al., 2020) (Szelag et al., 2017) (Li, Hu & Wang, 2021)

Herein, ML utilization within WWT sector will be overviewed through 3 basic groups of application, i.e., prediction, monitoring and optimization (process optimization and optimization of resource usage).

3.1 Prediction models

Back in 2002 ANN were used for the prediction of inflow wastewater (El-Din & Smith, 2002), and after several years another ML algorithms were applied for the same purpose, including SVM and RF in 2017 (Szelag et al., 2017) and RF in 2019 (Zhou et al., 2019a). In the first case, the ANN model was built in order to predict the quantity of wastewater influent in case of storms as the maximum capacity of WWTP can be achieved only in cases when there is a warning on incoming increased flows. The model was built on the rainfall data collected from 8 gauges from the Edmonton city drainage area. The modelling was based on a feed-forward neural network with a back-propagation training algorithm. This model has an advantage of insensitivity to the selection of the value of the learning and momentum factors - however, it faces challenges in terms of determination of the appropriate number of training cycles. The Obtained model was proven to be valuable for the prediction of quantity of WWTP influent and can be integrated into a real-time control system, where complete pollution minimization from WWT systems could be set as an ultimate goal (El-Din & Smith, 2002). Beside feed forward back propagation neural network, other ANN training algorithms could be used, such as feed forward back propagation neural network with distributed time delay, cascade forward neural network and elman neural network, which were tested and compared in terms of their viability to predict asymmetric breakthrough curves obtained from the multi-component heavy metal ions adsorption on a biochar (Moreno-Pérez et al., 2018). Within their research, Szelag et al. (2017) additionally highlighted the importance and advantage of the application of different modelling methods instead of restricting the research on only one. SVM, RF, k-nearest neighbour and of Kernel regression methods were used and tested for the prediction of sewage inflow into the sewage treatment plant. Among tested methods, SVM was superior in 9 out of 12 cases, having the smallest prediction errors. On the contrary, RF provided the best fit and the smallest error in case of two input and one explanatory variable (Szelag et al., 2017). Single technology performance could also be predicted by mentioned models. For instance, ML algorithms were efficient in prediction of an adsorption performance (Li et al., 2019), performance of full-scale constructed wetlands (Salem et al., 2022) or uncertain performances of the biological wastewater treatment process (Sundui et al., 2021).

3.2 Monitoring models

ML can be used for regular monitoring within WWTP or they can be used for detecting different anomalies, unexpected working conditions or contamination events. For instance, within anomaly detection, new observations were compared with learned data distribution in order to identify statistically improbable deviations (Zhong et al., 2021). Timely detected anomalies can help to avoid irregularities or unreliable operations (Zhong et al., 2021). Zhou et al. (2019b) used deep learning models in order to accurately locate pipe bursts in water distribution networks, which was important as that information could help efficient and time-relevant repair of the pipes and restoration of water supply (Zhou et al., 2019b). On the other hand, Cangialosi, Bruno & De Santis, (2021) tested ML algorithms, namely RF and ANN for fenceline monitoring of odor classes and concentrations at the WWTP. By utilization of instrumental odor monitoring systems and application of ML models, the most important sources of odor could be identified and their concentrations could be compared to permissible limits stated in the regulative (Cangialosi, Bruno & De Santis, 2021).

3.3 Optimization models

3.3.1 Process optimization

Different process optimizations could be achieved by application of ML algorithms. Optimization of different technologies performances and removal of different pollutants could be done considering the fact that the main goal is to achieve the highest technology performances by minimal time and resource consumption. Bhattacharya et al. (2021) conducted a study in which the ANN model was compared with a response surface methodology (RSM) in order to optimize naproxen removal by activated rice straw biochar. The input variables (time, adsorbent dosage and solution pH) were the same for both models ANN and RSM and the output was the percentage of naproxen removal. Both models showed high performances, however, ANN had a higher degree of correlation and could be declared as a better fitting model for the described purpose. Besides providing an optimal solution, the significance of parameters interactions was provided. The results proved that the application of computer-based technologies such as RSM and ANN was justified in the field of adsorption process optimization (Bhattacharya et al., 2021). There are other studies which confirmed a superior performance of ML models (such as SVM) in comparison to RSM (Foroughi et al., 2020). Although both approaches gives invaluable results in the field of wastewater management optimization, a slight advantage of ML approaches probably originates from the fact that ML present more modern multivariate mathematics able to solve and models complex, non-linear problems, while RSM’s quantitative analysis are based on the more traditional mathematical models (e.g., linear, polynomial) and validation analysis were done by several statistical tools (Foroughi et al., 2020).

Another commonly used wastewater treatment technology is coagulation-flocculation. However, its performance depends on different factors such as wastewater and flocculants properties etc. (Li, Hu &

Wang, 2021). In the study of Li, Hu & Wang (2021), the optimization of hydraulic conditions was conducted through 16 experiments consisting of different combinations of hydraulic conditions and two ML methods were applied for its evaluation. Support vector regression was superior in comparison to Gaussian process regression for the optimization of flocculation conditions in deinking WWT. Finally, determination of optimal hydraulic conditions (high and low-stirring speed and temperature) led to the improvement of the flocculation process (Li, Hu & Wang, 2021).

3.3.2 Optimization of resource usage

In today's rapidly developing world, resource depletion represents one of the most significant problem society is facing. Different resources can be used in WWT systems, from a wide variety of chemicals to energy consumption. Hence, utilizing computer-based techniques which can lead to optimization and savings are highly valued. NN and RF algorithms were recently used for the generation of energy cost models in WWTPs (Torregrossa et al., 2018). Until now, energy cost models have usually been generated using exponential, logarithmic or linear functions that were useful, but can sometimes struggle to accurately operate with complex data sets. In order to make progress Torregrossa et al. (2018) investigated utilization of machine learning approach for this purpose. The most significant variables for modelling were determined using databases from 317 WWTP, while energy price was for the first time used as one of the model parameters. The Study included two-steps methodology, which consisted of the regression model performance identification followed by the determination of parameters importance. In comparison to traditional approaches, the ML model provided better performance and the robustness of the model was guaranteed by the independent tests. On the other hand, the ML methodology required more time and input data than traditional methodologies. Hence, ML is not always the most viable methodology, but in the case of large data sets and unsatisfactory results of traditional models the, ML approach could be a cost-beneficial option as a single tool or as a part of integrations with the traditional approaches.

In the context of resource optimization usage, optimization of chemical utilization in some processes can be a part of th3 general process optimization (section 3.3.1). For instance, when the coagulant dosage is optimized by modelling the jar-test experiments, the excessive usage of the coagulant was avoided. The Mentioned optimization avoids additional-costs or excessive sediment in filtrate, while maintaining the good quality of the coagulant, and performance. The driving force for ANN application was to accurately and time-efficiently overcome limitations of jar-test experiments caused by changing characteristics of influent (Haghiri, Daghighi & Moharramzadeh, 2018). Djandja et al. (2022) highlighted that traditional optimization can be a time-consuming process in which a lot of resources can be wasted for the conduction of an excessive number of trial experiments. Hence, in their study, Djandja et al. (2022) used a RF model to generate a valuable predictor of phosphorus content in hydrochar, which could guide the production of sewage sludge based hydrochar with the desired content, without a conduction of large number of experiments, as the model was based on data collected from available literature (Djandja et al., 2022).

4. KNOWLEDGE GAPS AND FUTURE PERSPECTIVES

Generally, ML approach is a beneficial tool for processing large amounts of complex data, which might be insufficiently understood and interpreted by traditional statistical approaches. ML is a time and cost-beneficial technique, however, it is in the early stages of application in environmental science and engineering field. Lack of knowledge about its proper employment might lead to incorrect applications of ML algorithms to certain data sets (Zhong et al., 2021). Hence, those and similar problems that might occur if ML is used inadequately should be considered before the actual application of the ML. More articles which include several algorithms utilizations and viability comparison for the same purpose should be included, if possible. That way, the most appropriate model with the highest performance could be chosen. Furthermore, comparison with traditional models might give an additional justification of ML application in further studies. Currently, there are not many articles which included this aspect. In the field of resource management, literature is sparse with research which include energy cost optimization, which could be characterized as one of the most influential parts of cost-benefit analysis of the wastewater treatment. Additionally, there is an increment in the application of circular-economy principles within adsorption technology, where different waste materials could be used as starting materials for the adsorbent production. This way self-life of a material is prolonged and less raw materials were used. In order to additionally prevent the excessive use of raw materials, different traditional tools have been used, such as response surface methodology. Little is known about the utilization of ML algorithms as advantageous and advanced tools for adsorbent production process optimization. This can be valuable as the advanced ML approach might obtain more precise/trustworthy results in cases where complex and large data sets should be processed or when the traditional approach does not give a satisfactory response. A Similar approach might be investigated for optimizing other material production processes. Hence, those knowledge gaps could potentially be a part of some future research.

5. CONCLUSIONS

ML approach has been increasingly valued in the wastewater treatment sector as it provides a viable, flexible and high performing tool for optimization, prediction, monitoring and other enhancements of wastewater quality management. Its further implementation in environmental engineering and the complex wastewater technology sector might lead to a further decrease in resource depletion, energy and time consumption, as well as to th3 development of real-time control systems and a consequently timely reaction on extreme conditions such as accidental situations which can lead to an occurrence of higher pollutant concentrations in wastewater treatment plant influents etc. The Overall cost and environmental footprint of WWT systems could be optimized by application of ML models, which highly justifies further research in this direction.

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TYPOGRAPHY

https://doi.org/10.24867/GRID-2022-p90 Original scientific paper

LEGIBILITY ANALYSIS OF SELF-DESIGNED TYPEFACE WITH EYE-TRACKING DEVICE

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Abstract: *Typography appears in every aspect of our lives. It is closely intertwined with the representation of information, communication, and our cultural and national identity. Until the invention of computer in printing, only a few typefaces were in use. Then, almost overnight, a flood of new typefaces appeared in different type styles or in their combinations. Nowadays, a vast number of tools is available for designing typefaces, enabling almost anyone to do it. Nevertheless, not every typeface is well designed and useful, i.e. legible. A successful type design requires following the established aesthetic and technical principles. Moreover, it should follow perceptual principles. This study was concerned with evaluating the legibility of various useful typefaces in comparison to a self-designed typeface. The self-designed typeface was not based only on the principles of good legibility. Its design was based also on the paintings by the Slovenian Art Nouveau and later Impressionist painter Matija Jama, whose 150th birthday is celebrated this year. The Impressionist painter's typeface should not only have the qualities of artistic style, but also be usable, i.e. legible, for a longer text. To determine which type size is optimal for such a text, the test of legibility was conducted. The legibility of the self-designed typeface was analysed along with three other well-known and useful typefaces, i.e., an old style typeface (Minion), a transitional typeface (Bentham) and a sans serif typeface (Gill Sans). The reading speed and number of fixations were analysed using a Tobii 120X eye-tracking device. Different texts in all four typefaces in three different type sizes (i.e. 16, 21 and 26 px) were displayed on a 24-inch LCD display. The twenty tested individuals were aged between 19 and 23 years. The results showed that the choice of a particular type size affected the reading speed and legibility. It was also found that for some typefaces, different type sizes, when read, require more fixations. The results of our study show that a self-designed typeface is useful, i.e. legible, at larger type sizes. An appropriate type style and size can improve legibility on displays.*

Keywords: eye-tracking technology, LCD display, legibility, typeface, type size

1. INTRODUCTION

Typography appears in every aspect of our lives. It is closely intertwined with the representation of information, communication, and our cultural and national identity. Until the invention of computer in printing, only a few typefaces were in use. Then, almost overnight, a flood of new typefaces appeared in different type styles or in their combinations. Nowadays, a vast number of tools is available for designing typefaces, enabling almost anyone to do it. Nevertheless, not every typeface is well designed and useful, i.e. legible. A successful type design requires following the established aesthetic and technical principles. Moreover, it should follow perceptual principles. The communication through a page or display requires from the reader to translate symbols into meaning. Legibility refers to how easily this process is performed. To make reading possible, the text must be visible and recognisable; however, visibility and recognition are influenced by the typographical choice (Reynolds, 1988; Možina, 2001). Legibility and the reading process can be studied by tracking eye movement. Reading does not occur as a continuous movement of eyes along the lines of a text, but rather as a sequence of rapid eye movements (saccades) and individual fixations (cf. Figure 1). Fixations are short stops on individual words or groups of words which enable the brain to process information. They last between 200 and 250 ms (Rayner et al., 2001; Abadi, 2006), between 200 and 300 ms (Rayner, 1998), or even more (Feng, 2009). Saccades are extremely quick eye movements with which we change the direction of our gaze in a moment and align the image of the object of interest with the macula of retina. When reading, saccades move over groups of letters (Burr et al., 1982). Saccades are the most common type of eye movement; their speed can exceed 500°/s and an individual saccade may last from approximately 25 to 75 ms (Rayner, 1998; Leigh et al., 2015).

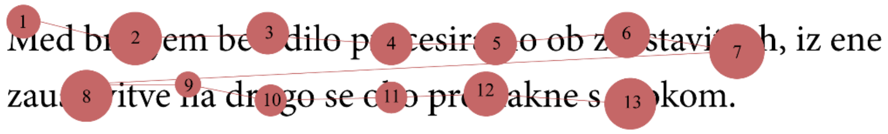

Figure 1: Eye movements (saccades) and fixations

A large number of studies on legibility points to its importance. There are some typographic characteristics to be observed to make a text more legible. For a small type size, it is known that differences in stroke weight and typographic tonal density (TTD) are significant (Rat et al., 2011; Možina et al., 2019), since they influence text legibility. Furthermore, a number of other typographic characteristics needs to be observed in order to make a text more legible, i.e. distinctive character features (counter shape), x-height, ascender, descender, serifs, contrast (stroke weight), set width, type size, leading (i.e. space between lines) etc. (Reynolds, 1988; Tracy, 2003; Franken et al., 2015).

For better visibility of information, colour can be of use as well (White, 1996). Most typefaces are designed to be read as black letters on a white background and they, in this manner, achieve optimum legibility. When reading large amounts of type, the contrast of black and white is what readers are most accustomed to (Carter, 1997; Možina, 2001). The legibility study (Franken et al., 2020) of different typefaces in different light-dark contrasts with different backgrounds displayed on an LCD display showed that a better contrast (however, not maximum, i.e. black on white) increases the reading speed.

The aim of this study was to examine the legibility of various useful typefaces in comparison to a self-designed typeface. The self-designed typeface was not based only on the principles of good legibility. Its design was based also on the paintings by the Slovenian painter Matija Jama, whose 150th birthday is celebrated this year. Matija Jama (1872–1947) studied painting at a private art school in Munich. After his Art Nouveau period, his work was influenced by the Italian and French Impressionists. The majority of his 450 well-known paintings are in oil technique. Jama was recognised for his landscape paintings; however, *vedute* and portraits are also greatly featured in his art. During his later years, he leaned more towards figuralism (Kocjan et al., 2015). The Impressionist painter's typeface should not only have the qualities of artistic style, but also be usable, i.e. legible, for a longer text.

2. EXPERIMENTAL PART

For the purposes of our research, we first analysed the self-designed typeface, entitled Mila (cf. Figure 2) and categorised it according to the classification of typefaces. Legibility was then tested in comparison to three established typefaces with similar design features. The old style typeface Minion, the transitional typeface Bentham and the humanistic sans serif typeface Gill Sans were used (McLean, 1996; Možina, 2003) (cf. Figures 3–5). The study was conducted by analysing texts in the Slovenian language from the book *Ernijeva kuhinja* (by Zoran Hočevar), using an eye-tracking device. Lastly, we analysed the results of the study.

Figure 2: Typeface Mila

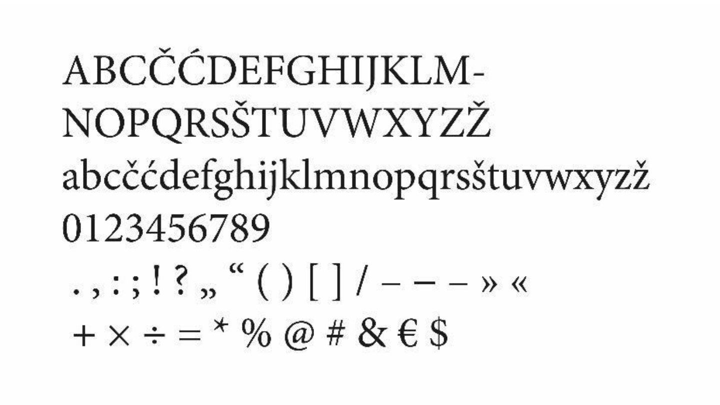

Figure 3: Typeface Minion

Figure 4: Figure Bentham

Figure 5: Typeface Gill Sans

In controlled laboratory conditions (*ISO 3664*, 2009), the reading speed, fixations and saccades were analysed with an eye-tracking device Tobii 120X. The texts in all four typefaces at 16, 21 and 26 px, were displayed on a 24-inch LCD display with the resolution of 1900 × 1200 pixels at a 120 Hz refresh rate. In each typeface, a different text was presented to tested individuals. We used 12 different texts with the length of around 70 characters per line (cf. Table 1). The texts were displayed in dark characters on light backgrounds (text colour #000000, background colour #EEEEEE).

Table 1: Selected texts for legibility analysis

Text number	Typeface	Type size (px)	Number of characters
1	Bentham	16	575
2	Bentham	21	569
3	Bentham	26	560
4	Mila	16	532
5	Mila	21	519
6	Mila	26	546
7	Minion	16	574
8	Minion	21	599
9	Minion	26	559
10	Gill Sans	16	611
11	Gill Sans	21	578
12	Gill Sans	26	566

The tested individuals were positioned 60 (±1) cm from the screen according to the recommendations of the ISO 9241-303 standard (2012). The texts were set in a CSS style sheet and displayed as an HTML document. In this way, we ensured a precise display of texts in the chosen size. The texts were displayed in the middle of the screen. Consecutive texts were invoked by successive mouse clicks.
There were 20 participants, 5 male and 15 female, aged from 19 to 23, with an average of 20.60 years; all participants had normal or corrected-to-normal vision. The participants read the same texts. We used the so-called Latin square design to vary the display sequence in order to prevent the possible fatigue effect with texts displayed towards the end of the experiment. The time required to read texts of different length, the number of fixations, saccades and the length of saccades (in number of characters) (cf. Table 2) were later calculated for 500 characters.

Table 2: Measurement data

Text number	Number of characters	Reading time (s)	Number of fixations	Number of saccades	Length of saccades (no. of characters)
1	575	32.02	353.80	352.80	2.23
2	569	32.62	349.25	348.25	2.13
3	560	30.58	331.75	330.75	2.07
4	532	33.85	330.70	329.70	2.34
5	519	30.82	288.00	287.00	2.33
6	546	32.04	352.10	351.10	1.92
7	574	31.49	322.60	321.60	2.30
8	599	32.50	360.05	359.05	2.00
9	559	32.71	368.55	367.55	1.79
10	611	35.45	397.55	396.55	1.92
11	578	31.92	370.70	369.70	1.90
12	566	31.51	351.30	350.30	1.91

3. RESULTS

When presenting the results, we focused on *reading time*, *number of fixations* and *saccade length*.

3.1 Reading time

The results (cf. Figure 6) showed the speed of reading for each of the tested typefaces (Bentham, Mila, Minion, Gill Sans). The reading speed for the typeface Bentham was the lowest at the type size 21 px. The texts displayed in the type size 26 px were read the fastest. The difference between the reading times for the type sizes 16 px and 26 px was 0.55 s. For the typeface Mila, the reading time descended proportionally with an increase in type size. The texts in the type size 16 px were read the slowest and in the type size 26 px the quickest. For the typeface Minion, the reading time was the shortest when the presented texts were displayed in the type size 21 px and the longest for the type size 26 px. Nevertheless, the difference between the two reading times was relatively small, i.e. 0.3 s. The results for the typeface Gill Sans showed that the texts in the type size 21 px were read the fastest and the texts in the type size 26 px were read by 0.23 s (0.83%) more slowly. The longest reading time was recorded for the type size 16 px.

As showed in Figure 6, the average reading time was the longest for the typeface Mila (in all type sizes). The texts displayed in the type size 16 px were read the quickest when set in the typeface Minion and the same outcome can be observed for the type size 21 px. At the size 26 px, the shortest reading time was measured for the typeface Bentham. On average, the shortest reading time was recorded for the texts displayed in the size 21 px (28.27 s). For the size 26 px, the average reading time was 28.43 s. The participants spent the most time reading the texts displayed in the type size 16 px (29.03 s). On average, the reading time was the shortest for the typefaces Minion and Bentham, both of which had an average of 27.94 s for all type sizes.

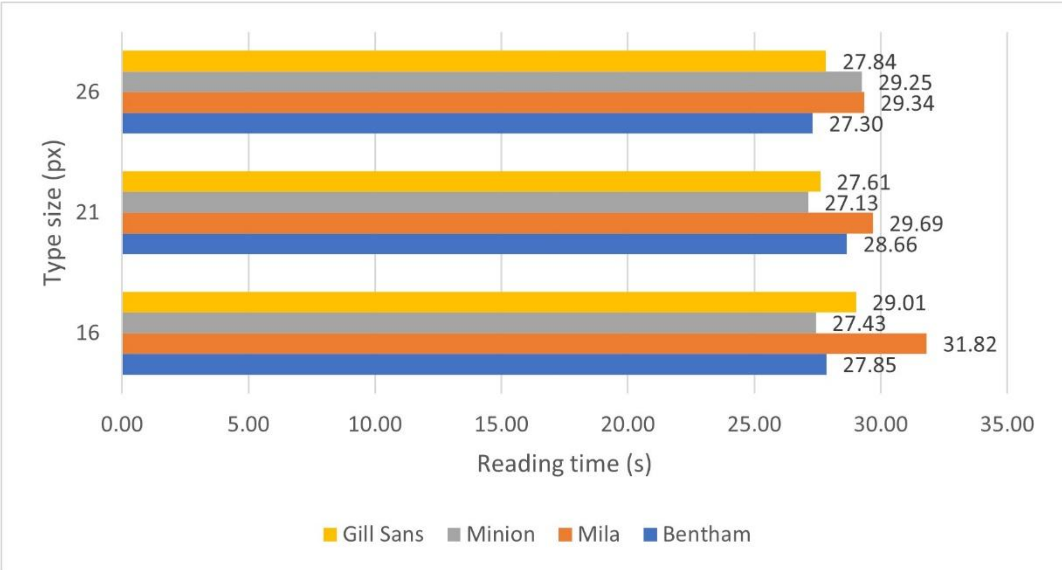

Figure 6: Comparison of average reading time (s) for all typefaces, depending on type size

3.2 Number of fixations

Figure 7 shows the number of recorded fixations for each type size. For the typeface Bentham, the most fixations were recorded at the type size 16 px. An increase in type size resulted in fewer fixations, meaning that at the size 26 px, the fewest fixations were made. The participants made the largest number of fixations for the typeface Mila at the type size 26 px. At the type size 16 px, by 3.42% fewer fixations were made. The smallest number of fixations was recorded for the type size 21 px, i.e. on average by 13.98% fewer fixations than for the type size 16 px. For the typeface Minion, the number of fixations ascended proportionally with an increase in type size. For the type size 16 px, the number of fixations was by 7.12% lower than for the type size 21 px and by 17.44% lower than in the texts displayed in the type size 26 px. The typeface Gill Sans had the most fixations recorded at the smallest type size. For the type size 21 px, there were by 1.23% fewer fixations made. The smallest number of fixations was made at the type size 26 px, i.e. by 4.62% fewer than at the type size 16 px.

On average (cf. Figure 7), the fewest fixations for all type sizes were made when reading the texts displayed in the typeface Bentham. For the type size 16 px, the typeface Minion had the smallest number of fixations, followed by the typefaces Bentham and Mila. Relatively more fixations were made for the texts in the typeface Gill Sans. For the type size 21 px, the smallest number of fixations was recorded for the typeface Mila, followed by the typeface Minion with on average by 8.66% more fixations. The highest number of fixations occurred with the texts in the typeface Gill Sans. The typeface Bentham had the smallest number of fixations at the type size 26 px. In comparison to other type sizes, there were fewer fixations for the typeface Gill Sans. The highest number of fixations was measured for the typeface Minion, the typeface Mila had on average by eight fixations less.

On average, the type size 21 px had the smallest number of fixations (301.39). For the type size 16 px, the average number was 306.20. The most fixations were made at the type size 26 px, on average 314.66. When compared, the typefaces Bentham, Mila and Minion had a similar average number of fixations (303.57–303.73). The typeface Gill Sans had a noticeably higher number, i.e. 318.78.

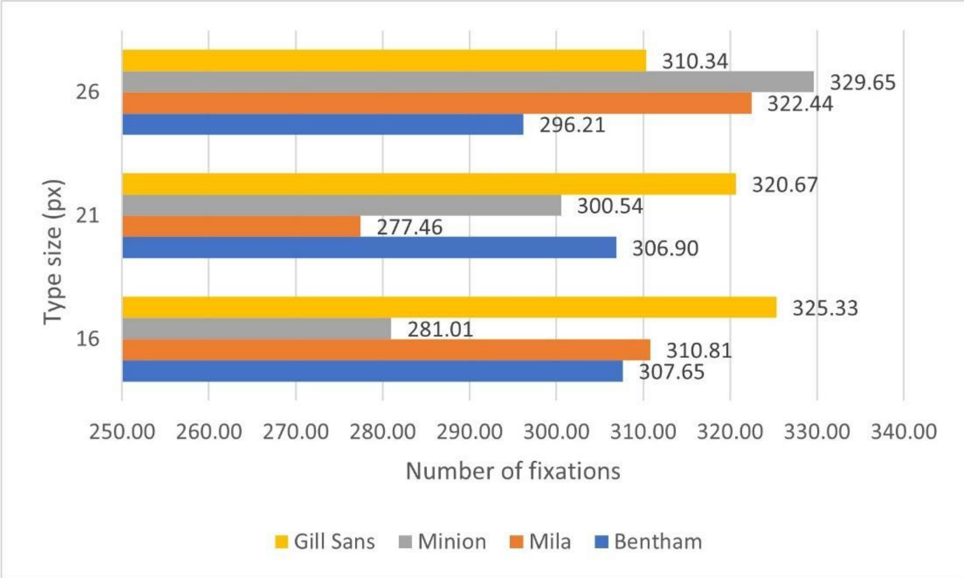

Figure 7: Comparison of average number of fixations for all typefaces, depending on type size

3.3 Saccade length

The results (cf. Figure 8) show the average length of a saccade, expressed in the number of characters recognised in different typefaces and different type sizes.

The saccade length for the typeface Bentham descended proportionally with an increase in type size. The saccades were the longest for the type size 16 px and the shortest for the type size 26 px.

For the typeface Mila, the saccades were the longest for the text displayed in the type size 16 px, somewhat shorter for the type size 21 px and the shortest (by 15.32%) for the type size 26 px. The saccade length also descended with an increase in type size for the typeface Minion. For the type size 16 px, by 9.09% more characters were recognised than for the type size 21 px and by 24.24% more than for the type size 26 px. The saccades had similar lengths in all type sizes for the texts displayed in the typeface Gill Sans. For the type size 21 px, by 0.53% fewer characters were recognised than in the biggest type size, i.e. 26 px. The difference between the type sizes 16 px and 26 px was 0.52%, where the smallest type size had the longest saccadic movements recorded.

On average (cf. Figure 8), the length of saccades was the longest for the typeface Bentham. For all type sizes, they were the shortest for the texts displayed in the typeface Gill Sans. For the type size 16 px, the saccadic movements were the longest for the typeface Minion, followed by the typeface Bentham. The typefaces Mila and Bentham had matching results and the longest saccades in the type size 21 px. Additionally, the typeface Bentham had the longest recorded saccades for the type size 26 px, followed by the typefaces Mila and Minion.

The length of saccades was the longest for the type size 16 px, where the length of a saccade was on average 2.40 characters. For the type size 21 px, the average saccade length was 2.29 characters. The shortest length recorded was for the type size 26 px, where the average saccade length was 2.08 characters. The typeface Bentham had the average saccade length of 2.43 characters. The typeface Minion had the length of 2.35 characters, followed by the typeface Mila (2.33 characters). The shortest saccade length, i.e. 1.91 characters, was recorded in the texts presented in the typeface Gill Sans.

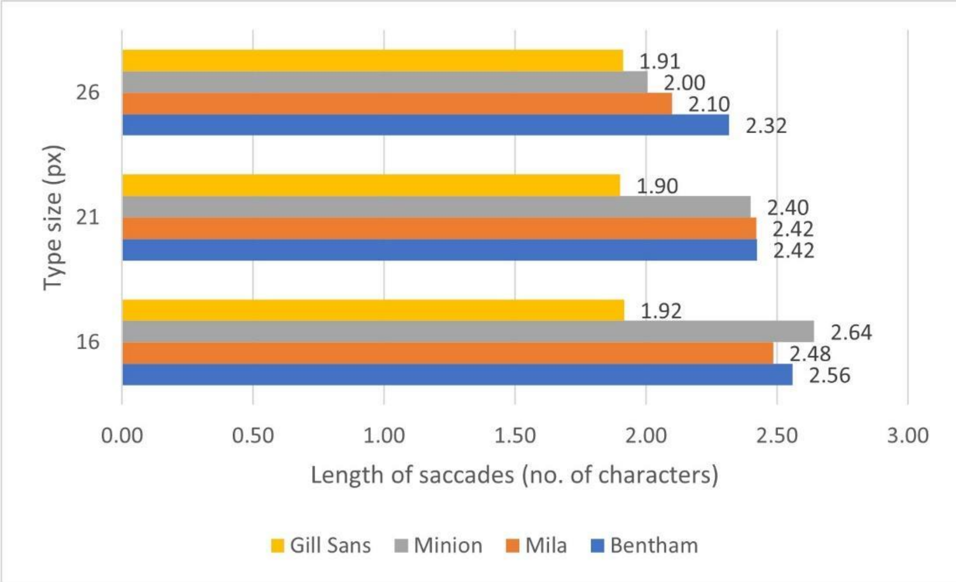

Figure 8: Comparison of average saccade length for all typefaces, depending on type size

4. DISCUSSION

In regard to the results of the study, the speed of reading for the self-designed typeface Mila and typeface Bentham proved to be the fastest for the texts displayed in the type size 26 px. For the typefaces Minion and Gill Sans; however, the reading time was the shortest at the type size 21 px. On average, the longest reading times were measured for the texts in the typeface Mila and the shortest for the typefaces Bentham and Minion, which had similar results. The shortest reading speed was recorded for the type size 21 px and the longest for the type size 16 px. The participants read the texts in the typefaces Bentham and Gill Sans with the smallest number of fixations at the type size 26 px. The texts displayed in the typeface Mila had the smallest number of fixations at the type size 21 px and for the typeface Minion, the fewest fixations were made at the type size 16 px. On average, the smallest number of fixations was recorded for the typeface Bentham and the highest for the typeface Gill Sans. The results indicate that the lowest number of fixations was made at the type size 21 px and the highest at the largest type size, i.e. 26 px. According to the results of saccade lengths, they were the longest at the type size 16 px for all typefaces except for the typeface Gill Sans. The latter had the longest saccade length at the type size 21 px. The participants made on average the longest saccade length when reading the texts displayed in the typeface Bentham and the shortest at the typeface Gill Sans. The lowest number of characters captured simultaneously were at the type size 26 px and the highest at the type size 16 px.

5. CONCLUSIONS

Based on the characteristics of different typefaces and the results of legibility analysis, we came to the conclusion that the typeface Bentham proved to be the most legible. The optimal results were obtained at the type size 26 px, where the length of saccades was the longest. The typefaces Bentham and Minion had the shortest reading times. Among all the studied typefaces, the texts in the typeface Mila were the slowest to read, with the reading times being the longest for all type sizes. The self-designed typeface turned out to be the most legible at larger type sizes. In smaller type sizes, legibility was worse due to thin character strokes and smaller size of serifs. The highest number of fixations and the shortest saccade length measured in texts displayed in the typeface Gill Sans indicate that this typeface is not particularly legible under the selected conditions.

The self-designed typeface Mila was analysed and according to its characteristics categorised into typeface style groups. We successfully reviewed the legibility of the typeface. This study showed interesting results, especially when observing the length of saccades, where all measured values were relatively small. Before starting this study, we assumed the self-made typeface to be useful and legible in larger type sizes, which was proven correct.

The findings and results of the research can contribute to a more appropriate type design in consideration of legibility and, consequently, to the design of more legible typefaces.

6. ACKNOWLEDGEMENTS

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DESIGN OF TYPEFACE WITH CONSTRUCTIVISTIC PROPERTIES AND RENOVATION OF PROMOTIONAL MATERIAL FOR MEMORIAL ROOM

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Abstract: *The diversity that occurs in the field of typography, more specifically in the planning and design of typefaces, plays an important role in our lives and in society more broadly. Therefore, purposeful product planning is important because it can facilitate our everyday communication and understanding of the environment. The goal of the collaborative project was to design a display typeface and use it in revised graphic products that, along with the typeface, fit the client, the Kosovel Memorial Room in Sežana, Slovenia. Srečko Kosovel is a well-known Slovenian poet whose work is representative of the cultural and social movement Constructivism. With new graphic products, we want to contribute to better publicity of Kosovel Memorial Room in Sežana. The theoretical part deals with the study and classification of typefaces in groups and larger sets. We also studied some basic properties of typefaces, contrast, stroke width and spacing, weight and height relationship within typefaces. We investigated the historical development of display typefaces, their properties, and their influence on various graphic products. Based on the content of the Kosovel Memorial Room, we examined the origin and development of the artistic avant-garde movement Constructivism abroad and in Slovenia. We highlighted important events in the life of Srečko Kosovel and familiarised ourselves with his work. Based on the client's needs, the existing promotional material (brochure, posters, etc.) was analysed in more detail. In addition, we conceptually prepared the typeface design, drawing on his other graphic products. The display typeface was used in revised graphic products that we designed in collaboration with the client. The final products were presented in February 2022 and will continue to promote Srečko Kosovel's work.*

Keywords: brochure, constructivism, display typeface, graphic product design, typeface design

1. INTRODUCTION

The preservation of cultural heritage and related monuments, memorials or other cultural institutions has been an indispensable part of culture for many years, and thus of the preservation of national consciousness. Increasingly, sub-areas that are commonly attributed to graphic design are also counted as part of cultural heritage. Here we would like to highlight the field of typography, which through the collection and analysis of typefaces can contribute an essential mosaic to the understanding of the past and provide guidelines for future development.

Typography is the science of fonts, typefaces and text design (Možina, 2003). Its basic function is visual communication and transmission of information to the reader with the help of type media (Možina, 2003). Great emphasis can be placed on the choice of typefaces, which are often most easily distinguished by the time period in which they were created. The order of development of typefaces would be (slightly different depending on the region, of course) the following: humanistic (Venetian Renaissance typefaces), garalde (French Renaissance typefaces), followed by transitional (Baroque typefaces), and modern (Classicist typefaces) (Možina, 2003). The typefaces differ mainly in the shape of the strokes, the contrast and position of the crossbar, for example in the letter e, and the thickness of the strokes. What they have in common is that these characteristics can be traced back to the time in which the typeface was created.

Historically, the basis for all typefaces can be found in calligraphy. In particular, calligraphy is an excellent starting point for determining where a particular letter has thin and thick strokes (of course, in the context of fonts that have different stroke widths) (Noordzij, 2006). Later developments, particularly the Industrial Revolution, contributed to the establishment of slab/square serif typefaces, characterized by angular serifs that are perpendicular to the base stroke. Still later, however, a reversal occurs when the letters also lose these shapes and we can speak of the development of San Serif (also lineale) typefaces. The latter typefaces can be divided into four groups, namely early, refined, geometric and humanistic (Možina, 2003).

The last three groups of typeface, which can be grouped into a series of accidental typefaces (Možina, 2003). These are glyphic, decorative, and display typefaces. In addition to the basic classification of typefaces, different groups can be distinguished according to their characteristics, such as: contrast, inclination of the base axis, stroke endings, stroke width and difference in x-height. In the case of typefaces, different proportions can be defined depending on the arrangement of the lines that determine the height of the letters *(Figure 1).*

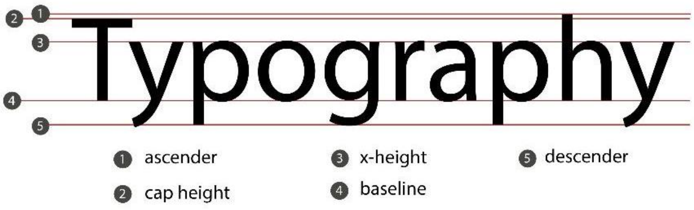

Figure 1: Definition of typeface properties and determination of the relationships between them.

In addition to the properties that determine the appearance of typefaces, they can also be defined according to their intended use (Bigelow et al., 2017). Thus, two groups can be defined: typefaces suitable for longer texts in a smaller format, and typefaces suitable for shorter texts in a larger format. The first group is characterized by the fact that their form does not demand much attention from the reader, so that she/he can fully concentrate on the written content. Due to their form, they have no relation to the content and do not contain decorative elements, so they have a low semantic value. The opposite is true for typefaces intended for short captions larger than 18 points (pt) (Bigelow et al., 2017). Such typefaces can be called display typefaces. They are characterized by the fact that they can also contain decorative elements and other design features that are undesirable in typefaces for longer texts (Puškarević, Nedeljković & Pušnik, 2018). The design features provide the semantic value of the text, i.e., the typeface is a carrier of meaning because of its form, which contains, for example, an emotional connotation (Puškarević, Nedeljković & Pušnik, 2018). In a sense, these typefaces can address the viewer with a form that reinforces the meaning of the text, adds a new connotation, or even contradicts the meaning with its connotation (Morrison, 1986).

2. METHODS

In accordance with the Kosovel Memorial Room, we wanted to create a display typeface that would attract the viewers by its appearance and remind them of the Slovenian poet Srečko Kosovel, who worked during the Constructivism period (Krkoč, 2014). Characteristic of constructivism in visual arts is that artists emphasised geometric shapes and constructions (Fran, 2020). Non-figurative paintings, photomontages, collages, and bold typefaces predominated. The colour palette was usually modest, often using red in addition to white and black, sometimes yellow, blue or another colour with a high degree of saturation (Strizver, 2017). In designing the typeface and graphic products, we adhered to the above principles mentioned. Our main focus was on the printed products for the Kosovel Memorial Room. They are used to communicate various information to target groups, mostly for promotional purposes. We limited ourselves to the design of a promotional poster, a leaflet and an information brochure.

The process of producing a display typeface was divided into four parts: determining basic features, conceptual design and sketches, vectorization and finishing, and determining metrics.

The typeface was used in the renewal of promotional materials (graphic products) for the Kosovel Memorial Room in Sežana, Slovenia. As part of the promotional materials, a poster, a leaflet and an information brochure had to be created. In order to best understand the idea and obtain relevant information, we conducted an interview with the responsible person prior to production and obtained the institution's opinion on the new materials. Existing promotional material served as the basis for the new material; analysis of formats, distribution of content, visuals and colour palette.

In the last part, we reviewed the promotional materials created. Using an online survey, we received responses from different age groups and, based on this, we were able to determine how successful we were in implementing the project.

The following describes the process of creating a typeface, promotional materials, and analysing of online survey.

3. RESULTS

3.1 Typeface making process

The first feature of the typeface we defined was its purpose. We decided to design a display typeface suitable for larger sizes and whose form would be associated with constructivism and the poet Srečko Kosovel. The type ratios were defined in a size of 1000 units. According to the baseline, the ascender has a height of 750 units, the height of the capital letter was set at 725 units, the x-height at 500, and the descender at -250 units. According to the proportions, the Ekstaza typeface is defined as having a larger x-height.

For the basic idea of the typeface we chose the graphic portrait of Srečko Kosovel by August Černigoj *(Figure 2).* We were inspired mainly by the black areas and negative space. We decided to use a sans serif typeface, since typefaces without different weights are classified as technical typefaces, which is in line with the idea of constructivism.

Figure 2: Portrait of Srečko Kosovel; author August Černigoj (Museums of the World, 2022)

The letters are designed to look as if different strokes are connected. In this way, we wanted to emphasize the construction of the individual letter. Within the typeface, we wanted to keep the geometric shape of the circle, as it was often used as a basic geometric element in Constructivism. In addition, the shape of the circle can also be associated with Srečko Kosovel's characteristic glasses and considered his trademark.

In a conversation with the client, we realised that they want to show other, gentler styles in which the poet created, in addition to the characteristics of constructivism, so we were careful not to make the type too robust. On graph paper, we made sketches *(Figure 3)* on which we drew the capital letter S and the lowercase letters a, č, e, j, k, n, o, and r. We chose these letters as a basic orientation for the further design of the letters in the digital environment.

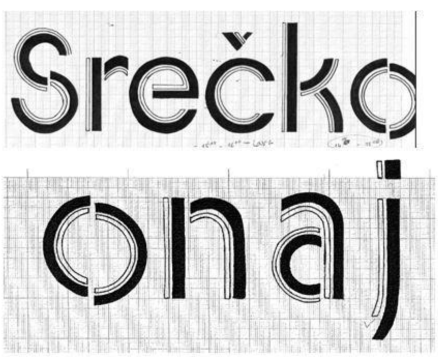

Figure 3: Initial sketches on graph paper

After sketching, we scanned the letters and transferred the photos into Adobe Illustrator. Using Illustrator, we roughly outlined the letters and vectorized them. Then the vector shapes were transferred to FontLab Studio 7, where further production of alphabetic and non-alphabetic characters took place. The first set of digitized characters is shown in Figure 4.

Figure 4: The first set of digitized characters

Since we were not completely satisfied with the character set, we adjusted it a bit *(Figure 5).* We changed the capital letters A, V, W completely, made corrections to the letters that had round shapes, and made some changes to the letters that were not quite finished. We decided to make these changes because the first version of the typeface did not look constructivistic enough.

Figure 5: The second (final) set of digitized characters

The next step after the production of alphabetic and non-alphabetic characters was the adaptation of metrics. The process was based on the recommendations of Karen Cheng in the book Designing Type (Cheng, 2005). First, metrics were defined for the letters H and O, which were the basis for determining metrics for uppercase letters. The metrics were determined using different combinations of these two letters (HHH, OOO, HHOOHH, HOHOH, OHOHOH...) and adjusted so that they were visually the same in all combinations. Based on the metrics for the letters H and O, we obtained five different values that were used to determine the metrics of the remaining letters. We repeated a similar procedure for lowercase letters, with the difference that we used the letters o and n as the basis. Based on the different combinations of these two letters, we determined the values to be visually the same in all combinations. Based on the metrics for the letters n and o, we determined six parameters. We applied the parameters to lowercase letters.

Despite the accurate determination of the metrics, it was necessary to determine the kerning pairs for some letters. In doing so, we compensated for whiteness by reducing the spacing between pairs of letters. This process is time-consuming because both alphabetic and non-alphabetic characters must be included in the combinations. Fontlab7 itself suggests the most common pairs. To speed up the process, we followed the list suggested by the program. For Slovenian and English (especially shorter) texts, where individual unordered combinations were still noticeable, the edited metrics were subsequently checked and adjusted according to visual suitability.

3.2 Promotional material making process

Based on the analysis, we came to the solution that the new information brochure will have a format of 200 × 790 mm, printed on both sides and folded into four equal parts. Thus, the folded format of the brochure will be 200 × 200 mm, forming a square related to the cube, one of the main elements of the Kosovel Memorial Room in Sežana. Figure 6 shows the described format, the four parts, the dimensions and the outlined topics that will fill a given page.

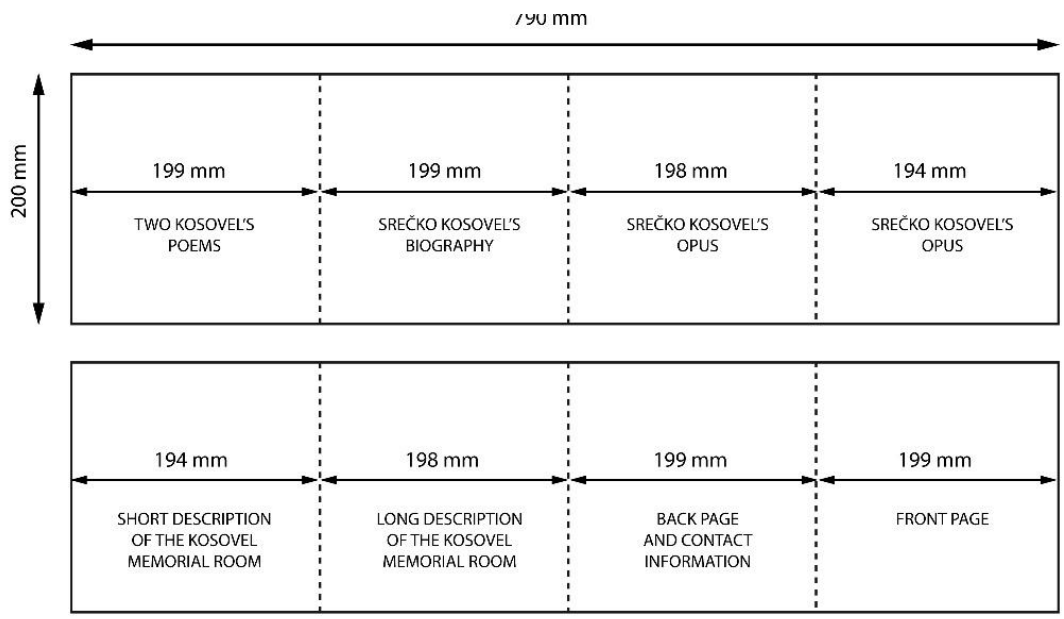

Figure 6: Plan of the information brochure with technical and content specifications.

In 2014, the memorial room of Kosovel was completely renovated. At the time of the renovation, architects and interior designers defined the space and its features; by this we mean primarily the use of colours. Based on this, we decided to use the colours blue, red, white and black in the revised information brochure to create accents. The selected colours are shown in Figure 7.

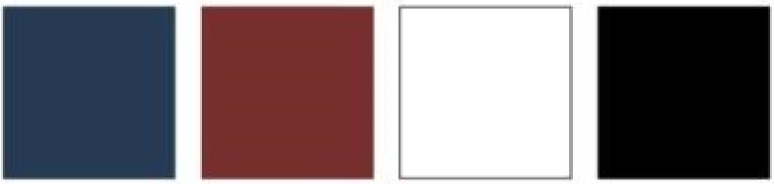

Figure 7: Colour selection for promotional material

We based the content of the information brochure on the previous brochure and created a similar layout for the content. The change that harmonized to some extent with the new folding style of the information brochure concerned the presentation or the structure of the contact information. The new folding style makes the contact information more noticeable as it is placed in a visible location.
We got the idea for the basic layout of the brochure from the appearance of the Kosovel Memorial Room (Figure 8), where we were most interested in the white walls with dark borders and the wooden floor, on which a red-blue pattern of lines is created by the blue light. The black borders on the walls come from the collection of poems Integrali.

Figure 8: Kosovel Memorial Room

Kosovel's art song Flying Ship, presented in the form of a collage (Figure 9), also served as inspiration for the design of the promotional material. We came up with the idea that longer texts can be broken down into smaller units using coloured backgrounds and irregular shapes, and so the text is presented in an information brochure in the form of a collage.

Figure 9: Kosovel's art song The Flying Ship (Digitalna knjižnica Slovenije, 2013)

For better design, we created a basic construction grid (Figure 10) to help align the lines of text in the various fields of the brochure. The grid was constructed so that each square was divided into 16 parts (4 × 4), which made the design easier and more efficient.

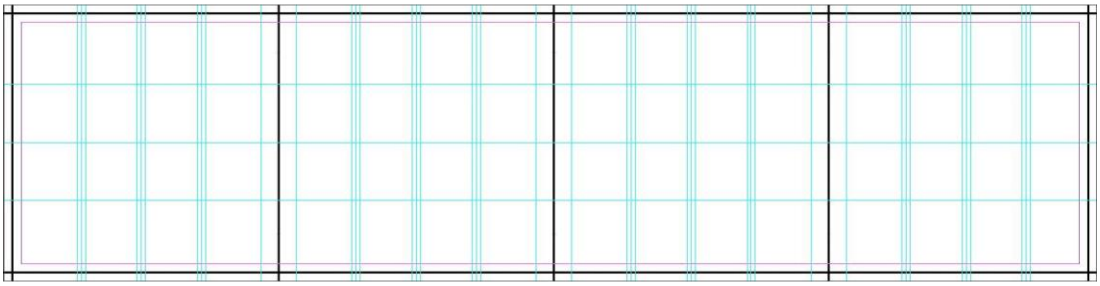

Figure 10: Basic construction grid

We added black lines to the borders (fold lines), reminiscent of the black borders in the Kosovel Memorial Room *(Figure 8).* We set the text on smaller, irregularly shaped colour areas. The colour areas were inconsistently shaped so that the alignment of the text alternated between left or right *(Figure 11).*

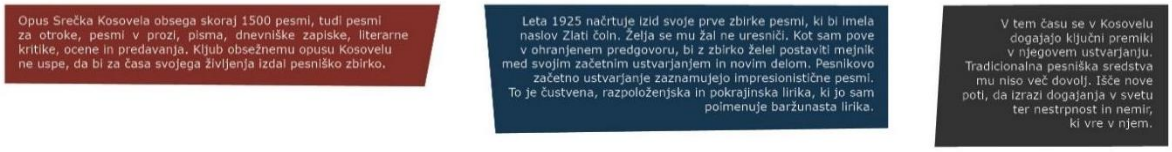

Figure 11: Display of colour plots and inconsistent text alignment

The text was supplemented by prefabricated graphic auxiliary elements (cubes, red-blue line pattern). Knowing that the information brochure would contain a longer text, it was decided to use the designed typeface only for titles and poems. The rest of the text was set in the typeface MS Reference Sans Serif Regular.
In designing the other graphic products, we started from the appearance of the information brochure *(Figure 12),* which was designed first as the most complex print product.

Figure 12: Information brochure for Kosovel Memorial Room

For the design of the poster we used the same colour scheme and basic graphic elements. According to the agreement with the client, the poster format B2 (707 × 500 mm) was required. The text on the poster is presented in the same way as in the information brochure; the coloured backgrounds on which the text is placed are used. The typeface created was used for the title. An example of a poster is shown in Figure 13.

Figure 13: Promotional poster for Kosovel Memorial Room

The last graphic product designed was a leaflet (Figure 14). We used a document measuring 210 × 99 mm. The chosen size allows printing three leaflets in A4 format. We designed the leaflet following the information brochure and poster and used the same graphic elements. The first page of the leaflet shows the title in the designed typeface, the second page contains the contact information and the logo of the Kosovel Memorial Room and the Sežana People's University, which manages the cultural monument Kosovel Memorial Room.

Figure 14: Leaflet for Kosovel Memorial Room

3.3 Online survey

With the online survey we wanted to check the success of the designed information brochure and the typeface used in it. The survey was sufficiently completed by 42 people, including 22 (52%) women and 20 (48%) men. All age groups were represented, with the majority of respondents between the ages of 18 and 29. In the survey, participants rated the extent to which they agreed with the statement, giving values from 1 to 5 (1 - I disagree, and 5 - I completely agree). The questions related to various visual aspects such as colour selection, appropriateness of typeface, layout design and text arrangement, and assessed the attractiveness of the appearance of the individual pages and the information brochure as a whole.

When asked if the appearance of the overall information brochure was appealing, 14 (33%) respondents answered that they fully agreed (rating 5), 20 (48%) agreed (rating 4), and 5 (12%) respondents described the appearance of the brochure as not appealing (rating 1 or 2). 3 (7%) respondents answered hesitantly (rating 3). The detailed results are shown in Figure 15. Similar results emerged for the individual pages of the brochure.

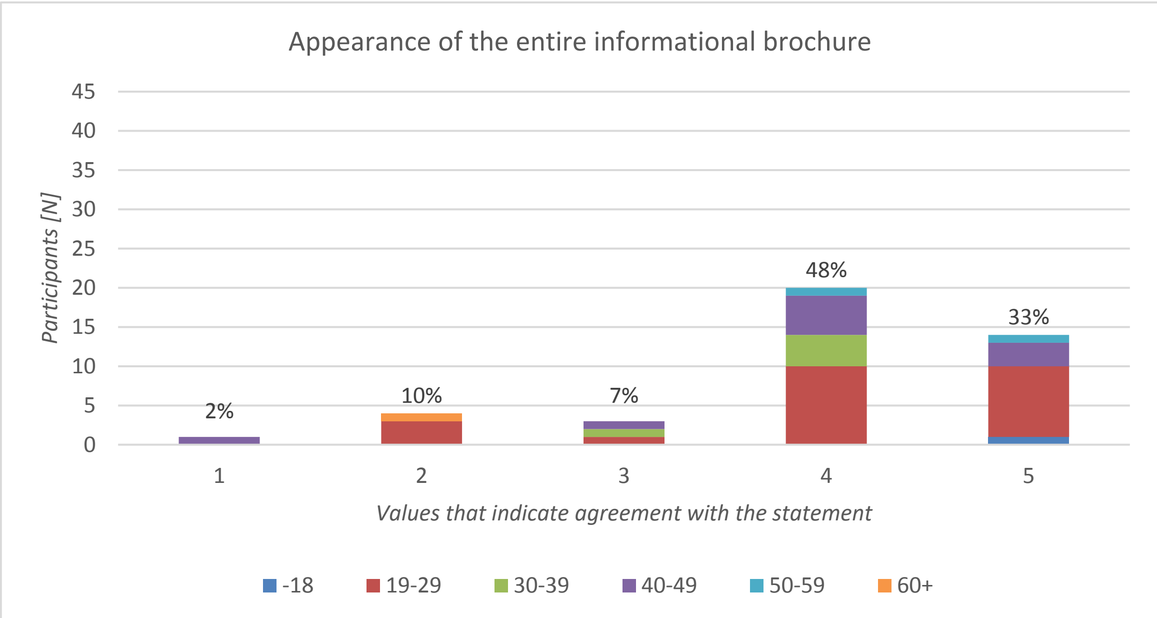

Figure 15: Diagram of responses with visible age groups to the question.
" Overall, I find the look of the entire information brochure appealing."

Regarding the appearance of the cover, we were interested in how many people were attracted to reading it. 7 (16%) respondents said they were very attracted (rating 5), and 20 (48%) said they were attracted (rating 4). 12 (29%) responded hesitantly (rating 3), 1 (2%) respondent described the cover as unattractive (rating 2), and 2 (5%) respondents rated the cover as completely unattractive (rating 1). More detailed results are shown in Figure 16.

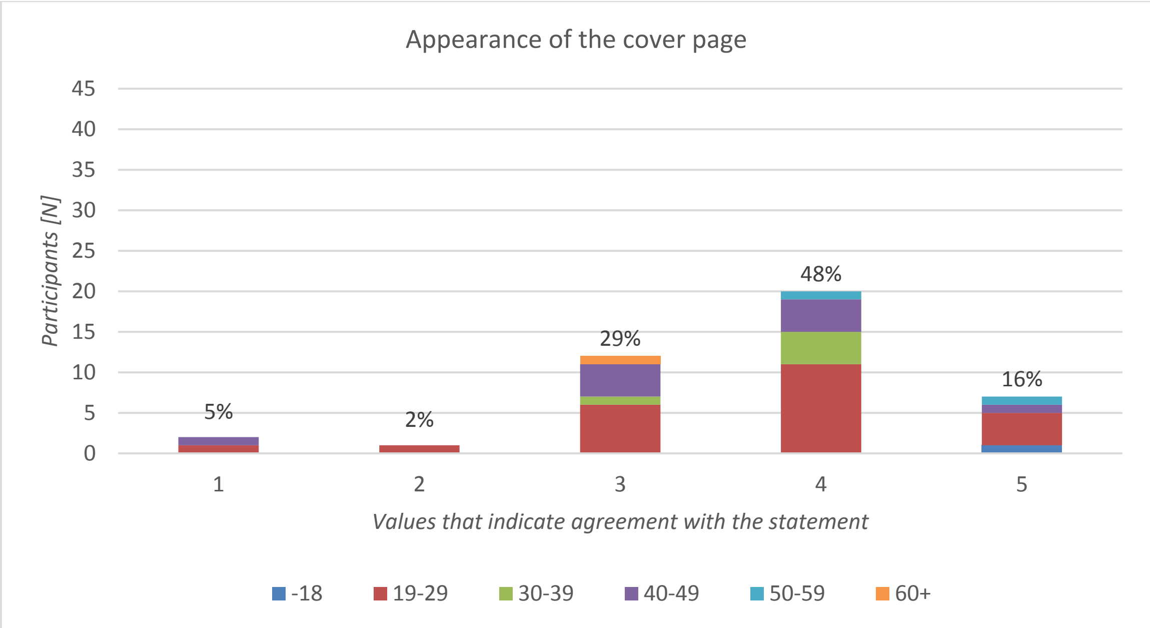

Figure 16: Representation of responses with visible age groups to the question.
" The title page attracts me to read the information brochure "

In general, respondents found the page with the photo of Srečko Kosovel (see Figure 17) the most attractive. On this page, only 3 (7%) respondents described the appearance of the page as unattractive (rating 2), 8 (19%) answered hesitantly, 19 (45%) said the page was attractive (rating 4), and 12 (29%) said the page was very attractive (rating 5).

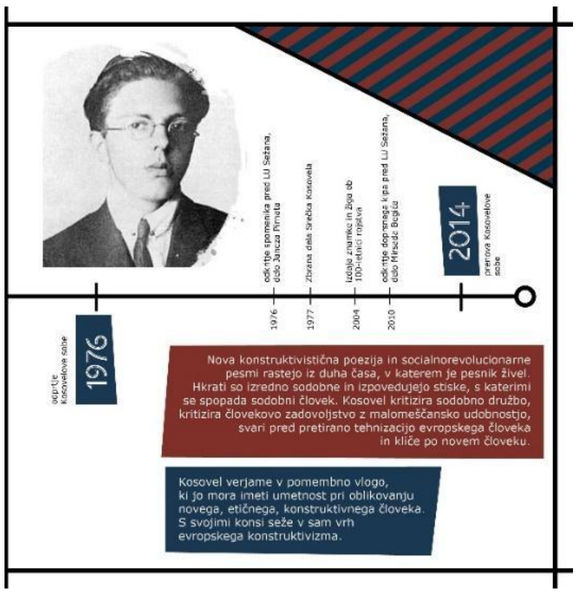

Figure 17: Best graded page from online survey

When asked if colours connect them to constructivism, 25 (60%) respondents answered "yes" (rating 4 or 5), 11 (26%) respondents answered "hesitantly" (rating 3), and 6 (14%) respondents answered "no" (rating 2). No one responded with "disagree at all" (rating 1). More detailed results are shown in Figure 18.

As many as 34 (81%) respondents confirmed that the colour contrasts are sufficiently visible, and 34 (81%) respondents answered that the colour scheme is generally appropriate.

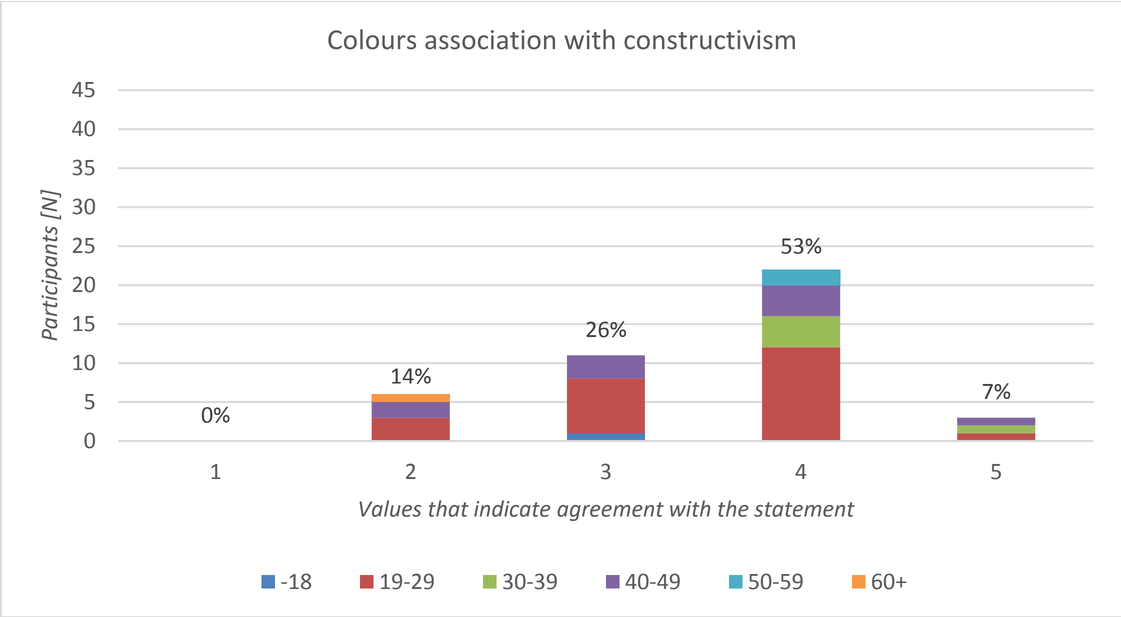

Figure 18: Representation of the answers with visible age groups to the question.
"The colours of the information brochure associate me with constructivism".

A few questions also about the Ekstaza typeface. When asked if you find the shape of the letters interesting, 15 (36%) fully agreed (rating 5), and another 25 (60%) respondents answered in the affirmative (rating 4). 2 (4%) answered hesitantly (rating 3). No one responded "disagree" (rating 2) or "disagree at all" (rating 1). More detailed results are shown in Figure 19.
27(63%) respondents also confirmed that the shape of the letters reminded them of constructivism. In the information brochure, the Ekstaza typeface is also used to present two poems by Kosovel. 35 (83%) of the respondents confirmed that they consider the choice of the typeface appropriate for presenting Kosovel's poems, 4 (10%) were undecided, 3 (7%) of the respondents disagreed with the choice of the typeface.

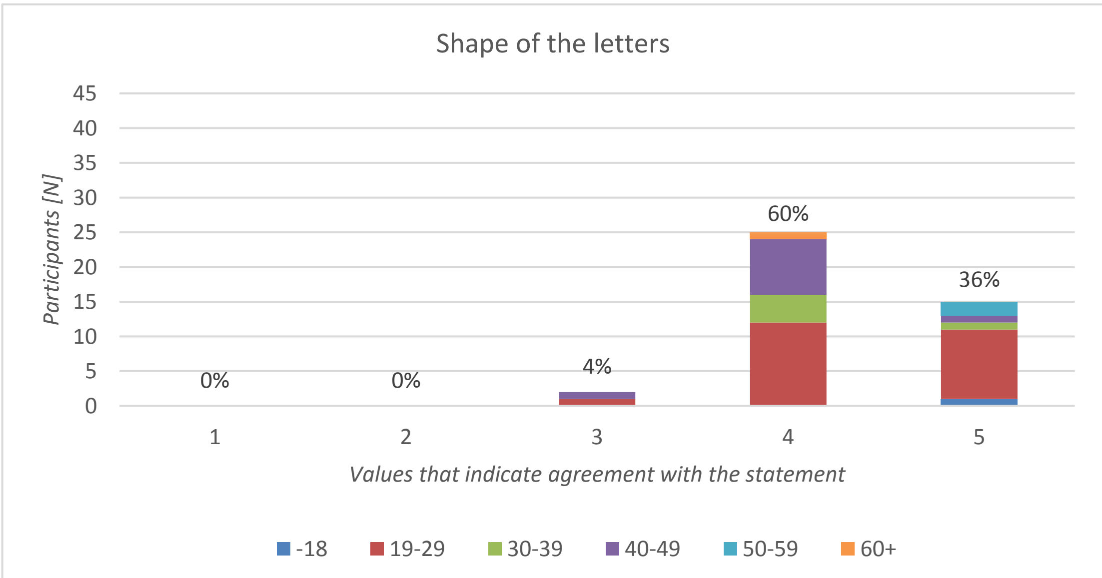

Figure 19: Representation of the answers with visible age groups to the question.
"I find the shape of the letters interesting."

In the information brochure, the text was divided into shorter sections several times and placed on different coloured areas. Most of the respondents confirmed that such a design stimulated them to read and made the appearance of the page more interesting. 8 (19%) of them answered "strongly agree"

(rating 5) and 19 (45%) answered "agree" (rating 4). 12 (29%) answered hesitantly (rating 3), 2 (5%) disagreed, and 1 (2%) disagreed at all. More detailed results are shown in Figure 20.
Most respondents also had no difficulty identifying how the different text boxes followed one another. In general, they felt that the elements in the brochure were arranged in a way that made sense. 39 (92%) confirmed that the contact information was placed in a highly visible location.

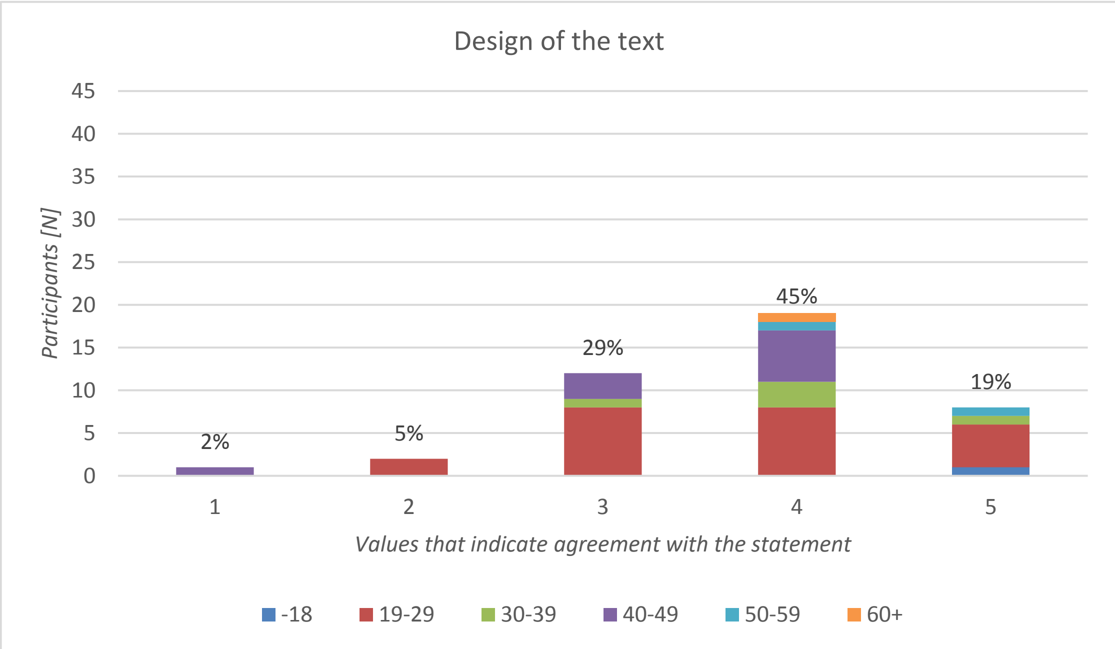

Figure 20: Representation of the answers with visible age groups to the question.
"The layout of the text, divided into shorter sections, encourages me to read the text"

4. DISCUSSION

Ekstaza typeface was named after one of the most famous songs from Srečko Kosovel rich oeuvre. The typeface is suitable for use in larger formats, especially for titles, conditionally also for shorter texts to be displayed in larger formats. It can be defined as a decorative typeface, according to its characteristics it can partially belong to the group of linear typefaces, as it has no serifs and differences in stroke width.
The base stroke consists of two lines, which are in a ratio of 5:2 for the lowercase letters; for the uppercase letters, the ratio is slightly different due to the thickness of the strokes, which are wider, and we had to make sure visually that the uppercase and lowercase letters look as equal as possible.
There is a blank space between the lines used as the basic element. There is also a blank space between the individual strokes of the letters, as they are not completely connected in the letter design. This feature is visible in almost all letters, especially noticeable in letters with round strokes (O, Q, U, o). In the case of a spine (letter s), the feature is particularly noticeable because the two parts of the letter are not perfectly aligned. In the case of the round stroke, we based our design on the shape of a perfect circle, which we adapted in the manufacturing process to give the font a more constructive look. Characteristic of our typeface is that the inclined strokes, with the exception of the letter X, are curved rather than straight. For this reason, we have adapted the letters A, V and W so that they are not symmetrical and consist of a vertical stroke and a rounded stroke.
Similar curved strokes are also found in the uppercase letters K, M, N, R, X, Y, Z, and Ž, and in the lowercase letters k, v, w, x, y, z, and ž. The typeface is characterized by open ends of round strokes, which can be seen mainly in the uppercase letters C, Č, Ć, G, S, Š, and in the lowercase letters c, č, e, f, g, r, s, š, and t. To emphasize the type form even more, we have used some design features on individual letters. The uppercase letter J is below the baseline, the curved strokes of the uppercase letter M do not reach the baseline, the letter X has a special asymmetrical shape, the letter Y is cup-shaped, and we also decided to make the lowercase letters a and g monocular.

The typeface was used for headlines and larger text in a new information brochure, poster, and leaflet for the Kosovel Memorial Room in Sežana. We conducted a survey to review the design of the brochure and find out what the opinion is about the typeface we designed that is part of the information brochure.

5. CONCLUSIONS

The aim of the project was to design a display typeface and use it in renovated graphic products for the Kosovel Memorial Room in Sežana. The typeface should be associated with constructivism and Srečko Kosovel, which we confirmed in the survey, where the appearance of the typeface seemed interesting to the respondents and they associated it with the period of constructivism. This confirms its otherness and semantic value, characteristic of display typefaces.

The survey also confirmed that the typeface is suitable for headlines and shorter texts, which confirms the purpose of using the display typeface. The client, with whom we cooperated at all stages of the project, was satisfied with all graphic products, especially the information brochure. The brochure is used as promotional material at the Kosovel Memorial Room in Sežana from February 2022. In this way, the project directly contributed to the promotion of Slovenian culture and the heritage of Srečko Kosovel.

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https://doi.org/10.24867/GRID-2022-p92 Original scientific paper

LEGIBILITY OF TYPEFACES AND PREFERENCES OF TEXT/BACKGROUND COLOR VARIATIONS IN VIRTUAL ENVIRONMENT

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Abstract: *Text legibility is an important and influential aspect of multimedia, not only on usual multimedia reading devices (displays, tablets, and mobile phones) but also in three-dimensional virtual environments (VE). In VEs, text can be used for many purposes in accordance with the category of experience (gaming, architectural visualization, exhibition, education). Font type used can deteriorate the VE experience if the user has to strain his eyes so that he may correctly read what has been written. The purpose of this research is to examine different fonts in order to determine which properties of a typeface are more suitable for VE. Four different fonts have been tested in 10 font sizes at three viewing distances (5, 10, and 15 meters). Times New Roman as a representative of serif fonts, Helvetica as a non-serif font, Caveat as a representative of handwritten fonts, and Roboto as a font for digital use, initially developed for the Android operating system. Different typographic characteristics of fonts significantly affect readability in VE. Additionally, was explored how the color of the text and the background color influence text readability in 20 combinations. It is known that the relationship between text color and background color affects readability. Since VR is a relatively new medium, we wanted to determine which relationship between colors of text and background is the best and whether it follows some rules present on the web. The colors of the text were black and white, and the colors of the background were black, white and gray, red, green, pastel green, blue, pastel blue, yellow, pastel orange, and pastel pink. Results regarding text color/background color have shown that most participants preferred black text on white background, black text on a gray background, and white text on a pastel orange background. On the contrary, participants rated white text on a yellow background as the least preferable combination, accompanied by white text on a pastel green background.*

Key words: virtual reality, virtual environment, typography, text legibility

1. INTRODUCTION

Text readability and legibility are terms that are often misused and used interchangeably when discussing typography, and for a better understanding of this research, definitions are provided. As Tefki stated in his paper, "*text readability studies are concerned that a given piece of writing reaches and affects its audience in the way that the author intends*" and text legibility encompasses many factors in typography that may affect ease and accuracy of reading, such as typeface, font size, weight, lower/upper cases and changes in spacing (Tefki, 1987). Other definitions state that the meaning of readability is "*how easy written materials can be read and understood*" and that efficient readability is dependent on good legibility (visual properties of the character) of the text (DuBay, 2004; Zamanian & Heydari, 2012; Zuffi et al., 2007). There are many research papers investigating formerly explained terms, and in their paper, Arditi and Cho give a comprehensive list of conducted studies and report their study of legibility where they tested nine different fonts (presented both on computer and paper) and concluded that (on relatively small sample size – 4 participants) no differences of legibility was found between typefaces that differ only in the presence or absence of serifs (Arditi & Cho, 2005). When comparing readability and legibility on paper versus iPad, research results showed that Sans serif Gotham font is more readable and legible on iPad than Minion Pro serif font (Čerepinko et al., 2017). Beside of aforementioned research on text legibility made on classic paper, digital screens, or tablets, a newer media comes into the digital era: virtual reality (VR). VR devices made a comeback in recent years, with improved technical specifications that allow users to experience high resolution stereoscopic content on a relatively light head mounted device. There are many aspects of VR application design to consider, but this paper focuses on typography. Kojić et al. (2020) in their paper compare two VR devices and three text samples in Arial font (short – 2 words, medium – 21 words, and large – 51 words), manipulate font size from 5 – 40 pt and distance of text from 0 mm – 10000 mm. They found significant differences regarding angular size depending on displayed text length. They found no differences regarding VR devices. Also, they tested the contrast ratio between text and background color and the results show that text settings are not significantly different for different text lengths or devices, but in all conditions are at least 7:1, and they had some very high contrast results

(Kojic et al., 2020). Dingler et al. (2018), besides optimal angular size, investigated UI parameters (dark/light background color, serif/sans-serif font and vertical position of the view box). Their results show that angular size of the text should be 41 ± 14 DMMs (DMM – distance independent millimeter is a unit presented by Google in 2017, and it represents unit where 1 dmm as 1mm height at 1m viewing distance). Participants preferred white text on black background (Dingler et al., 2018; Hinojosa, 2018). Another study conducted in 2016 investigated which visual properties a typeface should have, so that the user can better estimate the distance in VR. They used Arial font in three different styles (colored flat text, colored embossed text, and transparent embossed text in wireframe). Results show that two-dimensional and flat text performed better than the other two tested text samples (Vairinhos et al., 2016). Text is not only to be read in VR but also can be written in a form of input. Bowman et al., have in 2002 compared four text input techniques (one of the text input techniques authors developed themselves and named "The Pinch keyboard") but conclude in results that more research is needed to determine which text input technique is optimal for virtual environment (Bowman et al., 2002). Art is also being made with typography, as shown in examples given about experimental typography in VR (Banu Dur, 2021; Niyazi, 2019).

2. METHODOLOGY

This research aims to determine how different fonts impact legibility in a virtual environment, at different viewing distances. Thus, four different typefaces have been chosen as representatives: Times New Roman – serif font, Helvetica – sans serif font, Caveat – handwritten font, and Roboto – font for digital use. Figure 1 below depicts selected fonts.

Figure 1: Selected fonts for virtual reality

After the selection of the fonts, a scene for virtual reality was created in the Unreal Engine 4 (UE4) application. The scene was designed in such a way that it accommodates all four fonts, each in a separate compartment with an additional compartment for testing background-color text-color influence. Also, to equalize the movement on the scene while testing different distances of font readability, each reading distance (5 m, 10 m, 15 m) was key bound to a keyboard number or letter. For example, Times New Roman distance of 5 m was bound to keyboard number 1 (one), a distance of 10 m to keyboard number 2 (two), and a 15 m distance to keyboard number 3 (three). Following the same manner, the other three fonts' distances were bound to different keyboard numbers/letters. This was programmed in order to equalize the standing position for reading for all participants, to avoid participants being able to freely move around and accidentally stand nearer or further away from the text panel. That means that the experimenter clicks a number (or a letter) on a keyboard, and the participant is placed on that location in VR without having to navigate around and search for a position to stand. Figure 2 depicts a part of the VR scene for testing font legibility.

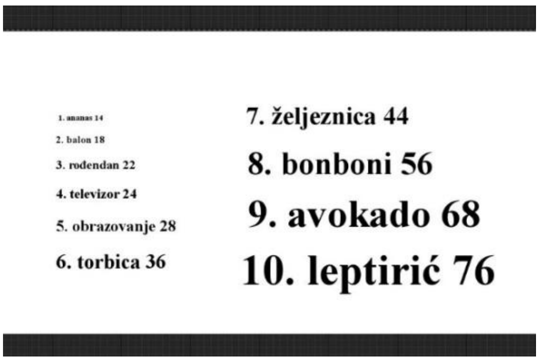

Figure 2: Example screenshot of a testing panel in VR – Times New Roman font

As mentioned earlier in text and depicted in Figure 2, each font tested had its own compartment for testing the legibility, the testing area. The participant standing in the testing area is frontally looking at the panel in front of him. On the panel, the participant sees ten words in different font sizes (14 pt, 18 pt, 22 pt, 24 pt, 28 pt, 36 pt, 44 pt, 56 pt, 68 pt, and 72 pt) firstly on 5 m distance, followed by 10 m distance and finally at 15 m distance. All words were written in the Croatian language. The participant is seeing the same ten words on all three distances, but the used words are different for different fonts tested. The participant is asked to determine which font size is the least comfortable for reading and which one is the most comfortable for reading (at every viewing distance). Finally, the participant is placed in front of the fifth panel, at 15 meters standing distance, to investigate how the background color and text color influence text legibility in 20 combinations. Combinations were as follows; black or white text color on black, white, gray, red, green, pastel green, blue, pastel blue, yellow, pastel orange, and pastel pink background color. Figure 3 depicts tested color combinations in the VR scene. For every color combination, participants were asked to determine visual recognizability, i.e., which color combination suits them better for reading in a virtual environment. Finally, participants were asked to rank three combinations that they considered most favorable for reading in VR and three combinations that they considered to be least favorable for reading in VR.

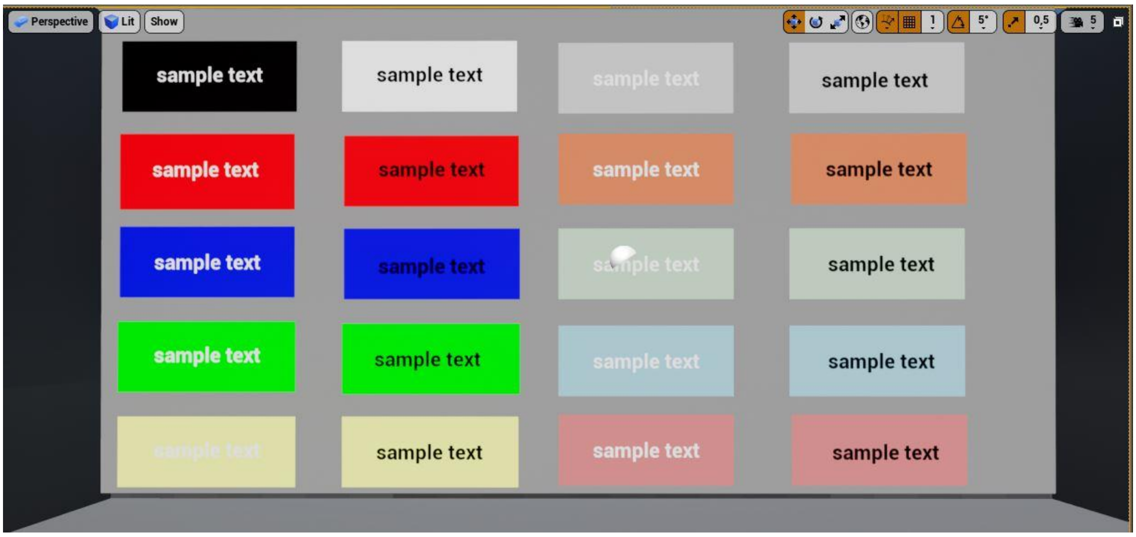

Figure 3: Example screenshot of a testing panel in VR – text color/background color combinations

2.1 Participants and equipment

Research participants were students and employees of the faculty, their participation was voluntary, and they did not receive any financial reimbursement for participation. Participants signed a written consent to agree to be in the study. They were introduced to VR headset and equipment (one at a time), and they could adjust headset settings to fit their comfort (interpupillary distance and head straps). A total of 18 participants were included, aged from 20 – 62 years (avg=29.4, SD=11.88), and in gender distribution, 11 participants were female (61%) and 7 (39%) male. Most participants had no experience with virtual reality 10 (55%) and almost half had some experience 8 (45%). No experts were among the participants. Furthermore, most of the participants' preferred reading medium is a book (11 participants), followed by a mobile phone (3 participants), a classic computer screen (2 participants), a tablet (1 participant), and an e-book (1 participant). Lastly, participants reported if they have normal or corrected eyesight (glasses/lenses); 12 (67%) have normal eyesight, and 6 (33%) have corrected eyesight. The virtual reality headset used was HTC Vive and the application was run on a Dell Alienware laptop.

3. RESULTS AND DISCUSSION

In this section, the results are divided into two parts; the first is designated to font legibility tested in VR and the second to text color and background color preferences in VR.

3.1 Font legibility test in VR results

As mentioned earlier in the text, a total of four fonts were tested for legibility at three viewing distances (5m, 10m, and 15m). A simple analysis was run to determine differences between typeface legibility preferences.

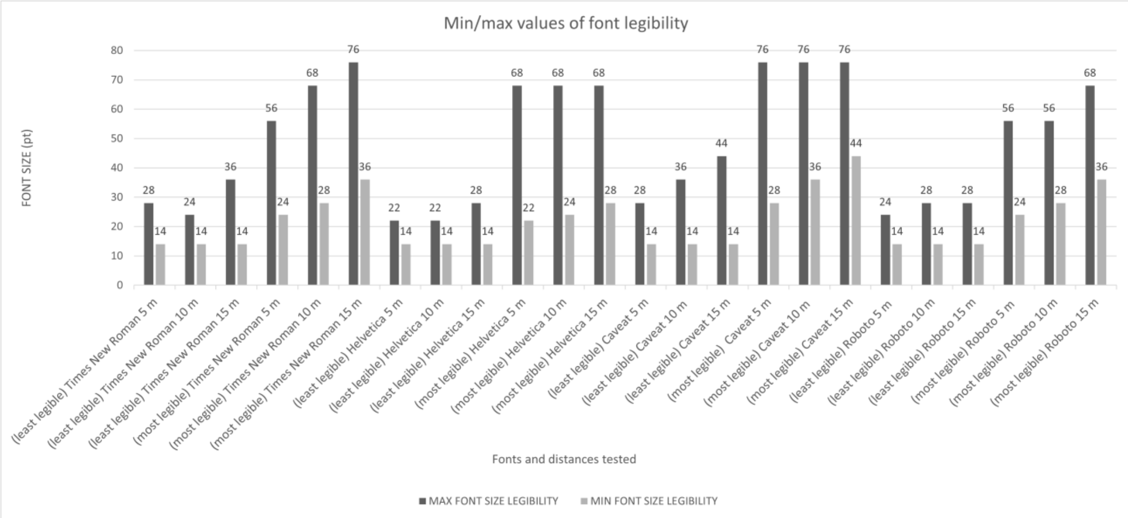

Figure 4: Minimal and maximal values of font legibility for all tested distances and fonts

From the Figure 4 the average font legibility for all tested distances can be observed. For Times New Roman, Helvetica and Roboto tested typefaces, minimal legible font size was 14 pt. For Caveat – (handwritten typeface) minimal font size legibility was 28 pt, then 36 pt and 44 pt, an obvious increase of minimal font size needed for reading in accordance with distance. In addition, a chart with calculated median values is presented in Figure 5 below, for the same data.

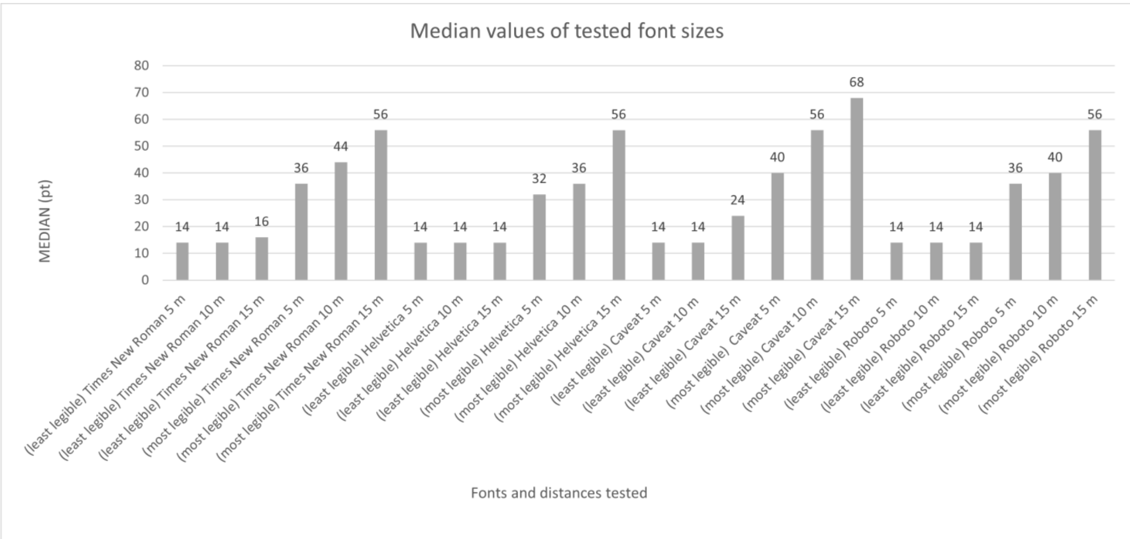

Figure 5: Median values of font legibility for all tested distances and fonts

Median values show that 14 pt font size is least legible for all 5 and 10 m viewing distances, but at 15 m an increase in size is recommended, at least in handwritten and serif typeface. For most legible font size at 15 m distance values are ranged between 56-68 pt. Higher font size is required for handwritten font.

3.2 Text color and background color preferences in VR

Figure 6 below represents results for text color and background color preferences in VR, where participants had to select between 10 color pairs of combinations. It can be observed that black text on a white background is preferred over vice versa and on several other background colors (gray, pastel blue, green, pastel green, and yellow). Other combinations like red, pastel pink, and pastel orange background do not have a predominant text color option.

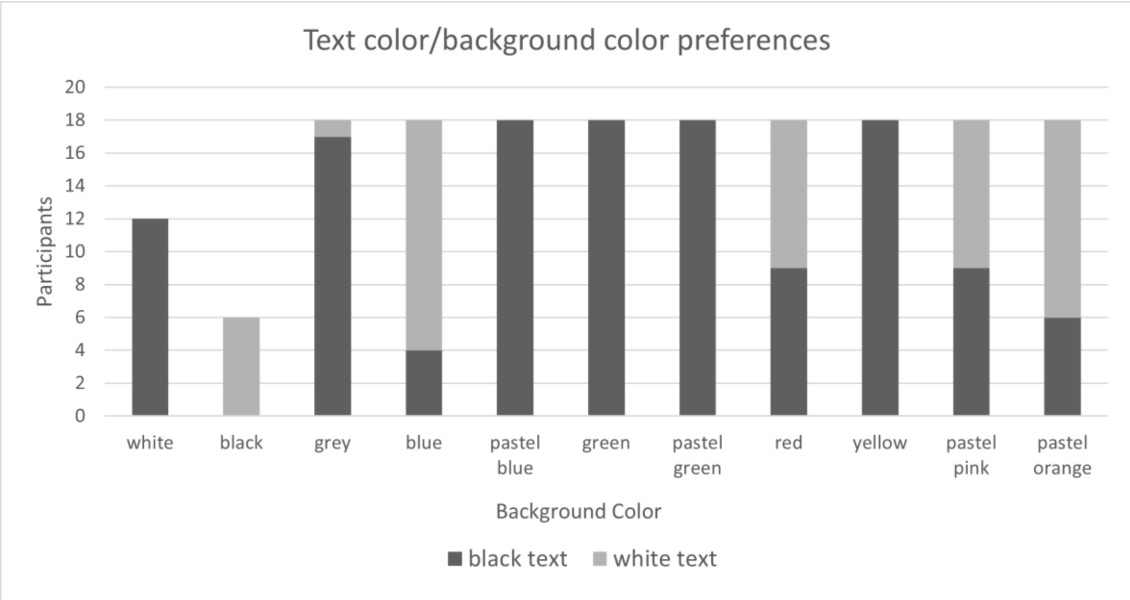

Figure 6: Text color and background color preferences in VR

The last question participants were asked was to determine three combinations that they consider most favorable for reading in VR and three combinations that they consider least favorable for reading in VR.
For better understanding of the results, one extra figure was added through simple scoring of the results. Scoring was set in such a manner that each participant ranking of the most favorable combination was multiplied by 3, second most favorable multiplied by 2 and third most favorable by 1. Least favorable rankings were issued corresponding negative scores, as shown in equation 1 below.

$$SCORE = (nt_1 \times 3) + (nt_2 \times 2) + (nt_3 \times 1) + (nb_1 \times (-3)) + (nb_2 \times (-2)) + \left(nb_3 \times (-1)\right) \qquad (1)$$

* nt_1 = number of times in top 1st position = multiplier 3
* nt_2 = number of times in top 2nd position = multiplier 2
* nt_3 = number of times in top 3rd position = multiplier 1
* nb_1 = number of times in bottom 1st position = multiplier -3
* nb_2 = number of times in bottom 2nd position = multiplier -2
* nb_3 = number of times in bottom 3rd position = multiplier -1

Figure 7 below shows results of the scoring of the most/least favorable color combinations. The highest score (top combinations) is black text on white background (which is the highest contrast), then black text on pastel blue background (lesser contrast), followed by black text on gray background (also lesser contrast). Interestingly, we can observe that top four highest scores have combinations with black text followed by four combinations with white text on pastel (also lesser contrast). These results can be explained in such way that participants are accustomed to black text on white background, and because of high contrast. Other preferred combinations are black text on pastel blue background, black text on gray background, white text on black background, and white on pastel orange and pink (lesser contrast combinations). When observing least preferable combinations, as expected, white text on yellow background is top worst. Jimenez et al., in their research also report this result for text legibility for white text on yellow background (Jiménez et al., 2020). Among other least preferable combinations are white text on green, gray and pastel green background, and black text on blue background.
From these results recommendations can be suggested for creating and designing typographic content for VR, even though one has to take into consideration other scene design parameters, such as overall scene illumination, which has impact on general visibility in virtual environment. It may seem logical to

assume that high contrast combination is better than low contrast combination, but it can be observed that white text on pastel color background is among most and least preferable combinations.

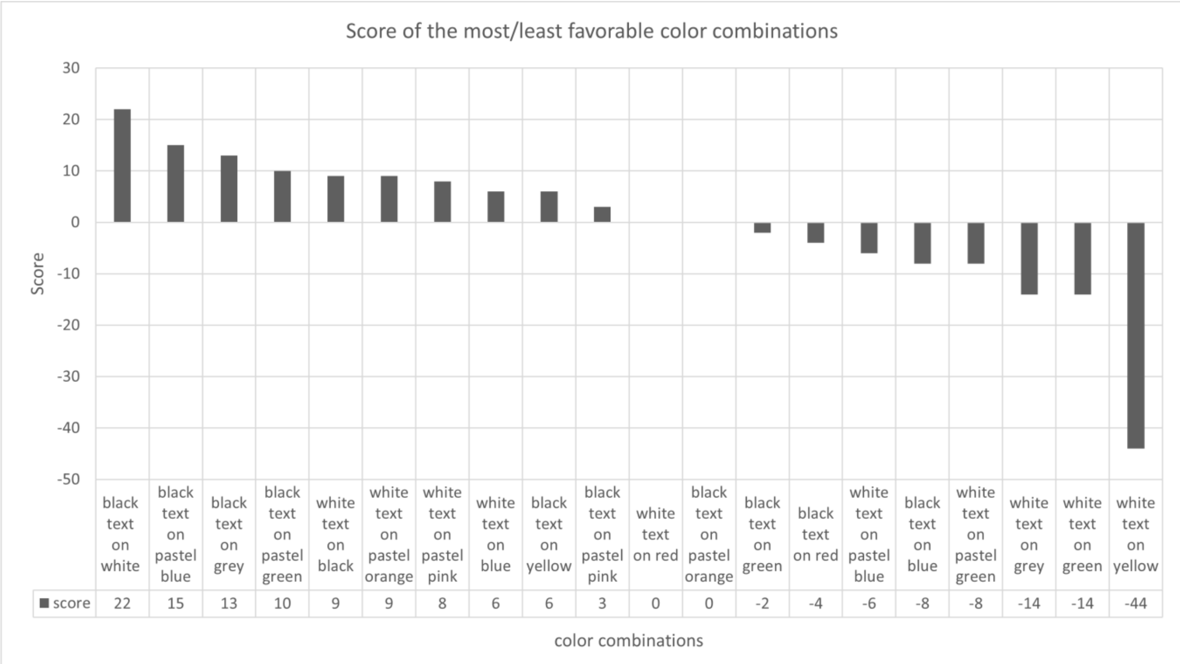

Figure 7: Scoring of the most/least favorable color combinations

4. CONCLUSIONS

This research explored some aspects of typography in VR. In a VR environment, four different typefaces were tested regarding legibility at three viewing distances (5m, 10 m, and 15m). Each typeface was distinct from another (serif, two sans-serif, and handwritten). In addition to text legibility, we tested the influence of text color and background color (also on text legibility). Median values repeat for most of the least legible typefaces (14 pt) for different typefaces. An exception is Caveat font at 15 m distance, 24 pt. For most legible font sizes at different viewing distances, an increase in font size is evident with distance. For all typefaces most legible font at 5m was between 32-40 pt, at 10m between 36-56 pt, and at 15 m 56-68 pt. A scoring formula was used for assessing the most/least favorable combinations for text and background color combinations. The highest score for the most favorable combination gained black text on white background, followed by black text on a pastel blue, gray, and pastel green background. As expected, the least favorable combination was white text on yellow background, then white text on green, gray and pastel green. Further research is needed to better understand legibility, readability, and color preferences in virtual reality, in the aspect of different illuminants or scene designs in VR.

5. ACKNOWLEDGMENTS

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RESEARCH METHODS

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A NEW METHOD FOR ANALYSING EYE-TRACKING MEASUREMENT DATA

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Abstract: *When it comes to the function of photography in graphic communication, we should be aware of many different aspects of the medium. The standard criterion for a correct and successful photograph should always be its technical and artistic aspect. If something is not right, for example, if the exposure or composition are not correct, a photo should not be used for professional purposes. The third aspect is the content or meaning, where final decisions are usually made. With this in mind, editors are usually presented with photos from which they must select those to be used in a final publication.*

Since most editorial decisions are made on the basis of content or meaning, which is usually described as communication value, some decisions also involve technical aspects, such as whether it is better to use a slightly underexposed or slightly out-of-focus photo. In these cases, the standard criteria changes because the shooting conditions did not allow the photographer to take a technically correct photo, but the content or meaning is too important not to be published.

The research focuses on measuring how the way people see different photos changes when they are not technically perfect. Using eye-tracking technology, where we can measure where a person is looking and for how long, we can get an accurate idea of what that person is seeing and the way their eyes move. This type of measurement is actually not a problem and has been successfully used in many research studies. The main question to be answered in this study was how the nature of image perception changes when the image is distorted in some way. Therefore, a new method for analysing eye-tracking data was developed. The results show that eye-tracking can be used to determine how technical aspects of photography affect the way we look at it. The final judgement that the method works was made by comparing the data with data gathered with subjective tests in which observers had to choose between different distorted images and decide which is more acceptable. The correlation between the results of new method and a subjective testing is very strong.

Key words: *eye-tracking, photography, communication value, data analysis*

1 INTRODUCTION

Photography is one of the most important communication media today (*Giannakopoulos, 2017*). It is available almost everywhere and in both conventional (printed) and modern (electronic) media. When we try to describe how good a photograph is, we often use terms like beautiful, nice, blurry, dark, and so on. All these descriptions play an important role in the communication value of a photograph and its ability to convey a message correctly or as intended. The main topic of this research is to determine the parameters that are crucial for communication success and to analyse which of these parameters has the greatest influence on the process.

The parameters that influence the quality of photography are mostly technical in nature. Researchers (*Ponomarenko et al., 2009*) have divided and described them into the following groups: Sharpness, contrast, lightness, saturation, noise, compression and resize. In research (*Mohammadi, Ebrahimi-Moghadam & Shirani, 2014; Wang & Li, 2010*) focusing on image quality assessment, researchers use various algorithms to simulate all the parameters described. Which algorithms to use and how to decide between them is mostly a decision of the researcher, but using similar algorithms used by others gives us a better way to compare results. For this reason, there are many image databases (*Winkler, 2012*) that focus on research to evaluate image quality, and this approach can also be used to analyse the communication value of photographs.

The communication value of a photograph can be described as the ability to transmit information or communicate in the intended way. These are extremely important qualities when it comes to advertising, teaching, informing, etc. The way the viewer looks at the photograph and how much time he/she spends on some elements of the photograph is the reason for the main interest of this research. The quality parameters of the photo can influence some of the crucial communication elements, and the poorer the quality of the image, the lower the communication value. Different quality parameters have different

influence on it, and measuring which ones have the most influence is the main goal of our research, for example: is it better to use desaturated or blurred photos?
Using eye-tracking technology to measure how people look at different photos was an obvious choice. This approach has been widely used to measure legibility or attention, but to determine which quality parameters influence the way we look at a photo, it has not yet been used. The most important goal of our research was therefore to develop a method for analysing the gathered data that would give us accurate information about how different distortions affect the way we look at a photo.

2 MATERIALS AND METHODS

2.1 Materials

The research was conducted using the novel image database, which was first introduced in 2017 (*Ahtik & Starešinič, 2017*). The database consists of 30 different motifs (Figure 1), which differ mainly in their complexity and variety of colours. These two aspects were decisive for developing a new database for our research rather than using one of the existing databases. The analysis of the most used database TID2008 (*Ponomarenko et al., 2009*) showed that the included photos are simply not diverse enough to conduct a study where the communication value is something we are interested in. Our database is therefore 57% more complex than TID2008 and also offers higher resolution originals (*Ahtik, Muck & Starešinič, 2017*).

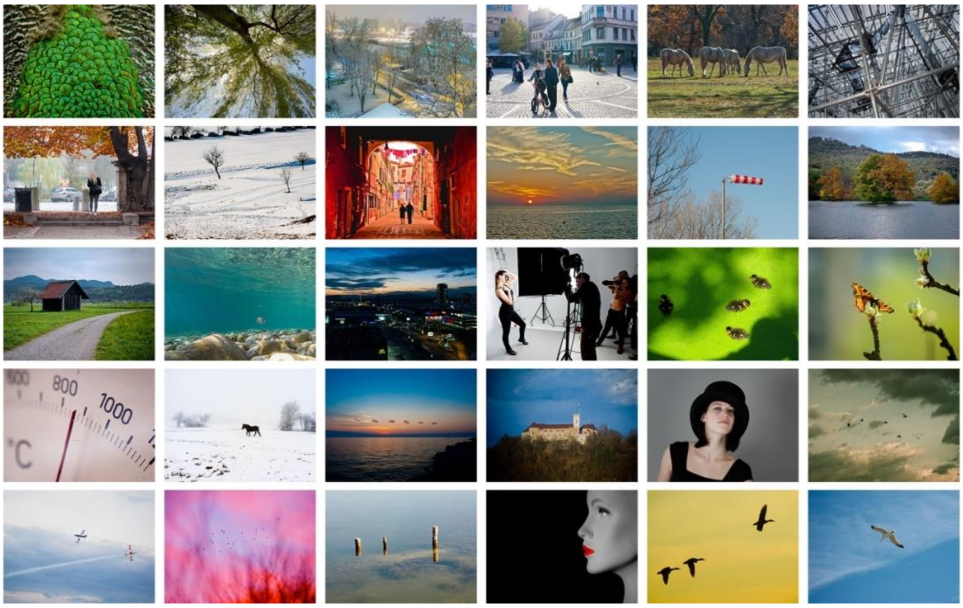


Figure 1: Reference images of novel image database used in the research

Various manipulations were then applied to the reference images, such as reducing/increasing contrast, reducing/increasing lightness, reducing/increasing sharpness, reducing saturation, compressing, adding noise and resizing. The parameters were applied in one to three steps using Mathworks Matlab R2014a. In total, we obtained 38 variations of each photo, so our database consists of 1140 photos. In this study, we used references (unmanipulated photos) and eleven manipulated photos where the manipulations are strongest (most seen). In total, 330 photos were used. Table 1 lists all the different manipulations of one of the photos used in the test - each observer saw only one of these variations.

Table 1: An example of the different manipulations on one of the photos used in the test

			
reference	resized	JPEG compression	desaturation
			
lower contrast	higher contrast	lower lightness	higher lightness
			
speckle noise	lower sharpness	higher sharpness	

2.2 Apparatus

A TOBII X120 eye-tracker, a HP ZR24W LCD screen, a PC, a controlled darkroom environment and TOBII Studio 3.4.4 software were used to perform the measurements. The room was set up according to ISO3664:2009, ISO12646:2015, ISO,9241-305:2008 and ISO9241-305:2008 standards. The photos were displayed in the centre of a black screen at a fixed resolution of 840 × 630 px so that each observer had the same viewing angle of the photos (Figure 2). Each photo was displayed for 5 seconds, followed by 2 seconds of dark screen.

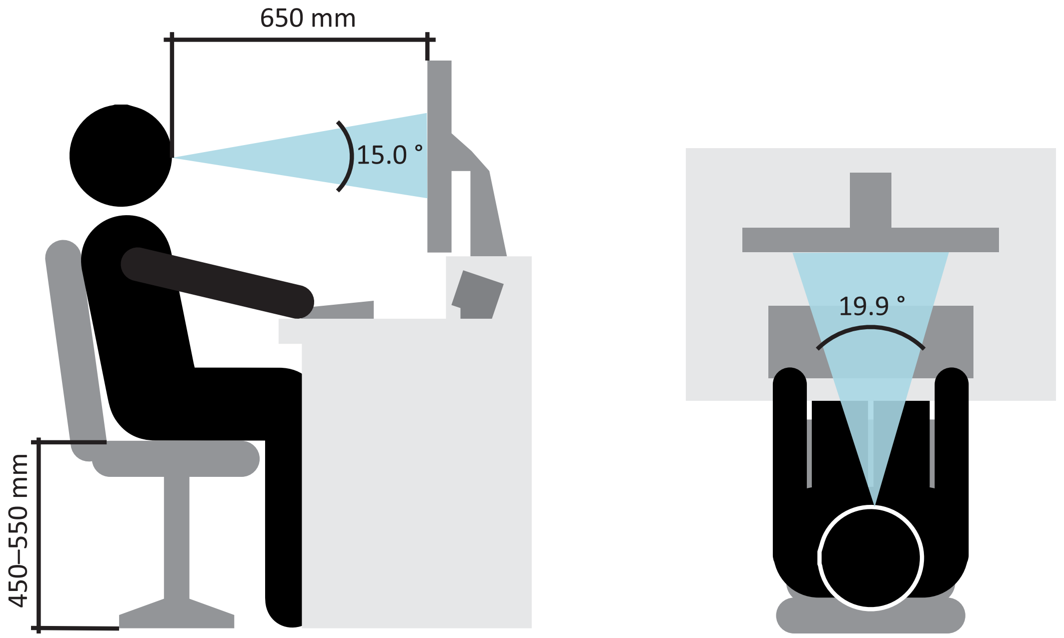


Figure 2: Eye-tracking measuring conditions.

2.3 Observers

We divided 330 photographs into 11 different tests so that each observer could see each motif only once, but with a different manipulation. One of the groups was the reference group, which looked only at unmanipulated photos. Each test included 10 participants, i.e. a total of 110 participants, 50% female and 50% male, 50% under 30 years old and 50% over 30 years old. The average age of all participants was 33.39 years, and the gender distribution was the same for all 11 tests. All participants are from Slovenia and have normal or corrected to normal vision.

2.4 Analysis

Since the TOBII Studio 3.4.4 software (*Tobii, 2016*) doesn't offer the possibility to analyse the change in the viewer's perception of different images, a new method was developed. We used TOBII Studio 3.4.4 to export duration gaze plots of each photo for all observers together. The gaze plots were exported as black circles in a transparent PNG file format. Since the aim of the research was to find out which parameter most influences the way people look at photos, regardless of the subject, all gaze plots for each parameter were combined. The end result was a cloud of gaze plots for each of the ten quality parameters and for the reference (unmanipulated) photos. Using Mathworks Matlab R2014a, we subtracted the reference cloud from each of the manipulation clouds and used the difference to obtain the result of which parameter most influenced the way the photos were viewed. For this purpose, we developed the following Matlab code:

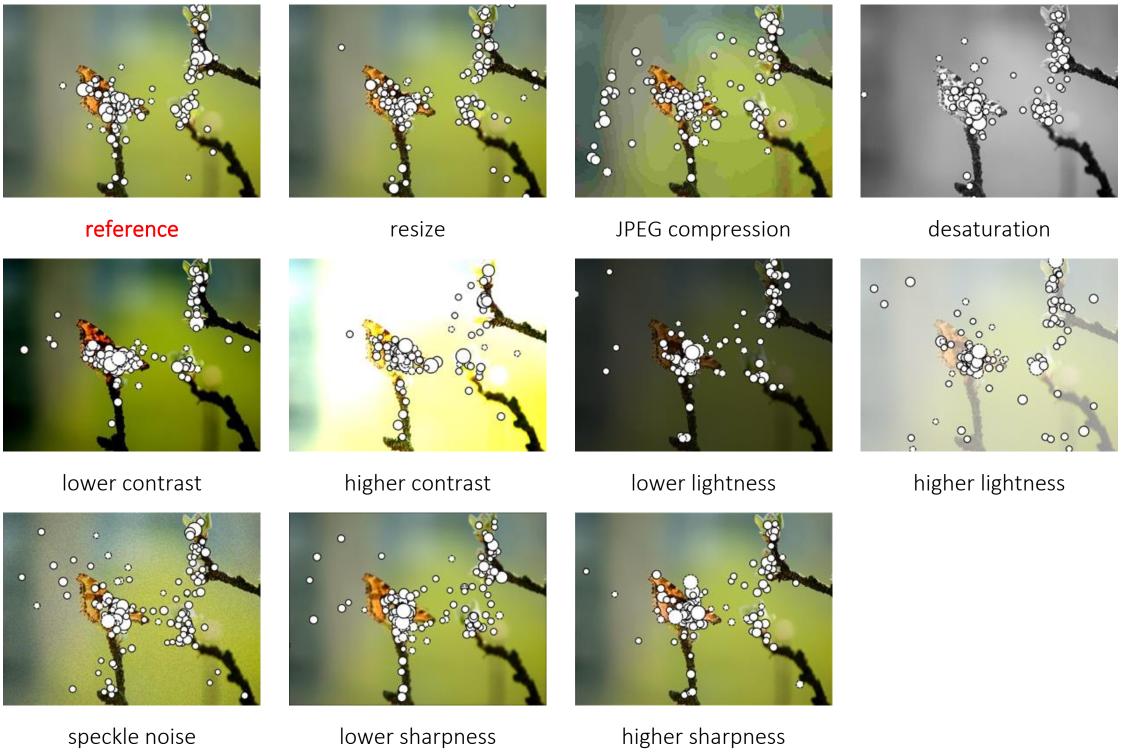
```
folder = 'folder_name';
files = dir([ folder '/*.png' ]);
fid=fopen([ folder '/result.csv'],'w');
fprintf(fid,'filename,totalPixels,fullPixels\n'); for file = files'
A = imread( [ folder '/' file.name ]);
Z = A(:,:,1) == 0 & A(:,:,2) == 0 & A(:,:,3) == 0; numTransparentPixels
= sum(sum(Z));
numAllPixels = size(A,1) * size(A,2);
numFullPixels = numAllPixels - numTransparentPixels;
fprintf(fid,'%s,',file.name); fprintf(fid,'%d,',numAllPixels);
fprintf(fid,'%d\n',numFullPixels);
end
fclose(fid);
```

3 RESULTS

The TOBII Studi software offers many ways to export measurement data. When we tried to find the most suitable way, we quickly realised that there is no direct way to find out, how observers look at some photos differently from others. Since our research hypothesis was that the greater the change in viewing, the greater the impact of the distortion on the communication value of the photo, it was crucial to determine how the way viewers viewed the photo changed as a function of the distortion.

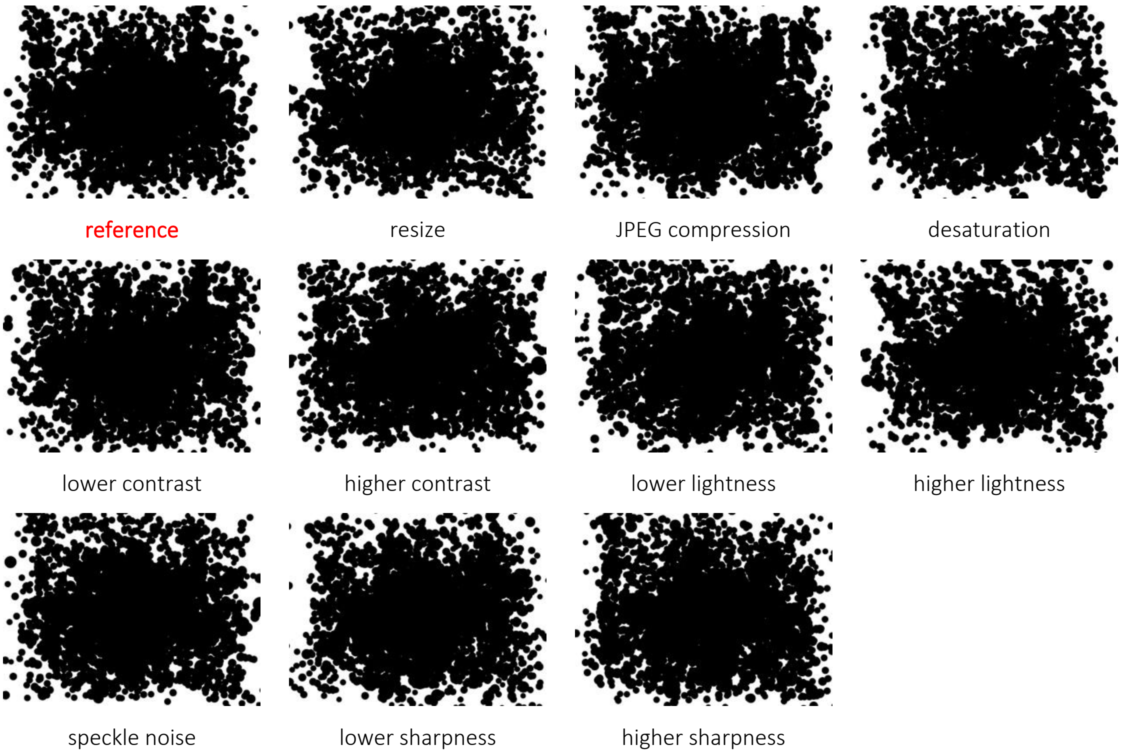
When visualising the data collected, there is a way to display the data in the form of fixation points or duration gaze plots, where the spots where the gaze stopped are shown in a form of a circle. The larger the circle, the longer the fixation of the eye was at that point. Table 2 clearly shows the difference in the collected fixation points of all observers at different distortions of the same image. The same data was exported for all 330 photos analysed. If we look at the "circle cloud" that appears on each photo after the export, we can see that there are already some quickly recognisable differences between differently distorted/manipulated photos. For example, the compressed photo offers much more data that appears in the form of posterisation in the background, and these details attracted many more views than in the reference photo.

Table 2: Duration gaze plot of all the different manipulations on one of the photos used in the test



It was not the aim of this research to determine the exact data for each of the photographs in the novel image database. The most important variable was the way in which the photos were distorted/manipulated. The novel image database consists of very different photos (Figure 1) that were carefully selected based on their detail complexity and colour variety. In this way, all the data collected for each photo was based on the distortion (Table 3).

Table 3: Combined gaze duration representation of all different manipulations on all photos used in the test.



The total coverage area of each duration gaze plot cloud represents the area observed by all 110 observers when observing the respective distortion on each photographic motif used. The more the total area deviates from the reference cloud, the more the way the observers perceived the distorted image has changed and the greater the influence of a distortion – in a negative sense, of course. This is where our developed Matlab programme (subsection 2.4) came into play as we counted all the black pixels on each of the exported clouds shown in Table 2. The calculation of the percentage by which the total area changed compared to the reference image is shown in Figure 3.

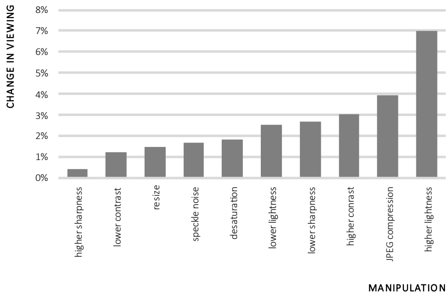


Figure 3: Change in viewing for each manipulation for every tested photo

4 DISCUSSION

The main aim of the research was to determine which photo distortion or manipulation most changes the way a photo is viewed. The way the photos were selected in the novel image database allowed us not to look just at the exact subject, but also at the average of all the photos. In this way, a final conclusion could be drawn that could really show the influence of different distortions on the communication value of photographs.

The manipulations analysed were selected on the basis of the practical use of photography in the real examples. Since photographic equipment, conditions and reproduction techniques often result in distorted photographs, where in many cases editors have to choose the best from the worst for publication, it is important to know what kind of distortion most changes the way we look at photographs. Sharpness, contrast, noise, lightness, compression and resize distortion were chosen in the end as these are the most common photographic errors we deal with. The data presented in Figure 3 shows us that increasing sharpness has the least impact on the viewing of the photographs (only 0.4% change). The result is predictable, as increased sharpness does not have a negative impact on image quality. The result also gives us an indication that our newly developed analysis method provides correct results. Second best was the lower contrast (1.2% change) and third best was the resizing effect (1.5% change). The result of the resize effect is somewhat surprising, as the artefacts that occur after resizing the photo to a larger format are clearly visible to the naked eye. We concluded that the reason for this lies in the observation conditions under which we tracked the eye movement. The observers were not looking at the photos on the full screen, but in a smaller format (Figure 2), and therefore the effect did not have as big an impact as it should. The second worst distortion is speckle noise (1.7% change), followed by desaturation (1.8% change). We see that the influence of colour is not that important for the communication value of photos, as we mainly perceive shapes and details. Lower lightness changed the way observers looked at the photos by 2.5%, lower sharpness by 2.7% and higher contrast by 3.0%. The greatest change was measured with JPEG compression (4%) and higher lightness (7.0%). JPEG compression results in the appearance of posterization artefacts, which are clearly visible in areas that normally have smooth gradients. As this posterization appears as details, it is very predictable that the change in viewing will be higher as the artefacts attract the viewer's eyes. The absolute worst result was measured at a higher lightness where the difference between subjects/objects and background is no longer as clear and seems to fade.

Almost all of the results are not surprising despite the effect of the size change and give the newly developed analysis method a solid foundation that can be used for further use cases.

5 CONCLUSIONS

Despite the fact that eye-tracking is a well-developed method, there are still many new ways in which we can analyse the collected data. TOBII Studio offers many different data exports, and the way we use them determines the form we want to interpret the final results. Since eye-tracking is mainly used to measure user experience, readability, the effectiveness of graphic design or the positioning of packaging on retail shelves, photography is not usually one of the most commonly analysed data formats. Therefore, there is much more room and opportunity to develop new methods.

As our research shows, we have succeeded in developing a method to analyse the data export of duration gaze plots in a way that provides usable and easy-to-understand results, not only in science but also in the real world, e.g. in advertising. Having a way to determine which distortion of a photo is more appropriate for publication can be critical to successful transfer of message. In use cases such as news, education or even printed publications, it is important to be able to decide which photo can better convey the desired message. Ultimately, successful communication with the target audience is the main goal of marketing and therefore the main goal of many industries. And as photography has become and continues to become an increasingly important communication medium, the need to understand its effectiveness is stronger than ever.

As we have successfully proven that the newly developed method works, we propose to integrate it into analysis software, such as TOBII Studio. A solution that works "at the push of a button" would bring the technology closer to industry, not just science.

6 ACKNOWLEDGEMENTS

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THE IMPORTANCE OF DATA ANALYSIS IN THE MODERN ERA OF PRINT PRODUCTION

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Abstract: *As the role of digital transformation becomes multi-fold in every sector, it generates huge amounts of information that can yield valuable insights at all fields of business and production activity. This has led to an expansion regarding the necessity of data handing and processing.*
Industry 4.0 is the current trend on automation and data exchange in manufacturing technologies. The elements that are included in Industry 4.0 create the so-called "smart factory" concept which indicates the direction towards the total transformation processes for all industries.
Data analytics, following data collection, storage and handling, has become a crucial component of any business management system as an integral tool for creating strategies in all major organizations. The printing industry -of course- is not an exception to this rule. Analytic tools are embedded in all major MIS (Management Information Systems) and data are collected throughout the production from prepress to postpress departments.
The present paper investigates the structure and formation of data from print management and production and the way that these can be used for providing actual and accurate information for the total business operation of a printing company.

Key words: printing industry, digital transformation, smart printshop, industry 4.0, data analytics, business intelligence

1. INTRODUCTION

The importance of data analytics in any sector is compounded, creating enormous quantities of knowledge that can provide useful insights. And these insights are needed for further production and growth. According to many, digital transformation is not just a current trend for all businesses. It is a survival issue. The pandemic period made clear a fact that was also known before COVID-19: each organization needs to have the ability to adapt quickly to supply chain disruptions, time to market pressures and rapidly changing customer expectations. For all these critical facts and company decisions, one must take consideration of all data analytics (The Enterprisers Project, 2016).
Data analytics applies generally to all processes and resources necessary for the collection and analysis of critical data. For all businesses to achieve a strategic edge, data analytics play a vital role for three main purposes:

- Product Development: data analytics offer estimation and exploration capability for information and provide a good understanding of the market or current state, while offering a solid base for forecasting future results.
- Target Content: for improving consumer orientation in campaigns, figure out which client case group responds to the initiative and thus increases the overall performance of the marketing activities.
- Efficiency in Operations: data analytics helps find more viable ways to streamline operations, recognize possible issues and act on them (Ohri, 2020).

In order to improve any operation, relevant data needs to be collected, either from the production itself or where else is needed. Organizations usually gather data from employees, companies, industry, and realistic expertise.
The first step is to determine the data requirements or how the data is grouped. The second step in data analytics is the process of collecting it. This can be done through a variety of sources, nowadays with

numerous IoT devices that can collect and send data in real time to a specific server or online platform. Once the data is collected, it must be organized so it can be analyzed. Usually, the software that is responsible for collecting the data also provides some out of the box insights that can be useful. There will be a use case at the end of this research.
In the printing industry, as in all other businesses, data analytics also help the optimization of the processes, so companies can help reduce costs, make better decisions and help analyze customer trends and satisfaction, which can lead to new –and better- products and services (Frankenfield, 2021). For example, data in the field of graphic arts that may be useful to be collected are ink level, ink consumption, setup per operation, idle time between operations, quality control metrics, scrap materials, warehouse information, inventory turns, printing speed of the machines, factory environmental conditions, product mean time in the warehouse, number of orders per day, availability of paper etc. With the use of data analytics, it is also possible to apply specific Artificial Intelligence (AI) algorithms so to foresee not only cost reduction and more efficient productivity, but also minimize environmental footprint by extending into a circular economy strategy.

2. INDUSTRY 4.0 AND BIG DATA

Industry 4.0 is often connected with digital transformation. And digital transformation is not only a high trend of the latest years, but the main procedure that a company needs to follow to stay competitive, grow up, survive. This is a lesson obtained from the last three years, due to COVID-19 pandemic where a high acceleration took place in adoption of digital technologies and digital transformation in all businesses and society.

2.1 Industry 4.0 and Printing Companies

According to Heidelberg (Heidelberg, 2022) just like Bill Gates and Steve Jobs, the early printers were also revolutionaries; hence nowadays printers face the challenge of revolution, with the use of digitalization of the printing industry. The last one is particularly affected for two reasons: on the one hand, printed media and material have become less important in the face of digital communication and on the other, the digital transformation is moving the goal posts when it comes to competition. The time has come to start making decisions driven from data collected and take advantage of any new business opportunities.
At the heart of industry 4.0 (Figure 1), there are themes that differentiate it from previous revolutions and highlight the main ideas surrounding it. By just naming them, these are:

- System Integration, which refers to the integration technologies that connect disparate parts of a company's slack together as well as third party solutions.
- Simulation and virtualization. Simulation is used in MIS solutions (which is widely used in graphic arts business) to compare the different production routes available and present the most cost-effective method of production. Virtualization can be used in a similar way by adding a virtual press, so the user can see how it affects the costs and help him make a purchasing decision.
- Internet of things. The most common usage in graphic arts is the warehouse, by adding RFID tags to provide read time visibility of the supplies.
- Cloud technologies have become more popular as an option to provide remote access to both employees and users.
- Autonomous robots. Although in its early stages in the graphic communication industry, there has been some adoption of machines, mostly used in the warehouse.
- Additive manufacturing: Typically, 3D printing to create working prototypes or replace parts. (Highman, 2021)

Figure 1: Themes at the heart of Industry 4.0

<u>- Big Data & Analytics</u>. Big Data refers to the analysis of extremely large and complex data sets to reveal patterns, especially (but not only) relating to human behavior. For example, in a typical offset printing company, data collection and data storage are taking place from various sources and operations, in order to enable intelligent decisions. This data can originate from:

- MIS: large amount of data, collected across the various departments including ink level, idle time between products, results from color spectrophotometer, scrap material, warehouse information, printing speed of the machines, factory environmental conditions, product mean time in the warehouse, number of orders per day, availability of paper.
- CRM/ERP systems: useful data can be analyzed to better understand a client's wants, needs and preferences and then these data can be used in marketing dept, to personalize direct mail and advertising.
- From production and operation: information about defects can be also analyzed, such as time and frequency of occurrence, fault reasoning, percentage of wasted resources, estimated financial loss etc.

Applying proper AI algorithms in the analyzed data, a company can foresee not only cost reduction and more efficient productivity, but also minimize environmental footprint. Therefore, this leads to the so called "Smart Print Factory", where all the above information is handled, allowing data to be constantly shared and analyzed through the connection of machines and production systems.
Yet, the Smart Factory is just one milestone (as Heidelberg suggests) because digitalization refers to enabling or improving processes by leveraging digital technologies and digitized data. Digitalization improves an existing business process or processes but doesn't change or transform them. That is to say, it takes a process from a human-driven event or series of events to software-driven. Digital Transformation on the other hand is really business transformation enabled by digitalization. Thus, the essence of digital transformation is the changing of business processes enabled or forced by digitalization technologies (Naik, 2020).
Concepts such as the smart print shop take a holistic approach to the value chain and demonstrate how the combined use of efficient workflows, IoT (connected machines) and data-based performance optimization can unlock potential in terms of productivity and costs. Despite that, the objectives associated with the Smart Print Shop can meet only some of the challenges of print industry digital transformation.

2.2 Data analytics / business intelligence

As a company's level of digitalization increases, huge volumes of data are generated. This is referred to as big data. If big data is to be used to control operations or to develop and monetize digital business models, the available data needs to be complete, centralized, and of a high quality. Only then does it

provide a true picture of the actual circumstances, which is in turn a prerequisite for reliable analyses and forecasts, and for efficient operational control.
However, most big data is nothing more than raw data. Only if this wealth of data is provided on a cross-company basis for data analytics solutions does it become valuable information and the driving force behind a data-driven organization. And only then can decision-makers use evaluations to react to changes quickly and confidently. The structured collection and analysis of data also creates transparency regarding purchasing processes and customer activities throughout the digital customer journey. The resulting in-depth understanding of customer behavior and expectations can be used to optimize offerings, products, and business ideas on an ongoing basis.
For printshops, transforming data into actionable intelligence can mean the difference between struggling and thriving. Maximizing the value of information requires data analytics: the process by which raw data is analyzed to reach conclusions.
In terms of Industry 4.0, data analytics focus on “what will happen” rather than “what has happened”. These problems are entitled as predictive analytics and aim at building models for forecasting future possibilities or unknown events. Data Analytics helps printshops to get actionable insights resulting in smarter decisions and better business outcomes (Jain, 2017). For this reason, data analytics is becoming a very attractive topic for almost every manufacturing firm in Industry 4.0 era.
Understanding data at a deep level is critical to building a successful printshop. Data analytics is the process by which raw data becomes usable knowledge that can be acted on (Figure 2). The Analytics applications should be present at every stage of the data pipeline to make it easier for printshops to collect and analyze data for practically any purpose. Data analytics solutions can be implemented on premises but also offered as a cloud SaaS application such as the Predictive monitoring application by Heidelberg.

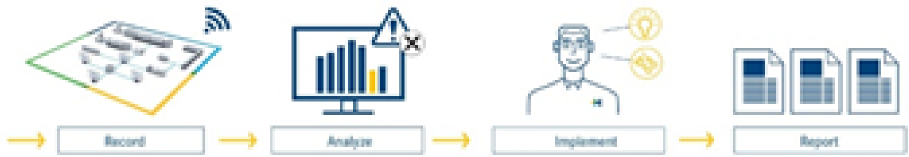

Figure 2: Data analysis process steps as proposed in the Heidelberg predictive monitoring solution. Recording - Analyzing – implementation – Reporting

While almost every organization analyzes data, modern analytics enables an unprecedented level of understanding and insight. How far has your company gone toward a data-led, analytics-driven culture—and what’s the next step? It all starts with the data pipeline (Intel, n.d.).
The data pipeline should include the following 4 stages:

- Ingestion: Data Collection
- Preparation: Data processing
- Analysis: Data modelling
- Action: Decision Making

Furthermore, Data analytics can be divided into four basic types: descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics. These are steps toward analytics maturity, with each step shortening the distance between the “analyze” and “act” phases of the data pipeline.

2.2.1 Descriptive Analytics

Descriptive analytics is used to summarize and visualize historical data. In other words, it tells the printshop what has already happened. The simplest type of analysis, descriptive analytics, can be as basic as a chart analyzing last year’s sales figures. Every analytics effort depends on a firm foundation of descriptive analytics. Many print companies still rely primarily on this form of analytics, which includes dashboards, data visualizations, and reporting tools.

2.2.2 Diagnostic Analytics

As analytics efforts mature, organizations start asking tougher questions about their historical data. Diagnostic analytics examines not just what happened, but why it happened. To perform diagnostic analytics, analysts need to be able to make detailed queries to identify trends and causations. Using diagnostic analytics, new relationships between variables may be discovered: Rising sales figures in a customer segment may correlate with a certain periodic fact. Diagnostic analytics matches data to patterns and works to explain anomalous or outlier data.

2.2.3 Predictive Analytics

While the first two types of analytics examined historical data, both predictive analytics and prescriptive analytics look to the future. Predictive analytics creates a forecast of likely outcomes based on identified trends and statistical models derived from historical data. Building a predictive analytics strategy requires model building and validation to create optimized simulations, so that business decision–makers can achieve the best outcomes. Machine learning is commonly employed for predictive analytics, training models on highly scaled data sets to generate more intelligent predictions.

2.2.4 Prescriptive Analytics

Finally, an advanced type of analytics is prescriptive analytics. With prescriptive analytics, which recommends the best solution based on predictive analytics, the evolution toward true data-driven decision-making is complete. Prescriptive analytics relies heavily on machine learning analytics and neural networks. These workloads run on high-performance computers and memory. This type of analytics requires a firm foundation based on the other three types of analytics and can be executed only by companies with a highly evolved analytics strategy that are willing to commit significant resources to the effort.

2.3 Company holistic transformation

In the future, the most successful commercial and packaging printers will be the ones who make their processes leaner and faster, who get more out of their data, and who can adapt more effectively to the needs of customers with an increasingly digital setup. All that requires new ways of thinking and working, which in turn demands an understanding of the key technologies and their potential for the printing industry.

Digital transformation and implementation of a smart printshop ecosystem based on industry 4.0 and Lean manufacturing practices is not a readymade product or a one-and-done project or just another IT initiative. To truly keep each company competitive and adaptable, it is necessary to adopt a holistic approach. As Hartl and Hess claim (Hartl & Hess, 2017), the rapid advancement of digital technologies has fundamentally changed the competitive dynamics of industries. To cope with an increasingly unstable environment and to fully leverage the opportunities opened by new technologies, organizations need to transform their businesses. As such, digital transformation initiatives are prevalent throughout industries, yet often experience failure due to inert organizational cultures preventing change.

Digital transformation differs from any other IT-enabled business transformations in its holistic nature and speed. Therefore, change is an inevitable part of every organization’s life due to our rapid global, economic, and digital developments. Change and transformation are crucial for building an organization that can thrive in the digital age. Furthermore, digital transformation requires fundamental changes in an organization, including structure, processes, strategy, and culture (Vial, 2019).

In terms of organizational changes as a part of digital transformation, small and small to medium enterprises SMEs are often, by nature, more flexible, faster, and less constrained than larger companies (Barann et al., 2019). However, their size also poses some noticeable constraints for evaluating and implementing digitalization opportunities, including potential knowledge gaps and limited resources.

The printing industry in Greece is consisted of micro, small and SME companies that face pressures resulting from rapid changes in technology and market environment. In many cases they need transformation to grow or to cope with evolving competition. They often need to transform their strategic business approaches, including implementation of new products and increasing business models efficiency. Printshops share certain qualities such as high independence, superficial structures, direct company relations and natural flexibility of action. These qualities may influence the organizational culture (Klat & Matejun, 2012). Moreover, cultural factors support or oppose digital transformation. However organizational cultures embracing people- and development-oriented values were the most supportive for successful digital transformation adaptation and implementation (Leidner & Kayworth, 2006).

3. CONCLUSION

While many printing companies have made significant progress with their digitalization efforts, smaller companies are still struggling to find and implement a workable digitalization strategy. Accordingly, the challenges they face are different, too. The task confronting those companies that are lagging behind is normally to bridge fundamental digitalization gaps by replacing outdated technology and modernizing processes that are still analog. Other businesses have been investing in the relevant technology for years but are struggling to adapt their business model, while others still, despite having the latest technology and an innovative business model, are unable to find a viable operating model.

These few examples alone demonstrate that there can be no one-size-fits-all digitalization strategy. Each company needs to find its own way based on its strengths and its goals. Often, the best way of establishing what is possible and makes sense is to bring in external experts with proven industry experience. However, it is vital to aim for a holistic strategy from the outset – even if a new or modified digital organization initially takes shape little by little and point by point, something that is strongly recommended.

If digitalization is the leveraging of the processes and information themselves, digital transformation is the sustained implementation of new business practices enabled by digitalization. Digital transformation should start with manageable projects and defined subgoals to limit the expense and the resources required. This approach removes any risk from ongoing operations, while also encouraging acceptance among management and other staff. Rather than being achieved through single ground-breaking solutions, a successful transformation is based on the orchestrated interaction of various solutions.

Another important consideration is that Lean manufacturing philosophies and continuous improvement processes first need to be implemented to unlock the full potential of digitalization. If these prerequisites are met, nothing further stands in the way of successful digitalization.

Even after 30 years of the Internet economy, do printing companies still have time to switch to systematic digitalization? Time is running out, though, because increasingly – unlike in the analog/traditional business world – the winner takes it all in the Internet economy. Anyone who fails to make the transition or delays doing so, runs the risk of becoming a victim of the digital era. For industrial settings such as the printing industry, that means the time to act is now.

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COLOR SCIENCE

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THE INFLUENCE OF THE SURROUNDING SPACE ON THE LIGHTING CONDITIONS IN A PHOTOGRAPHIC SCENE

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Abstract: *Lighting conditions are one of the most important factors for good photographic exposure. In enclosed spaces, like a photography studio, we can control the light in several ways. We can adjust the type of light source, the shape of the light source, its intensity, and in some cases the colour temperature of the emitted light. The distance of the light source from the observed photographic scene affects the amount of light that reaches the desired target, and therefore the actual lighting conditions on the photographic scene. However, the environment surrounding the photographic scene is often overlooked. The light emitted interacts not only with the objects within the photographic scene, but also with any obstacle in the path upon which a light ray falls. Light rays can be reflected, partially reflected, absorbed, or scattered from any surface in the immediate vicinity of the scene, depending on the material properties of the objects they encounter. In the case of reflection, the observed scene is additionally illuminated by the reflected light, since the reflecting surface in the near environment acts as another light source. Light-absorbing surfaces, on the other hand, do not affect the scene in the same way, since the light is absorbed and not multiplied by the reflection. Reflections from the surrounding environment can therefore affect the intended lighting conditions of the observed scene in ways that we did not anticipate.*
This study focuses on the influence of the surrounding space on the lighting conditions in an observed photographic scene by comparing the lighting situations in a scene from a photographic studio with a diverse environment and from a darkroom with minimal environmental influence. Halogen, LED, and xenon light sources are tested individually, illuminating the test scene with different intensities and colour temperatures. The illumination conditions at the observed photographic scene are described using spectrophotometric methods and image analysis to numerically describe the differences in uniform illumination of the flat scene surface. The results are analysed and compared to illustrate the influence of the surrounding space. Based on the results, guidelines for a suitable test environment in photographic research are proposed.

Key words: *photography, lighting conditions, photographic scene, light reflection, colour properties*

1. INTRODUCTION

When we think about photography, there is always one important thing to consider - light. As the word photography itself suggests, when we take pictures we are literally painting with light, so conditions are always the most important factor affecting the end result. When it comes to studio photography, there is one big advantage compared to outdoor photography: we have complete control over the photographic conditions. A typical photographic setup usually takes into account three main variables: the surrounding space, the lighting conditions and the camera exposure. Changing one of these three variables will affect the effect of the other two and change the outcome. Understanding each of these conditions is therefore crucial to being able to fully control the photographic scene.
The way we use lighting equipment in the photographic scene can vary greatly, but all uses are based on an understanding of the physics of light, such as light intensity, softness/hardness of light, correlated colour temperature (CCT) (McCamy, 1992), colour rendering index (CRI) (Davis & Ohno, 2009), type of light and also how light is emitted, reflected, absorbed, transmitted, reflected, etc (Bitlis, Janson & Allebach, 2007). Having in mind that the lightning conditions are determined not only by the light source but also by the environment, it is important to understand the environment as well.
The colour of the photographic scene is one of the factors that define the surrounding space and has a great influence on the lighting conditions because of the reflected light. The use of different coloured backgrounds can therefore be a very powerful way of defining the look of the final photographic result, and in the creative process it is very common to use very chromatic photographic surroundings. However, when we consider the need for accurate colour reproduction, the way in which light is reflected from the scene can have a major impact on the result. Reflected light can in some cases even decrease the quality of a captured image (Raskar et. al., 2008).

The typical photo studio is usually white, and different colours are achieved by using backgrounds, which are usually made of paper, textiles or by painting walls. Choosing the right background for the scene is, as mentioned, not only a matter of artistic expression, but we also need to keep in mind the quality of colour reproduction. There are different ways to deal with light in a photo studio (Gunde et. al., 2009; Hough, 2013; Štampfl, Možina & Ahtik, 2021). There are also different approaches to normalising colour reproduction in relation to the colour of the surrounding space using colour management (Ahtik, 2017), where we calculate ICC (Morris, 2005) or DNG (X-Rite, 2022) colour profiles. However, the most important research question remains how big the influence of the environment on colour reproduction actually is. Research therefore focuses on the use of different coloured scenes in combination with different light sources.

2. METHODS

2.1 Test environment and photographic scene

To test the influence of the surrounding space on the lighting conditions at the observed scene, we tested five different experimental setups, as shown in *Figure 1*, with additional variations within the first. The first four test environments were in a photographic studio, mimicking the general use of the space and arrangement of objects for photographic projects and research. In setting *(a)*, a series of 5 paper backdrops and two reflective surfaces were used in front of a white wall, in *(b)* a series of photographic light sources with light-shaping attachments were placed in the background with the front of the shaper facing the scene, in *(c)* the light-shaping attachments were facing the other direction, while in *(d)* two of the light sources were facing the wall and the other two were facing the setup. The fifth setup *(e)* was located in a darkroom whose walls were painted with low reflectance black paint. A photograph of the setup *(d)* is shown in *Figure 2*.

A black, uniform surface served as the base for the photographic scene. A *GretagMacbeth ColorChecher D*C test chart was placed in the centre of the plane. The scene was located 1 m from the background at a height of 0.8 m. The *Lupo Superpanel Dual-Color* LED light panel with a colour temperature of 5040 K was used to illuminate the scene, placed 1.5 m from the scene and aimed at the background from a height of 1.5 m. This allowed for a uniform illumination of the scene, despite having only one light source.

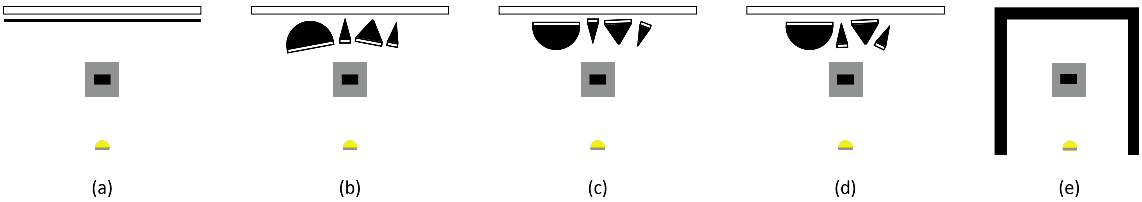

Figure 1: Test environments: (a) paper backdrops in a studio, (b) white background in a studio with white surface objects, (c) white background in a studio with mixed-colour surface objects, (d) white background in a studio with black surface objects and (e) darkroom.

Figure 2: Photo of test environment from Figure 1(d).

2.2 Data capture and analysis

A camera was placed above the centre of the test chart, which allowed us to take a photograph of a flat area of the scene. A series of photos were taken in all 11 conditions in specified test environments. We used a Nikon D850 camera with AF -S Nikkor 50mm f/1.4G lens with ISO speed set to 100, white balance set to a manual setting of 5040 K, aperture set to f/5.6 and 1/40 second exposure time. The fixed settings allowed for comparison between test environments.

All images were captured in the native Nikon raw format (NEF) and processed before final analysis. Photos were imported into *Adobe Photoshop Lightroom Classic* (version 11.2), rotated, and cropped to the original alignment marks on the *ColorChecker DC*. The images were not processed in any way and exported in JPG format in sRGB colour space, as this is a common choice for photographers.

We developed a Python programme with a set of open-source libraries, whose actions are represented with the following pseudocode:

```
import images
read RGB values of all patches on all images
import measured RGB values of all patches
convert all RGB values to CIE XYZ
convert CIE XYZ to CIE Lab
calculate colour differences dE00 for test images and imported colour values
calculate colour differences dE00 for test images and darkroom image
convert CIE XYZ to CIE Luv
convert CIE Luv to CIE LCHuv
get average differences for each component in CIE LCHuv
plot results
```

All colour transformations were performed using the built-in functions of the open-source *colour* library (Colour Developers, 2022). For colour conversion from RGB values to CIE XYZ, a conversion matrix was used that takes into account CIE xy chromaticity coordinates of a reference light source and Bradford chromatic adaptation. The conversion matrix is shown in Equation 1 (Lindbloom, 2022).

$$RGB\_to\_XYZ = \begin{matrix}[[0.4360747, 0.3850649, 0.1430804], \\ [0.2225045, 0.7168786, 0.0606169], \\ [0.0139322, 0.0971045, 0.7141733]]\end{matrix} \quad (1)$$

No additional parameters were required to convert CIE XYZ to CIE Lab, CIE Luv and CIE LCH_{uv}. The CIE Lab values were needed for the calculation of colour differences, while CIE Luv was necessary for CIE LCH_{uv} calculations. The colour differences were calculated according to the Delta E (CIE 2000):

$$\Delta E_{00} = \sqrt{(\Delta L'/(K_L S_L))^2 + (\Delta C'/(K_C S_C))^2 + (\Delta H'(K_H S_H))^2 + R_T (\Delta C'/(K_C S_C)) (\Delta H'/(K_H S_H))} \quad (2)$$

where *$\Delta L'$, $\Delta C'$, and $\Delta H'$* are differences of the two observed colours for lightness, chroma and hue, S_L, S_C, and S_H are compensations for lightness, chroma and hue, k_l, k_c, and k_h are parametric weighting factors set to unity ($k_l = k_c = k_h = 1$), and R_T is a hue rotation term.

The colour differences were calculated twice. First, we calculated ΔE_{00} for test images and measured the colour values of the patches, and then we used the image of a test chart taken in the darkroom as a reference image and compared images from other environments with it. We chose to use this correlation in the second part of the study because the objective of this study is not only to evaluate the influence of the surrounding space on the lighting conditions of the photographic scene and to determine the appropriate variations of the environment to achieve optimal results, but also to evaluate our laboratory conditions, i.e., the darkroom, in comparison with other possibilities.

2.3 Colour properties

Since it was expected that the major surfaces in the test environments would affect the lighting conditions in the observed scene, their colour properties were described.

We measured the degree of reflected light from the black wall in the darkroom, five coloured backgrounds, two reflective surfaces, and both sides of the light-shaping attachments (front and back) using a *Zehnter Gloss ZGM 1022* glossmeter at an angle of 75°, as this is the standard angle for paper materials. Three measurements were taken for each material, changing position and material orientation to eliminate the influence of fibre direction where appropriate. The results for surface reflectance are shown in *Figure 3*.

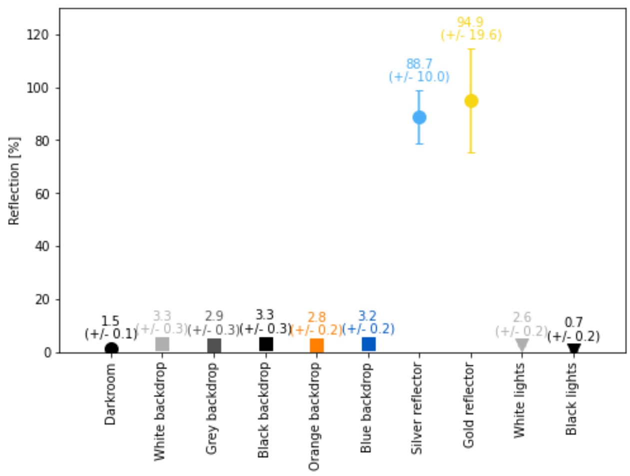

Figure 3: Surface reflection of key materials in the scenes.

We measured the CIE XYZ values of these key surfaces using the *X-Rite i1 Pro* spectrophotometer in reflectance mode and *Argyll* software and plotted them in *Figure 4* in CIE xyY colour space. Each colour patch on the *ColorChecker DC* was measured using the Argyll *spotread* function, returning CIE XYZ values. To determine the colour characteristics of the observed scene, we used the *X-Rite i1 Pro* in emission mode. The spectrophotometer was placed in the centre of the *ColorChecker DC* test chart with the measurement head pointed at a grey ceiling and not directly at the light source or reflective surfaces. Light source emission was measured with the same setting, while the instrument was directed into the light source. All measured CIE xyY values are shown in *Figure 4*, along with spectral power distribution plot.

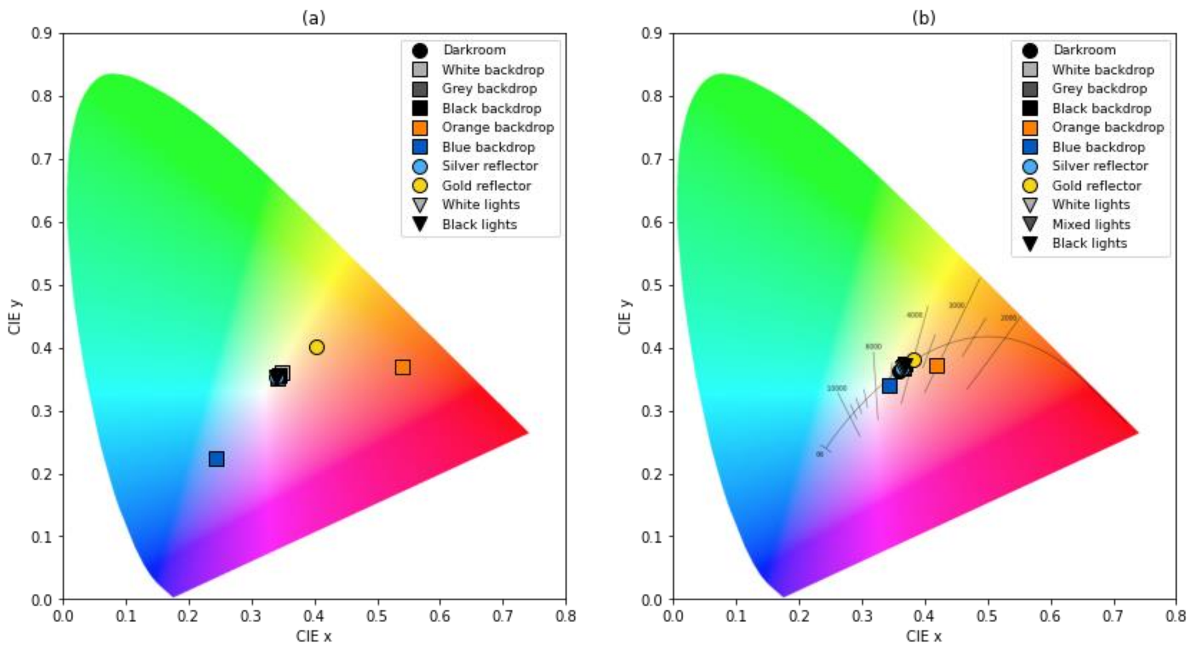

Figure 4 (part 1): Colorimetric data in CIE xy colour space for (a) main surfaces in test environments, and (b) light properties at the scene. (c) shows CIE Y lightness data from the CIE xyY colour space for main surfaces in test environments (material), and light properties at the scene. Plot (d) shows the emission spectra of light source.

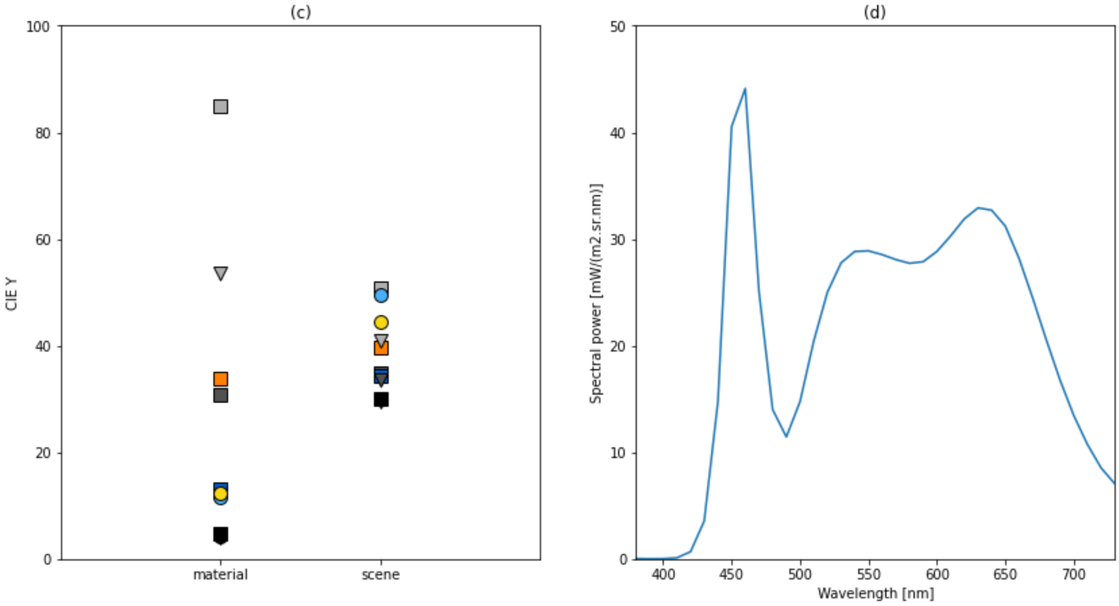

Figure 4 (part 2): Colorimetric data in CIE xy colour space for (a) main surfaces in test environments, and (b) light properties at the scene. (c) shows CIE Y lightness data from the CIE xyY colour space for main surfaces in test environments (material), and light properties at the scene. Plot (d) shows the emission spectra of light source.

3. RESULTS AND DISCUSSION

The ΔE_{00} colour differences were first calculated for all 240 colour patches on the test chart, using the measured colour values of the patches as a reference. The average values for the entire test chart are shown in *Figure 5*, together with the standard deviation within the sample.

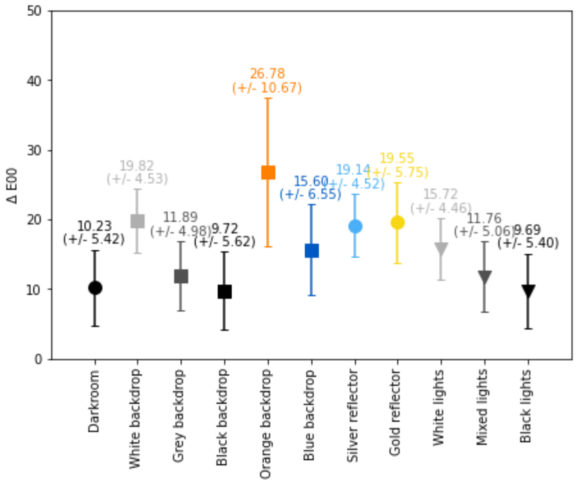

Figure 5: Mean colour difference ΔE_{00} with standard deviation of the sample between measured colour values of the ColorChecker DC and tested setups.

The results in *Figure 5* show that the lighting conditions in the scene change drastically when the background is changed. In darker environments such as darkroom, grey and black backdrops, and grey and black lights, the colour differences are the smallest, indicating the best colour rendering conditions. This is due to the combination of: (1) low surface reflectance of the materials (0.7% for black lights, 1.5% for darkroom, 2.9% for grey, and 3.3% for black background), (2) their CIE xy values are near the white point and have no obvious chromaticity, and (3) the brightness values are relatively low compared to other samples, except for the grey background (3.99 for black lights, 4.36 for darkroom, 30.82 for grey, and 4.86 for black background). We expected the white background and white lights to give similar results, but they show a higher colour difference (19.82 and 15.72, respectively), although their reflectance rates (3.3% and 2.6%, respectively) are in the same range as the darker backgrounds and show no obvious material chromaticity. However, their CIE Y values are the highest of the entire test group (84.91 for white backdrop and 53.46 for white lights). This indicates that the brightness of the background material is a sufficient parameter to affect the colour differences that appear in the photographic scene, but there is a threshold in the brightness of the material affecting the scene, as a grey backdrop does not produce the colour differences to the same extent. This finding prompted us to analyse the brightness and colour properties separately in the further course of the study.

Based on the data in *Figure 4(a)* and *(b),* we would expect the blue and orange backdrops, along with the gold reflector, to produce the greatest colour differences, as a colour shift is clearly seen on a scene when comparing plot *(a)* with plot *(b)*. The corresponding colour differences in *Figure 5* do have higher ΔE_{00} values: 15.60 for the blue background, 19.55 for the gold reflector, and 26.78 for the orange background. However, the silver reflector has a ΔE_{00} value of 19.14, although it shows no obvious effect on the colour shift when comparing plots *(a)* and *(b)* in *Figure 4* and has a relatively low CIE Y value as a material (11.68). This suggests that the ability of the material to reflect light can strongly influence the colour differences produced in a photographic scene. Not only the chromatic properties of the gold reflector can be the reason for the change in the properties of the scene, but also its reflections since the brightness CIE Y is similar to the silver reflector (12.32). The gold reflector reflects an average of 94.9% of the light, with a standard deviation between the three samples of 19.6%, while the silver reflector reflects an average of 88.7%, with a deviation of 10.0% between the samples. These measurements indicate a high degree of optical non-uniformity of the surface, making the material unpredictable in reflecting light on the observed scene.

To further investigate the influence of background brightness, chromaticity, and reflectance on the photographic scene properties, we converted the results to the CIE LCH_{uv} colour space, which gives us more detailed information about the brightness, chromaticity, and hue changes. The differences between the average values of 240 colour patches of each scene and the measured reference values are shown in *Figure 6(a)*, separately for each of the three components *ΔCIE L* for the difference in brightness, *ΔCIE C* for the difference in colour, and Δ *CIE* H_{ab} for the difference in hue. Since results have different ranges (from 0 to 100 for *Δ CIE L* and *Δ CIE C*, and from 0 to 360 for Δ *CIE* H_{ab}), they were normalised to illustrate the influence of backgrounds on each of the three colour components. The normalised values are shown in *Table 1* and *Figure 6(b).*

Table 1:Normalized values Differences for each component in CIE H_{ab} colour space between measured colour values of the ColorChecker DC and tested setups.

Sample	Dark-room	Backdrops					Reflectors		Lights		
		White	Grey	Black	Orange	Blue	Silver	Gold	White	Mixed	Black
Δ CIE L	0.199	0.529	0.276	0.179	0.803	0.058	0.489	0.572	0.404	0.259	0.190
Δ CIE C	0.024	0.182	0.065	0.002	0.416	0.940	0.222	0.360	0.163	0.045	0.002
Δ CIE H_{ab}	0.069	0.162	0.090	0.063	0.245	0.021	0.153	0.185	0.127	0.085	0.066

In *Figure 6(a)* and *(b)*, we see similar trends in the results as in *Figure 5*, with the curves changing drastically and splitting in the blue background arrangement. In this case, the ratio between the components affected by the scene adjustment is the largest, as the chromaticity is changed the most (0.94), while the change in brightness and hue is close to 0 (-0.06 and -0.02, respectively). This leads to the conclusion that even materials that are neither very bright nor extremely reflective can influence the colour situation of the scene only due to their chromatic properties. In this particular case, however, we expect this result to be a consequence of the blue colour of the material surface, which corresponds to the region where the light source radiates with the highest intensity. This can be seen in the emission spectra (*Figure 4(d)*). Therefore, we expect the material to absorb most of the illuminating light, resulting in less reflected light and consequently less influence on the colour differences of the scene.

For all other setups, the brightness difference *Δ CIE L* is most affected out of the three parameters and becomes proportionally larger with background brightness. This is evident when comparing the *Δ CIE L* results for black (0.18), grey (0.28), and white backgrounds (0.53) with their CIE Y values of 4.86, 30.82, and 84.91, respectively. The difference between chromaticity and hue for grayscale background situations (backgrounds and lights) is at least half that of brightness and never exceeds 0.2, indicating that the light reflected from the background does not contain any additional chromaticity not generated by the light source. However, once any type of chromatic surface is present, this drastically changes the properties of the scene. For coloured samples (orange and blue backdrop, silver and gold reflector), not only the *Δ CIE C* chromaticity values are the highest, but also the *Δ CIE* H_{ab}, indicating a shift in hue, the *Δ CIE* H_{ab} for blue backdrop deviating from this thesis only due to illumination conditions.

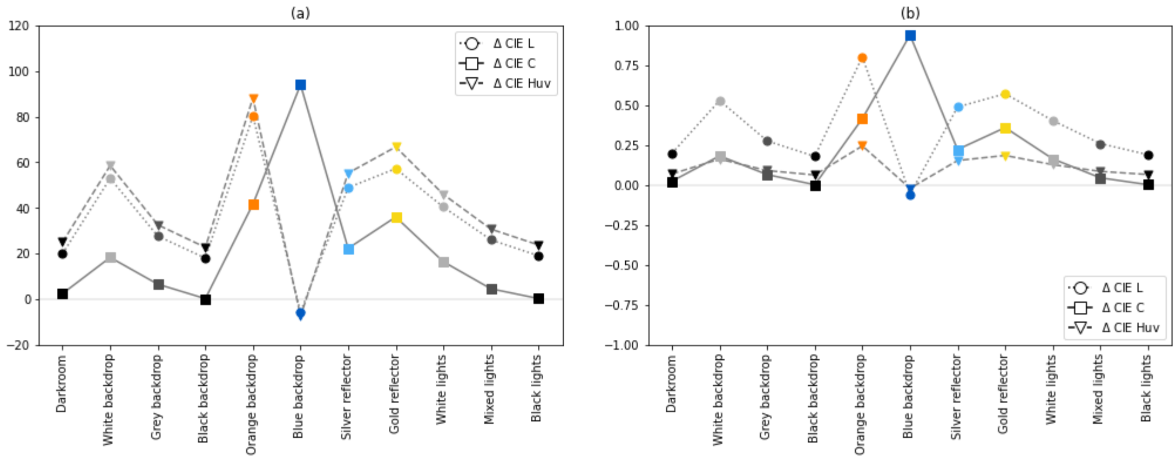

Figure 6: Differences for each component in CIE H_{ab} *colour space between measured colour values of the ColorChecker DC and tested setups (a) in their original values and (b) normalized values.*

Results for the darkroom setup show low ΔE_{00} values (10.23), along with the black backdrop (9.72) and black light (9.69). All three samples are closely followed by grey backdrop (11.89) and mixed lights (11.76). These five setups also produce the lowest chromaticity and hue differences, while darkroom, black backdrop, and black lights have low *Δ CIE L* values, ranging from 0.179 to 0.199. Therefore, we evaluate the darkroom, black backdrop and black lights setups as the most successful in having no effect on the colour properties of the scene and suggest that such setups should also be used in research analysing the colour properties of scene elements.
To further determine the usefulness of our darkroom laboratory, we calculated ΔE_{00} between the setups and the reference values, this time using the darkroom results as reference. The results are shown in *Figure 7* and show the largest deviations for coloured and bright setups.

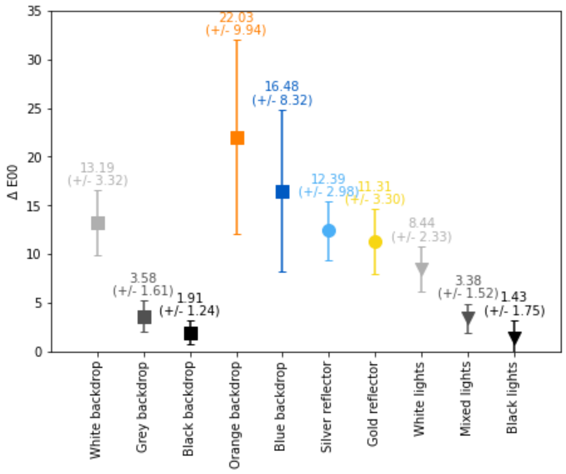

Figure 7: Mean colour difference ΔE_{00} *with standard deviation of the sample between darkroom image and images of other setups.*

According to Mokrzycki & Tatol (2011), a colour difference that is not perceptible to the human eye has a ΔE_{00} value of less than 5, so the black backdrop, grey backdrop, black lights, and mixed lights setups are suitable substitutes for our laboratory darkroom. However, we would like to point out that the experimental setups in this study were small, illuminated with one light source, and set up to determine the influence of a single key area. In setups with multiple light sources, the light moves in different directions and can be reflected not only from the background but also from the sides of the photographic scene. In this case, the studio setups would only be applicable if all sides had the same surface properties and were equidistant from the subject. The darkroom laboratory involved in this research makes these conditions possible and is therefore our choice for further research.

4. CONCLUSION

Research has shown that surfaces in the environment should have the lowest possible reflectance, no obvious coloration, and low brightness values so that the photographic scene is affected as little as possible by the environment. Each of these three parameters has been shown to have a significant effect on the observed colour properties of the scene.

We have observed a large influence of the properties of the light source on the colour conditions of the scene in cases where the emission spectrum of the light source overlaps with the reflection spectrum of the material under study, resulting in the majority of the light being absorbed and therefore the background having less influence on the illumination differences of the scene.

We recommend the use of a special environment for any photographic examination that includes colour analysis. Surfaces in this environment should be grayscale and low brightness, preferably grey or black, with a low reflectance. In order to design more specific and numerical guidelines, a more extensive research should be conducted that defines an acceptable threshold for the brightness and reflectance of the surfaces.

5. ACKNOWLEDGEMENTS

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IMPROVED RECONSTRUCTION OF THE REFLECTANCE SPECTRA FROM RGB READINGS USING TWO INSTEAD OF ONE DIGITAL CAMERA

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Abstract: *The colour of an observed object can be described in many different manners, and the description by its reflectance provides the unambiguous colour representation. The reflectance description can be acquired by expensive multispectral cameras or, e.g., with time-sequential multispectral illumination. In our experiment, we propose that under the condition of constant and uniform illumination, the reflectance can be deduced from the object's RGB camera readouts, captured alongside the set of colour patches with known spectral characteristics. Translation from a colour description in RGB space into reflectance spectra, independent of illuminant and camera sensor characteristics, was performed with the help of an artificial neural network (ANN). In our study, the hypothesis was proposed that the ANN's performance of reflectance reconstruction can be enhanced by employing richer learning datasets using RGB input sets of two cameras instead of just one. Additional second camera information would be adequate only if the equivalent channels of cameras used are linearly independent. A quantitative measure of nonlinearity (QMoN), which is the metric primarily developed for use in chemistry, was employed to estimate the degree of nonlinearity. Additional attention was paid to ANN training, structure and learning set sizes. Two ANN training algorithms have been utilised, a faster GPU executed standard backpropagation and an order of magnitude slower CPU based, but with significantly better convergence Levenberg-Marquardt training algorithm. The number of neurons in the hidden ANN layer varied from the size of the input layer to a number greater than the number in the output layer. The complete set of colour samples was divided into five learning sets of different sizes, with the smaller sets being subsets of the larger ones. To assess performances of the resulting ANNs, mean squared error, the goodness of fit and colour differences calculated from original and reconstructed reflectances assuming several standard illuminations have been compared. A noticeable reflectance performance improvement has been found by using two cameras, even though the cameras' equivalent channels exerted only small degrees of nonlinearity.*

Keywords: artificial neural network, reflectance spectra reconstruction, enriched learning set, two cameras, equivalent channel's nonlinearity

1. INTRODUCTION

In many areas, the description of colours using the camera's colour space, i.e. RGB is sufficient, but for a more accurate description, we use colour spaces such as XYZ or CIELAB. The former depends on both the characteristics of the capture device and the illumination, while the latter is independent of the device but still includes illumination. If we, for some reason, e.g. archiving a medieval facsimile or an artwork, want to achieve a colour description independent of the lighting at the time of capture, colours should be described through the reflectance spectra, for which several different image capture strategies have been developed. Multispectral cameras, which describe the image with more than three frequency bands, and hyperspectral cameras, which describe the image with a large number of narrow frequency bands, are expensive, and by increasing the spatial and frequency resolution, the temporal resolution can be compromised (Cucci et al., 2011). Due to the affordability of consumer cameras, their high image resolution and capture speed, the possibility of converting an RGB image, which varies from camera to camera, into a reflectance spectrum is becoming more and more intriguing. Such methods range from purely mathematical models that incorporate knowledge of image capture conditions and limitations to learnable models that exploit the capabilities of artificial neural networks (ANNs). Some of the many methods of spectrum reconstruction from camera readings have already been mentioned in our previous work (Lazar, Javoršek & Hladnik, 2020), and some are described below.

In (Imai & Berns, 1999), an alternative approach to capturing multispectral images via a combination of RGB digital camera and either absorption filters or multiple illuminations is described. Imaging spectroscopy through faster electronically tuneable filters in front of a monochrome camera to build an image cube of spectral layers is reviewed in (Gat, 2000). Tuneable filters in front of the camera enable narrow-band filtering, where the build of the image cube requires a time sequence of consecutive photos. In (Chi, Yoo & Ben-Ezra 2010), the multispectral image is obtained with the carefully selected set of filters placed in front of the illumination source and the unknown moderate indoor ambient light is cancelled out. Besides hyper/multi-spectral imaging using special equipment, other techniques are being developed. For application in spectrally-based rendering systems, the algorithm for converting RGB labelled object and texture colours to spectrally presented reflectances has been described in (Smits, 1999). In a three-step algorithm proposed by (Jia et al., 2017), the spectrum has been accurately reconstructed from RGB values of photos taken in daylight. The first step is a nonlinear dimensionality reduction of the high dimensional spectra of natural scene images to a 3D embedding of spectra. Then, RGB values of observed spectra are calculated, considering the known lighting conditions and camera spectral response and training the ANN to connect the RGB values and 3D embedding of spectra. In the third step, conversion from 3D embedding to high dimensional spectra is done through a low to high dimensionality dictionary.

Multispectral and hyperspectral images are helpful in many fields, e.g. in geology (Ninomiya & Fu, 2019), agriculture (Hassan-Esfahani et al., 2014), food industry (Benouis et al., 2021), healthcare (Wang et al., 2022) and cultural heritage (Colantonio et al., 2018). Research in the field of multi- and hyperspectral image capture is useful and current, as well as, due to the affordability of high-resolution commercial cameras, also research that uses various techniques of converting RGB to multidimensional spectral image space.

In most studies, at least some knowledge about the image capturing conditions, e.g. lighting conditions and/or sensory response, is required. The precise measurement of the illumination spectrum is not always feasible, and the manufacturer does not necessarily specify the camera spectral response. Instead of using absorption filters or alternating bandpass illumination, which requires additional technical expertise, we propose that an array of reference colour patches with known reflectance spectra be captured alongside the object of interest with one or more cameras. Thus, the relationship between RGB values and the reflectance spectra can be established through a subsequent software approach. In our previous work, the possibility and effectiveness of an ANN-based spectral reflectance reconstruction from a single camera RGB data has been studied. An open question remained whether the efficiency of reflection reconstruction could be enhanced if the RGB data from two cameras were available.

There are many possibilities for using the data of the reflection spectrum of the observed object. Depending on the light reflection, the surface type is essential, where the reflection can be complete or diffuse. If the surface is uniformly coloured, the reflectance can be measured using a spectrophotometer. In the case of large colour variability, such as in works of art, its use is impractical or impossible. For our planned future use for archiving works of art in watercolour, pastel, chalk, crayon, or printing material on matte paper, we used non-glossy - matte samples in our experiment.

2. REFLECTANCE RECONSTRUCTION USING ANN

It has been shown (Hornik, 1991) that multilayer feedforward networks are, under very general conditions on the hidden unit activation function (continuous, bounded and nonconstant), universal approximators provided that sufficiently many hidden units are available. In recent years, the availability of graphics cards with high computing power and data throughput has fuelled the evolution of neural network architecture. Convolutional and deep NNs are used to analyse large-scale input data through compacting the input data, like images and natural language and absorbing a huge amount of complex knowledge (Ciresan et al., 2011, Zhang & Wallace, 2015, Szegedy, Toshev & Erhan, 2013, Rolnick & Tegmark, 2017). Our research focuses on a relatively small learning set (hereafter LS) with a small number of inputs; thus, reducing input data dimensionality would not contribute to network efficiency. We built a three-layer ANN, where an input layer accepts R, G and B values of one or two cameras, a hidden layer harbours a variable number of neurons, and the output layer's exit values consist of a reconstructed reflectance vector containing spectral power distribution of visible light, with a 10 nm wavelength resolution from 380 to 730 nm.

The generic architecture of utilised ANNs is shown in Figure 1, where $x_{k,j}$ are k-th inputs, which can be RGB readings of one or two (depicted) cameras (hereinafter 1RGB or 2RGB); $b_j^{(L)}$ and $w_{j,i}^{(L)}$ stand for biases and connection weights and $y_{k,j}$ are output layer neurons' output values, representing 36 spectral components of k-th reconstructed reflectance; j is neuron index in (L)-th layer and i in $(L-1)$-th layer.

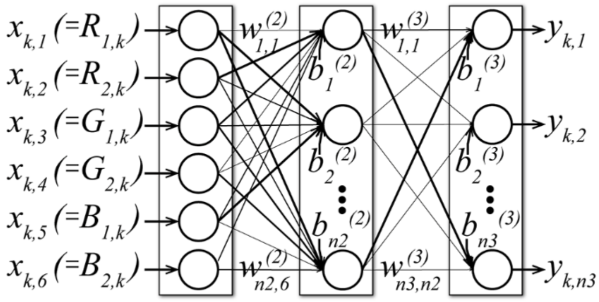

Figure 1: Architecture of an ANN with a single hidden layer and a variable number of hidden neurons, for the reconstruction of reflectances from RGB

Having a LS of (1RGB/2RGB, reflectance spectrum) pairs from the reference set of patches, the training of the ANN is performed by a learning algorithm, adjusting connection weights and biases so that the network cost function -mean squared error (Eq. 1), is minimised.

$$C = \frac{1}{N_p}\sum_{k=1}^{N_p} \left[\frac{1}{N_\lambda}\sum_{j=1}^{N_\lambda} \left(r_{k,j} - y_{k,j}\right)^2\right] . \tag{1}$$

N_p is the number of patches, N_λ number of reflectance wavelengths, k is patch index and j wavelength index, $r_{k,j}$ is a j-th spectral component of k-th patch *measured* reflectance and $y_{k,j}$ j-th spectral component of k-th patch *reconstructed* reflectance.

The software part of our experiment was programmed in Matlab, where the two ANN learning algorithms are set for the purpose of function approximation, namely "standard gradient descent based backpropagation" (hereafter BP) ANN training algorithm is high-speed due to the ability to run on GPU and another, Levenberg-Marquardt (hereafter LM) algorithm, which only supports computing on CPU, but is specially adapted to minimise the sum-of-squares error functions (Aldrich, 2002). As in our previous research, it shows again that the LM learning algorithm, with an increased number of hidden layer neurons, requires at least an order of magnitude more time but results in order of magnitude better learning convergence by means of epochs repetition and better ANN performance compared to BP.

Functions embedded in the modelled ANN translate RGB readings into components of the reflectance spectrum. Each of the 36 embedded functions in our case translates the three input readings (a point in a 3D space) into one spectral component. If we take two RGB readings that are not linearly dependent, triangulating these two points into one spectral value should give more accurate results and partially eliminate metamerism. Metamerism caused by the light source cannot be decreased or eliminated in this way. Suppose a part of the illuminant spectrum is missing. In that case, it prevents sensing the reflection of a missing part of the spectrum from the object. Whereas, if a light source with a smooth spectrum is used (e.g., sunlight or incandescent bulb) when the photo of an object and the reference array of patches is captured, their reflectance should convey its complete spectrum, which in the camera is transformed into RGB readouts. If cameras used in the experiment have a nonlinear relationship between equivalent colour channels, the observer (or camera) metamerism could be reduced. The integration defining the R, G and B values includes the product of illuminant spectrum $I(\lambda)$, object/colour patch spectral reflectance $S(\lambda)$ and camera spectral sensitivity function $\tau(\lambda)$, which is different for each channel of each camera (Eq. 2):

$$y_{cam.,ch.,i} = \int_{\lambda_{min}}^{\lambda_{max}} \tau_{cam.,ch.}(\lambda) S_i(\lambda) I(\lambda) d\lambda \, . \tag{2}$$

Here "*cam.*" indicates camera (in our case, 1 or 2), "*ch.*" represents colour channel (R, G or B) and "*i*" denotes colour index (e.g., colour 1, 2 … num. of colour patches).

If one camera gives the same RGB outputs for two different samples, a metameric pair of samples is found, meaning that the integrals of equivalent channels of two samples give the same result ($R_1=R_2$, $G_1=G_2$ and $B_1=B_2$). If the second camera's equivalent channels are not linearly dependent on the first camera, the integrals for outputs of the *second camera* will *likely* give different results for the previously metameric pair of samples ($R_1 \neq R_2$ and/or $G_1 \neq G_2$ and/or $B_1 \neq B_2$). Because RGB values are 8-bit integers, too slight differences could still result in the same values. The greater the nonlinearity is between the equivalent channels, the more significant the possibility of *different values for the previously metameric pair*. We can conclude that the second camera can provide additional information. It is challenging to prove analytically; however, by expanding the ANN's LS with an algorithm that allows learning through a series of examples, an additional camera could allow for better ANN performance, which we hope to demonstrate through our experiment.

As stated in the hypotheses below, we assume that the equivalent colour channels of the cameras used are linearly independent. If so, we believe the ANN performance will improve if the LS input data is doubled.

Our hypotheses are as follows:

1. Equivalent channels (R_{C1}-R_{C2}, G_{C1}-G_{C2}, B_{C1}-B_{C2}) of different cameras are most likely linearly independent.
2. An ANN for reflectance reconstruction from RGB readings, trained with input data of two different cameras, will perform better than an ANN trained with single-camera RGB data.

3. MATERIALS AND METHODS

Our study aimed to explore the possibility of improving the recovery of reflectance spectra from trichromatic camera values by supervised learning of an ANN with a single hidden layer, modelled with Matlab Neural Network Toolbox. The ANN LS inputs are vectors of 3 or 6-dimensional RGB readings from one or two cameras, and outputs are higher dimensional vectors of reflectance spectra – readings of the spectrophotometer.

The source of colourimetric data for our experiment was The Munsell Book of Color Matte Collection, with 44 sheets providing 1301 colour patches, varying chroma, hue and value. Forty sheets are divided into 2,5 steps Munsell hue circle (2,5, 5, 7,5, 10 for Red, YR, Yellow, GY, Green, BG, Blue, PB, Purple and RP). Four remaining sheets contain neutral colours - neutral and subtly hued greys. Reflectance spectra of patches were measured by spectrophotometer X-Rite i1Pro 2 at five points (on both diagonals, a quarter of the distance from each corner, and at the patch centre). Reflectances - vectors with 107 components for wavelengths from 376.66 to 730 nm with a step size of 3.33 nm were calculated as an average value of the five measurements with a maximum standard deviation of less than 0.4%.

Because of the absorption characteristics of human-made and natural colourants, the sampling rate can be significantly decreased (Imai & Berns, 1999). Surface spectral reflectances of many organic and inorganic substances are characteristically smooth, low-pass functions of wavelength (Maloney, 1986). By observing reflectance spectra of all the available colour patches, which include many natural colours (soil, skin, foliage etc.), the smoothness has been confirmed without exception; therefore, the decrease in sampling rate is acceptable. Subsampling was made from 3.33 to 10 nm step, resulting in 36 reflectance spectral components in the range from 380 nm to 730 nm.

The sheets with colour patches were photographed in a photo studio under constant lighting conditions. We used three cameras (Nikon D600, D700 and Panasonic GH-4) with fixed manual settings (Figure 2). A spectrophotometer measured the light source spectral power distribution at the sheet location, and a correlated colour temperature (CCT) of 3019° K was read out. Images were captured in RAW format and required conversion to 8-bit RGB. All images were processed equally - normalised using Adobe Lightroom software to the measured CCT, the tint was balanced to 0, and chromatic aberration, even though unnoticeable, was corrected with corresponding lens profiles. This process resulted in conversion to digital photos in AdobeRGB (1998) colour space. The RGB value of each patch was calculated as the median (rather than the mean) of the inner 50% of the squared patch area to avoid the influence of possible minor colour deviations.

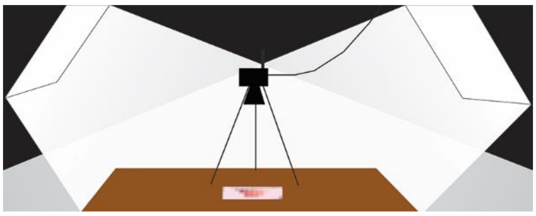

Figure 2: Photo studio setting

The complete set of RGB-reflectance pairs included data of all 1301 Munsell Matte colour patches, with three camera sets of R, G and B values and 36 values for each reflectance vector. Before training the ANN models, the complete set was split into a training set and the remaining independent samples, for which additional measures of reflectance reconstruction performance were calculated. At the beginning of each ANN model training iteration, the LS was randomly split into training, validation and testing sets in a 70:15:15 ratio.

Due to the nature of ANN learning, where the algorithm tends to find a local instead of a global minimum of the cost function, for each model with selected cameras, a training set size and number of neurons in the hidden layer (3 to 48, in steps of 1), the search for optimal ANN parameters was repeated 41 times. In preliminary experiments with 21 ANN training repetitions with selected LS sizes, it was found that increasing the number of neurons in the hidden layer (hereafter HLN) above 48 does not improve the ANN performance noticeably or even worsens, while the calculations become very time-consuming.

In this experiment, we wanted to increase the possibility of finding the best ANN models, so the number of repetitions was almost doubled. The odd number of 41 repetitions was chosen due to the calculations of some additional statistics not presented in the article. Calculations with the BP and LM learning algorithms were performed on five different sizes of learning sets and corresponding sets of independent samples (Table 1).

Table 1: Size of learning sets

descriptive size of learning set	% of learning set vs complete set of 1301 colour patches	num. of 1/2RGB - reflectance learning set pairs	num. of remaining independent samples
very large	90	1171	130
large	50	650	651
medium	30	390	911
medium	20	260	1041
smaller	15	195	1106

4. NONLINEAR RELATIONSHIPS BETWEEN CAMERAS

In our experiment, we observed RGB readings of the patches acquired with three disparate cameras. Polynomial regression has been calculated relating values of R, G and B channels of the same patches, pairwise between these three cameras. The relationship of equivalent channels for one of these pairs (Panasonic GH4 and Nikon D600), their polynomial regression functions of the second-order and the residuals as the difference between the polynomial regression of the 2[nd], 3[rd] and 4[th] order and linear regression are shown in Figure 3.

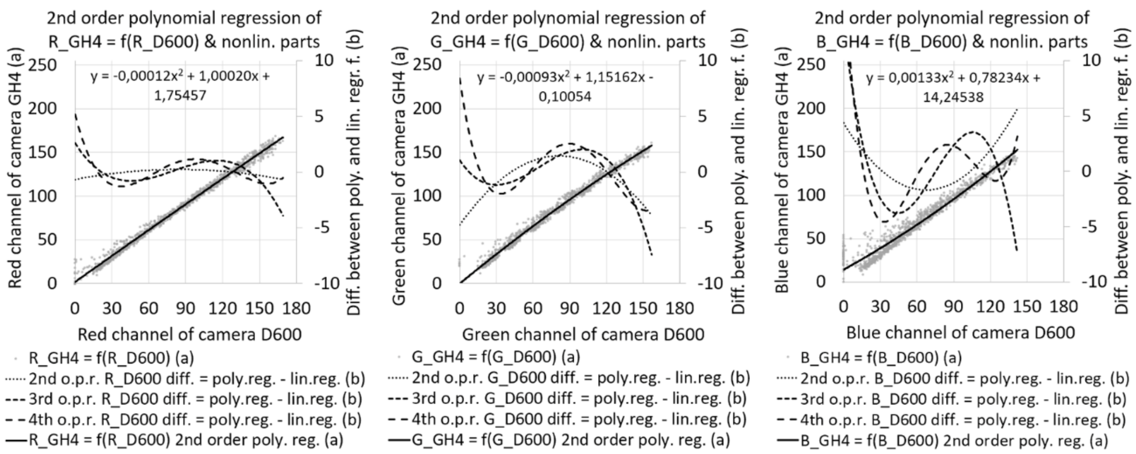

Figure 3: The relationship of equivalent channels from camera GH4 and D600, the polynomial regression functions of the second-order and the residual parts as the difference between the 2nd, 3rd and 4th order polynomial regressions and the linear regression

The efficiency of polynomial regression has been evaluated by observing the difference between the regression functions and actual data, averaged for each Munsell hue section. The difference for the 2nd order polynomial regression functions varies from 4,2% to -2,7%. When including neutrals and lightly hued greys, the average difference is almost 0%, with the standard deviation span between 1,49% and 2,8% through all channels and camera combinations. With the third order, the standard deviation decreases a little (1,46% to 2,68%), with a still smaller decrease with the fourth order polynomial regression (1,43% to 2,66%). Therefore, the 2nd, 3rd and optionally fourth order regression is suitable for observing the sensor functions (R, G and B) of the first in dependence on the second camera.
To assess the nonlinearity between equivalent channels of cameras, we utilised the quantitative measure of nonlinearity (QMoN) suggested in (Emancipator & Kroll, 1993). The "dimensional nonlinearity" of a method is defined as the root mean square of the deviation of the response curve from an ideal straight line, chosen to minimise the nonlinearity. The "relative nonlinearity" is the "dimensional nonlinearity" divided by the distance between the largest and smallest tested values. The definition of quantitative nonlinearity measure suggests different nonlinear regression methods, among others also polynomial, which was used in our experiment. Due to a large number of test values (1301) and the associated small number of different values along the x-axis (167), the F-distribution with the proposed degrees of freedom gives very small values of the 95th percentile of the F-distribution (1,2). Hence the optional algorithm for searching the advisable order of polynomial regression, proposed by Emancipator and Kroll, is inadequate, and the nonlinearity has been therefore calculated by relative QMoN for the polynomial regression for up to the fourth order, as shown in Table 2. The linear regression (1st order) with expectedly small values is introduced as a nonlinearity measure control group.

Table 2: Quantitative measures of nonlinearity between the equivalent channels of the cameras used, varying the order of polynomial regression

	R channel nonlinearity [%]			**G channel nonlinearity [%]**			**B channel nonlinearity [%]**			**All channel average nonlinearity [%]**		
order of polynomial regression	R_D700 = f(R_D600)	R_GH4 = f(R_D600)	R_GH4 = f(R_D700)	G_D700 = f(G_D600)	G_GH4 = f(G_D600)	G_GH4 = f(G_D700)	B_D700 = f(B_D600)	B_GH4 = f(B_D600)	B_GH4 = f(B_D700)	RGB_D700 = f(RGB_D600)	RGB_GH4 = f(RGB_D600)	RGB_GH4 = f(RGB_D700)
4th	0,929	0,707	0,498	1,160	1,448	0,599	1,520	2,953	3,258	1,203	1,703	1,452
3rd	0,962	0,646	0,399	1,124	1,268	0,666	1,656	3,116	2,659	1,247	1,676	1,241
2nd	0,729	0,160	0,251	0,738	1,083	0,720	0,603	1,446	1,746	0,690	0,897	0,906
1st = lin. r.	0,002	0,002	0,001	0,002	0,002	0,002	0,003	0,003	0,002	0,002	0,002	0,002

5. RESULTS

In our experiment, we wanted to determine the influence of using an additional camera's RGB data on the improvement of the reflectance reconstruction performance by ANN models. With three cameras, six different camera combinations and thus six sets of data have been prepared, three for modelling ANNs based on the single camera and three for ANN input RGB values from two cameras. For each of five different LS sizes (Table 1), ANNs with a varying number of neurons from 3 to 48 in their hidden layers have been trained, each one for 41 times by both BP and LM training algorithms. The average and the best results have been recorded, compared, and visualised. Unfortunately, a slower CPU-executed LM learning algorithm shows better results than a significantly faster GPU-executed BP algorithm (Lazar, Javoršek & Hladnik, 2020). The calculations were performed on two computers, partially on a 4-core 2nd gen. i7 CPU with Nvidia 550 GPU and the rest on a 6-core 9th gen. i7 with Nvidia RTX 2060 GPU. Calculations consumed more than 1000 hours of CPU and 65 hours of GPU time.
The MSE performance of each ANN model trained with BP and LM learning algorithm has been calculated for the test set of samples, and the average and the best performance of 41 model iterations for each combination of cameras, the number of HLNs and LS size has been registered. The average and best test set MSE performance depending on the number of HLNs for 2RGB ANN trained with a medium-sized LS and both learning algorithms, with D600+GH4 camera combination, is shown in Figure 4 in the form of the third order polynomial approximation.

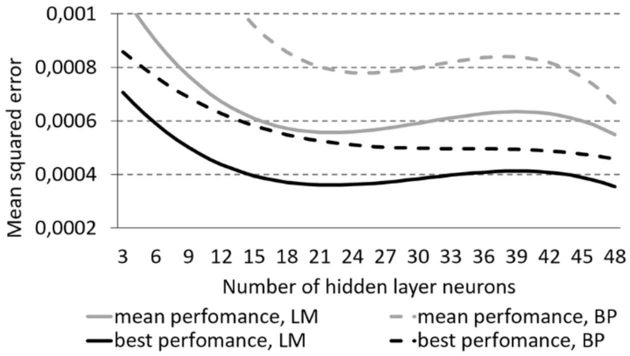

Figure 4: Mean and best test set performance of BP and LM trained ANNs, with 2RGB inputs of D600 & GH4 cameras and 41 iterations for each number of HLNs, with the third order regression trendlines for performances

Even when the training of each ANN model has been repeated many times, the mean and even more the best MSE values jump around a bit. It is possibly due to the random selection of training, validation, and test sets from the LS at the beginning of training for each ANN model. Besides, in most cases, the local minima of the cost function are found by the nature of the ANN training algorithm. In some cases, the polynomial regression curve is plotted along with the data plot, whereas for better illustration, only polynomial regression curves will be presented for the most part. The performance of ANNs trained with the LM algorithm is always better than the BP algorithm, so only the results obtained with the first one will be presented below.

The interpretation of results opens various aspects due to the collection of the ANN models' mean and best performance, variations in modelling ANNs with two different RGB input sets, six camera combinations and a varying number of HLNs:

- comparison of mean vs best MSEs, and varying LSs, for each camera combination
- comparison of all camera combinations best MSEs depending on the number of HLNs, for each fixed LS size
- comparison of the mean and best one- and two-camera MSEs, depending on the number of HLNs, for each fixed LS size
- comparison of all six pairs of 2RGB vs 1RGB ANN MSE performance improvements as a function of LS sizes

In the following, the procedures of these four aspects are described in more detail.

Observing the mean and best MSE in parallel as a function of the number of HLNs, by varying LS sizes for each of the six camera combinations shows that the best MSE values for all five LS sizes reside significantly below the mean values. Only in the case of one-camera data does the best MSE curve with the smallest LS at a higher number of HLNs partially surpass the mean MSE curve of the largest LS. For the D700+GH4 camera combination, the mean vs best trend observation is shown in Figure 5.

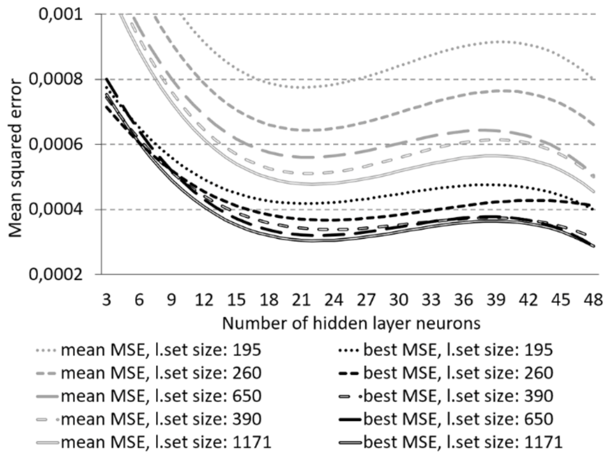

Figure 5: Mean and best MSE of 2RGB LM trained ANNs with D700 & GH4 camera combination and varying learning set size in dependence of the number of HLNs, shown by the trend lines of the 3rd order polynomial approximation.

Larger learning sets give better results in the search for the best performance. Here the ANN performances of LS sizes from 1171 to 390 colour patches almost overlap, and the trends for smaller LS sizes of 260 and 195 are still very close to the best results.

If we focus on ANN MSE performance as a function of the number of HLNs, observing in parallel all six camera combinations at each LS size separately, the ANNs trained with 2RGB perform appreciably better than with 1RGB input data. Figure 6 depicts the best performance for all six camera combinations and the smallest LS. By increasing the LS size from the smallest to the largest, the area between the trend curve of the 1RGB ANNs largest MSE and the curve of the 2RGB smallest MSE is almost halved. The range of MSE minima for the six camera combinations at the largest LS spans from 0.00030 to 0.00047, while at the smallest LS, from 0.00040 to 0.00068.

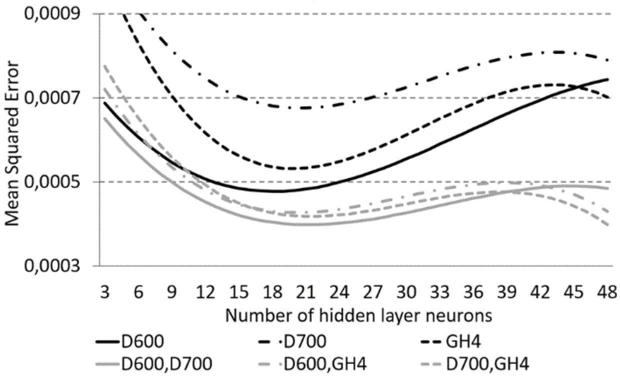

Figure 6: 3rd order polynomial regression trends of the best MSE performance ANNs trained with LM algorithm and smallest learning set (195), plotted for all six camera RGB input combinations

For each combination of two-camera models, the comparison of MSE performance has been made with 1RGB models of two involved cameras, and mean, and best performances have been visualised. In Figure 7, only one such combination is shown: the mean and best performance of ANNs trained with inputs from 2RGB D600+GH4 combination and 1RGB GH4, alongside the *MSE performance improvement with two versus one camera input, as a difference in [%]* = 100*(MSE_{1RGB}-MSE_{2RGB})/MSE_{1RGB}). For clarity, the third-order polynomial regression curves are displayed, with the actual values in only two cases, for illustration. The circle at 1 and 2RGB best MSE regression curves indicates the first minimum. In the nearby area, the best performing ANN models could be found within a moderate ANN modelling time (Lazar, Javoršek & Hladnik, 2020).

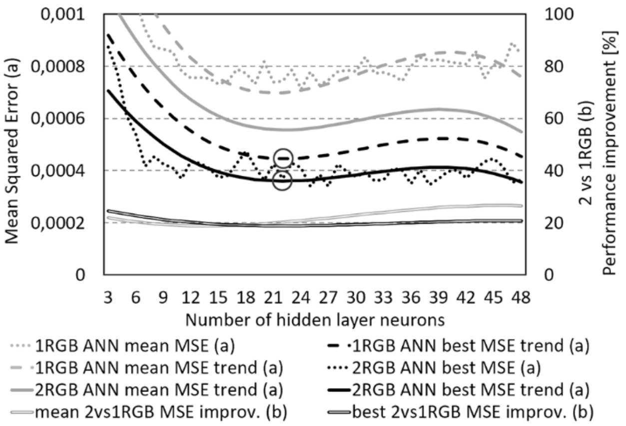

Figure 7: Mean and best performance of ANNs trained with LM algorithm and 1RGB (GH4) and 2RGB (D600+GH4) medium size learning set

To compare 2RGB versus 1RGB ANN MSE performance improvements as a function of LS sizes, the MSE performance improvement at the points of the first minimum of MSE 3rd order polynomial regression has been calculated for six two versus one-camera combinations and five LS sizes (Figure 8). Comparing the mean and the best MSE performance of 2RGB ANNs, the best is, on average, between 33% and 47%

better than the mean MSE, but, in terms of 2 vs 1RGB ANN MSE performance improvement, for the best ANNs, it is only about 5% better than the mean.

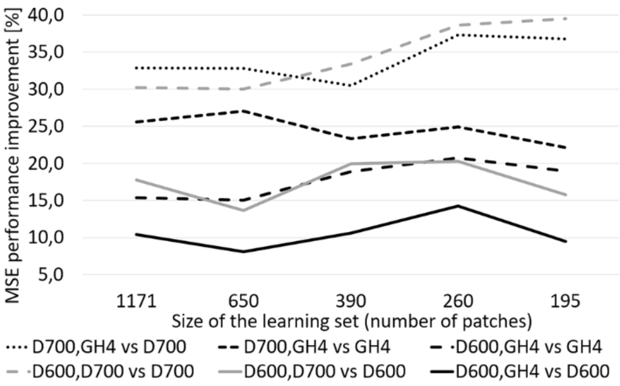

Figure 8: MSE performance improvement of 2RGB over 1RGB ANNs at peak values of the best 2RGB ANN performance for all two-camera combinations as a function of the learning set size

Reflectance reconstruction efficacy with additional quality measures has been evaluated for the best 1/2RGB ANN LM trained models, employing the five sets of leftover independent samples (Table 1). Two quality measures and one error measure were calculated to compare the measured (original) and the reconstructed spectra of independent samples.

The goodness of Fit Coefficient (GoFC) and the Peak Signal to Noise Ratio (PSNR) were used as the quality measures to compare both spectra directly. GoFC results were divided into four classes (Poor, Accurate, Good, Excellent) as proposed in (Hernández-Andrés, Romero & Lee, 2001), while PSNR into three (Poor, Accurate, Good) as proposed in (Lehtonen et al., 2009). Figure 9 compares the quality estimations of the best 1RGB and 2RGB LM trained ANNs with LS of 390 samples and, consequently, the 911 independent samples classified into the proposed classes. Only the sums of percentages for the two best classes are shown.

CIE 2000 was calculated as the error measure nearing the human eye's colour difference perception. Combining different illuminations (incandescent A, daylights D50, D65, and fluorescent F2) with the measured and reconstructed reflectance spectra, the pairs of L*a*b* colour values were calculated. Then their ΔE_{00} colour differences were sorted into seven quality classes (Hardly, Slight, Noticeable, Appreciable, Much, Very much and Strongly Perceptible Colour Difference) proposed in (Yang, Ming & Yu, 2012).

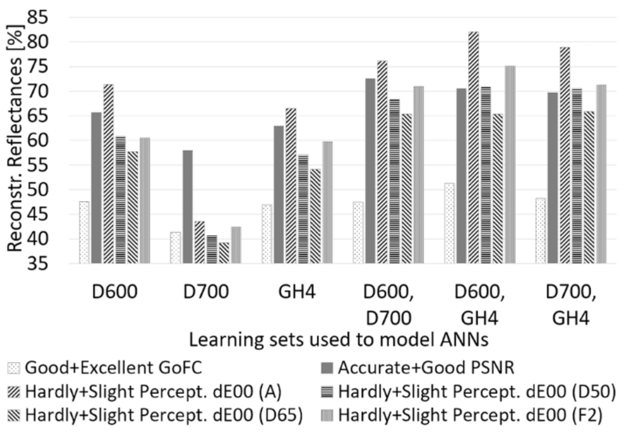

Figure 9: Reflectance reconstruction quality assessment of the best 1 and 2RGB ANNs trained with the LM algorithm and medium learning set size of 390 patches, with results that fall into the two best classes

The composite in Figure 10 presents some examples of bad and good reflectance spectra reconstruction. Falu Red, Sahara Yellow, Casal Blue and Deep Saphire Blue have "noticeable" or "appreciable" perceptible colour differences, "poor" PSNR and "poor" or "accurate" GoFC. Basket Ball Orange, Pastel Olive Green, Fountain Blue and Opera Mauve Purple have "hardly" or "slight" perceptible colour difference, "good" or "Excellent" GoFC and either "accurate" or "good" PSNR.

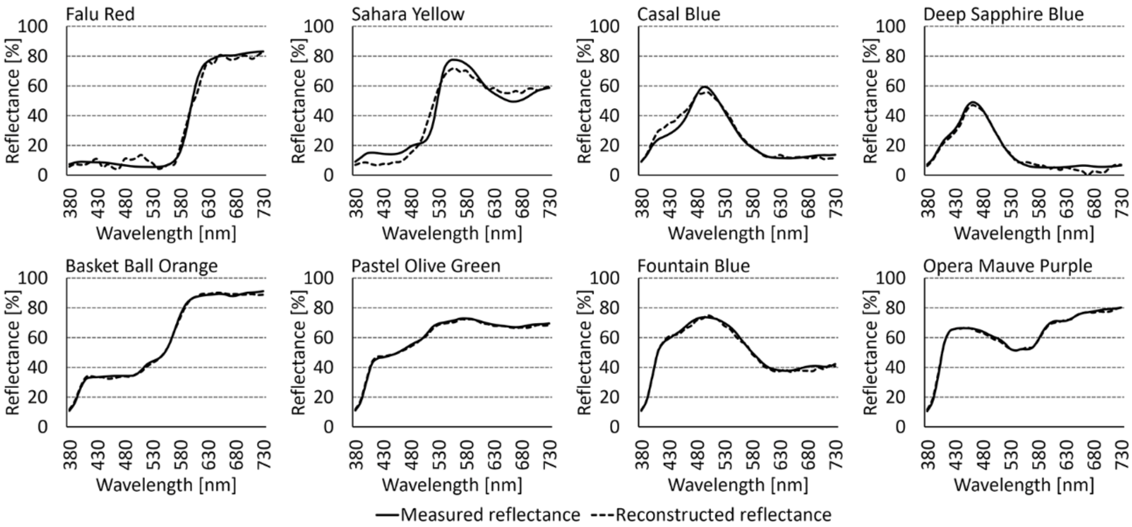

Figure 10: Examples of some bad and good reflectance reconstruction by 2RGB ANN trained with LM algorithm and medium learning set size of 260 patches

Shown reconstructions are made by 2RGB ANN trained upon LS of 260 patches (20% of the complete set) captured by D600 and GH4 cameras. Reconstructed samples belong to the separate independent set of 1041 patches not included in LS. For a better representation of the colour differences, in Figure 11, the above colours are also presented with colour fields, where the left field represents the measured (original) colour and the reconstructed colour on the right. The colours of the example patches have been calculated from the original and reconstructed spectra into AdobeRGB colour space considering D50 illuminant and a 2° observer.

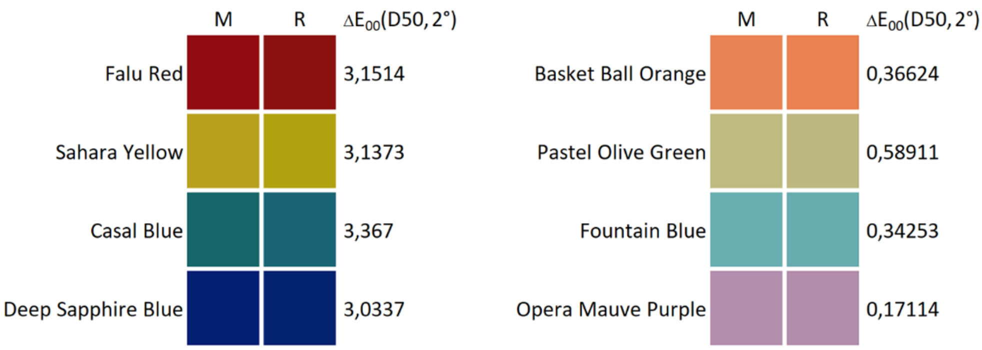

Figure 11: Colour examples of some measured (M) and reconstructed (R) colours, where the colours on the left have considerable and the colours on the right have small error estimates.

6. DISCUSSION

The described method has some limitations regarding camera settings and illumination, but they are not challenging to brace:

- The camera capturing mode must be set to manual and should not be changed during the time interval from capturing the object to capturing the table of reference colour patches.
- The illumination should be invariant in the area of the object and reference patches. Uneven illumination, shadows and glares are unwelcome.
- If possible, the reference colour table of suitable size should be captured simultaneously with the object of interest (e.g. drawing or painting). Otherwise, we should strive for constant

illumination during the time interval of capturing one after another, which is especially important when shooting in daylight.

- For capturing small flat objects, a flatbed scanner could be used. In this case, scanner options for image auto-correct options must be switched off during the time interval of sequential scanning of objects and reference samples.

When using two cameras to capture an object and reference patches, it is also necessary to ensure the registration of both captured images, which would be essential in practical implementation. Image registering is a broad topic that goes beyond the purpose of our experiment, in which capturing the same colour "pixels" with different cameras was provided through sequential capturing of the same homogenous colour patch surface under invariant illumination.

The expansion of the ANN training set from the data of one camera makes sense as long as the new input data contains additional information, which would not happen in the case of linear dependence of the equivalent channels of the cameras used. Finding nonlinearities to enhance reflectance reconstruction is thus crucial. In (Emancipator & Kroll, 1993), the lower limit of 2,5% as a criterion of nonlinearity assessment of curves for use in chemistry is proposed with the remark that in other fields of use, the lower limit may differ. In our experiment, only the blue channel, in some cases, with the 4th and third-order regression function, exceeds the proposed lower limit (Table 2). But, considering the improvement of the reflectance reconstruction, despite the otherwise small nonlinearities, we can assume that nonlinearities close to 1% are sufficient to improve the performance of 2RGB trained ANNs. In all considered cases, a nonlinear connection was detected between the equivalent channels of the experimental camera pairs, thus confirming our first hypothesis.

It is not straightforward to see a connection between the nonlinearities of paired cameras' equivalent channels and reflectance reconstruction improvement. In the R channel, QMoN values of D700 vs D600 exceed the other two camera combinations, in the G channel, this is the case with GH4+D600, and in the B channel, the GH4+D700 beats the other two camera pairs. Even though the D700+GH4 camera pair's QMoN for the R channel is lower than 0,5%, the 2RGB ANN performance still surpasses both the 1RGB ANNs performances, most likely due to some degree higher nonlinearities in the G and B channels.

Observing MSE performance in dependence on camera combinations (Figure 6), when training ANN with the 1RGB LS, the ANNs trained with the D600 camera performs better than with GH4 and even better than with D700. With these results, it could be expected that 2RGB ANNs trained with data from the combination of better-performing single camera learning sets will thus perform better. However, on the contrary, ANNs trained with the D700+GH4 perform better than those trained with the D600+D700 or D600+GH4 learning sets. It suggests that when training ANNs for reflectance reconstruction from RGB data of two or more cameras, the impact of individual cameras' somewhat better performance is not crucial.

Set side by side, the MSE performance of double and single-camera readings trained ANN models at peak values of the best ANN performance as a function of LS sizes (Figure 8), the most pronounced improvement (> 35%) appears at D600+D700 compared to D700 at smaller LS, and the smallest at D600+GH4 compared to D600 (10%) with all LS sizes. It can be attributed to a good performance of the ANNs trained with the D600 single camera readings. But despite this, and only slight nonlinearity of the GH4 R channel in relation to the R channel of D600 (Table 2 - middle R column, Figure 3 - left graph), the improvement of these two-camera ANNs' performance, in comparison to D600 single-camera trained ANNs, is still evident. The most noticeable improvement has been accomplished with D700+GH4 compared to both single-camera ANN performances, where two-camera ANN performance vs D700 is for all learning sets well above 30%, and vs GH4 above 20%. Comparing the performance of ANNs trained with the learning set of a pair and then with two individual cameras, the performance improvement is evident in all two-camera combinations. Therefore, our second hypothesis was experimentally confirmed.

To verify our findings, the reflectance reconstruction efficacy has been tested on 911 independent samples, wholly separated from the medium-sized training set of 390 samples (Figure 9). Various quality measures were used: MSE clearly confirms our findings, ΔE_{00} for four different illuminants also shows noticeable improvement with 2RGB compared to 1RGB trained ANNs, whereas GoFC does not manifest an unequivocal distinction between 1 and 2RGB trained ANNs.

7. CONCLUSION

With the presented study, we wanted to improve the spectral reflectance reconstruction from camera RGB values while capturing object colours with two instead of one camera. As detected, the relationship between the equivalent channels of cameras employed proved to be nonlinear. Therefore, each camera gives a bit different aspect to colour readings and adds some enrichment to the learning set. The ANN training benefits from this information, resulting in a better reflectance reconstruction, as presented through the attending experiment and confirmation of our hypotheses.

There are certainly possibilities to improve the results of our experiment. The selection of samples in five learning sets is fixed, does not vary, and each smaller LS is a subset of a previous larger one. Learning sets have been selected visually and are most likely not entirely optimal. A better selection could give better results. Another possibility is upgrading the structure of the artificial neural network, e.g., by adding additional hidden layers. Nevertheless, these suggestions are out of the scope of the current experiment and may be explored in the future.

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FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF GRAPHIC ENGINEERING AND DESIGN