

SUSTAINABLE APPROACH TO BOOK DESIGNING CONCEPTS IN BINDERY SECTOR: AN OVERVIEW

Suzana Pasanec Preprotić , Marina Vukoje , Gorana Petković , Mirela Rožić 
University of Zagreb, Faculty of Graphic Arts, Zagreb, Croatia

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 CO₂ 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).

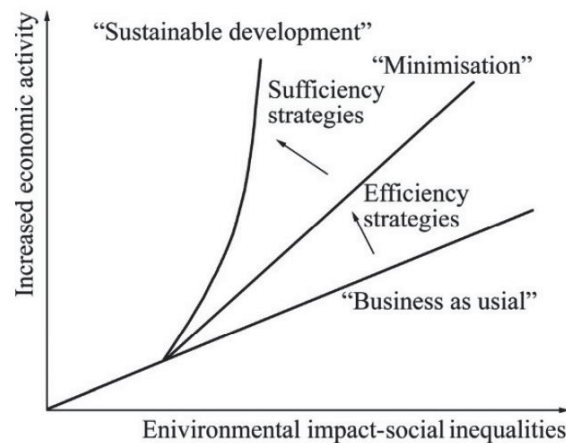


Figure 1: Developing path towards sustainability

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).

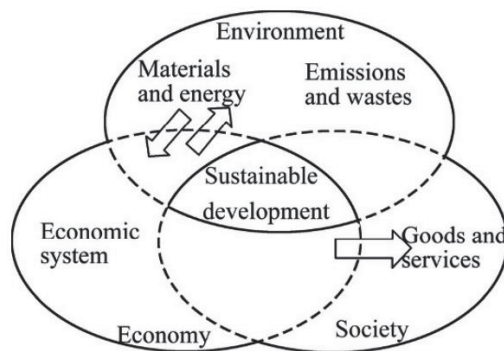


Figure 2: Practical sustainable development model

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 correlates 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 bleached 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 readers 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 comparison 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 are 100% 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 correlate 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).

<p><u>Note 1: The rectangles present inputs and outputs in post press.</u></p> <p>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</p>	<p><u>Note 2: The rhomboids present processes in post press.</u></p> <p>O: cutting: knife principle I: folding “right-angle” principle + I¹ pressing II: gathering signatures into “multi-layer” block III: perfect binding method: joining block and cover IV: 3-sided trimming</p> <p style="text-align: right;">ISO 12637-4:2008</p>	<p><u>Checklist for DfE method in post press.</u></p> <p>Potentially hazardous waste: 5 Smiles Hard recycling waste: 4 Smiles Partially recycling waste: 3 Smiles Recycling waste: 2 Smiles Neglecting waste: 1 Smiles</p> <p style="text-align: right;">ISO 16759:2013</p>
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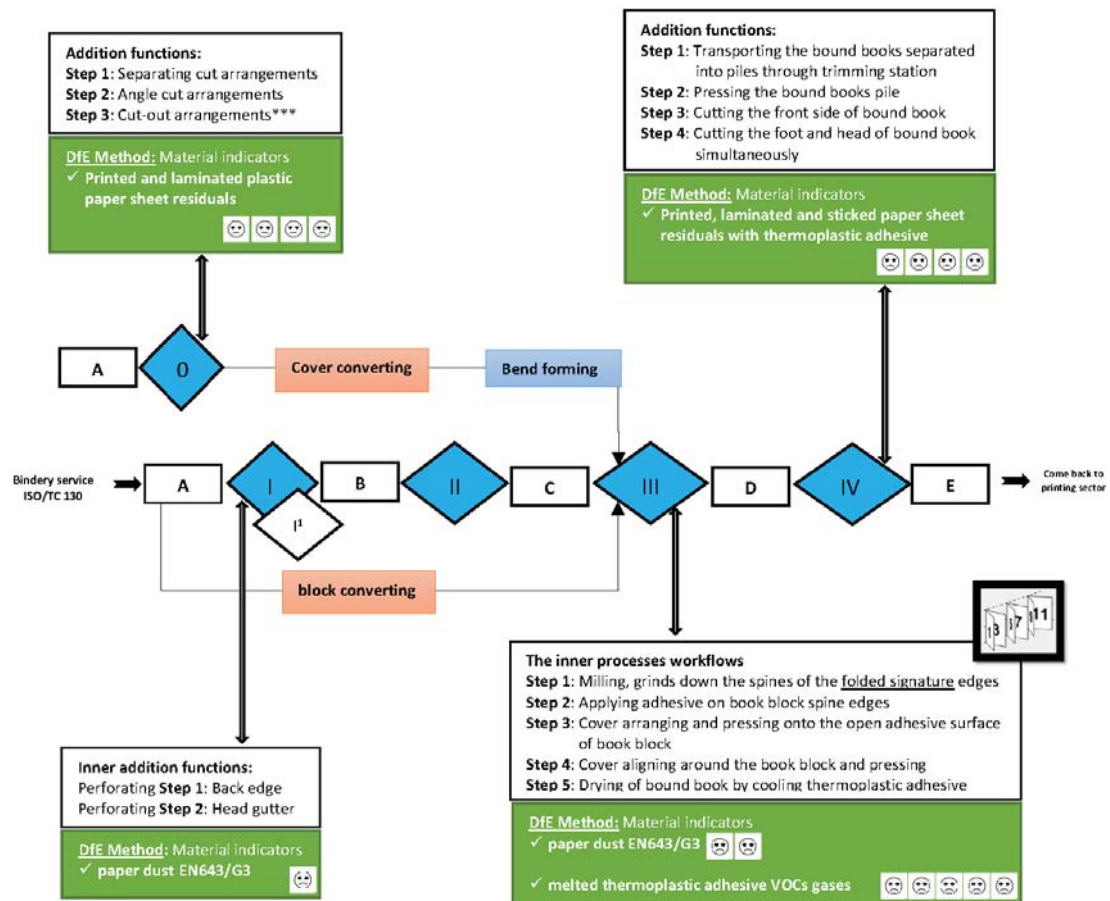


Figure 3: Processes with inputs and outputs in perfect binding workflow connected and capturing environmental impact of graphic arts materials (mass-bound book production)

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 entrepreneurship 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 correlates to waste management.

<p><u>Note 1: The rectangles present inputs and outputs in post press.</u> P^A: High-grade paper sheets, size: 320x460 mm, EN643/G3 A¹: printed paper sheets: book block imposition A²: printed paper sheets (cover) C: book block D: semi-bound book product E: bound book product</p>	<p><u>Note 2: The rhomboids present processes in post press.</u> O: cutting: knife principle I: digital printing + I¹ gathering printed paper sheets III: perfect binding method: joining block and cover L^{A2}: laminating printed paper sheets - cover</p>	<p><u>Checklist for DfE method in post press.</u> 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</p>
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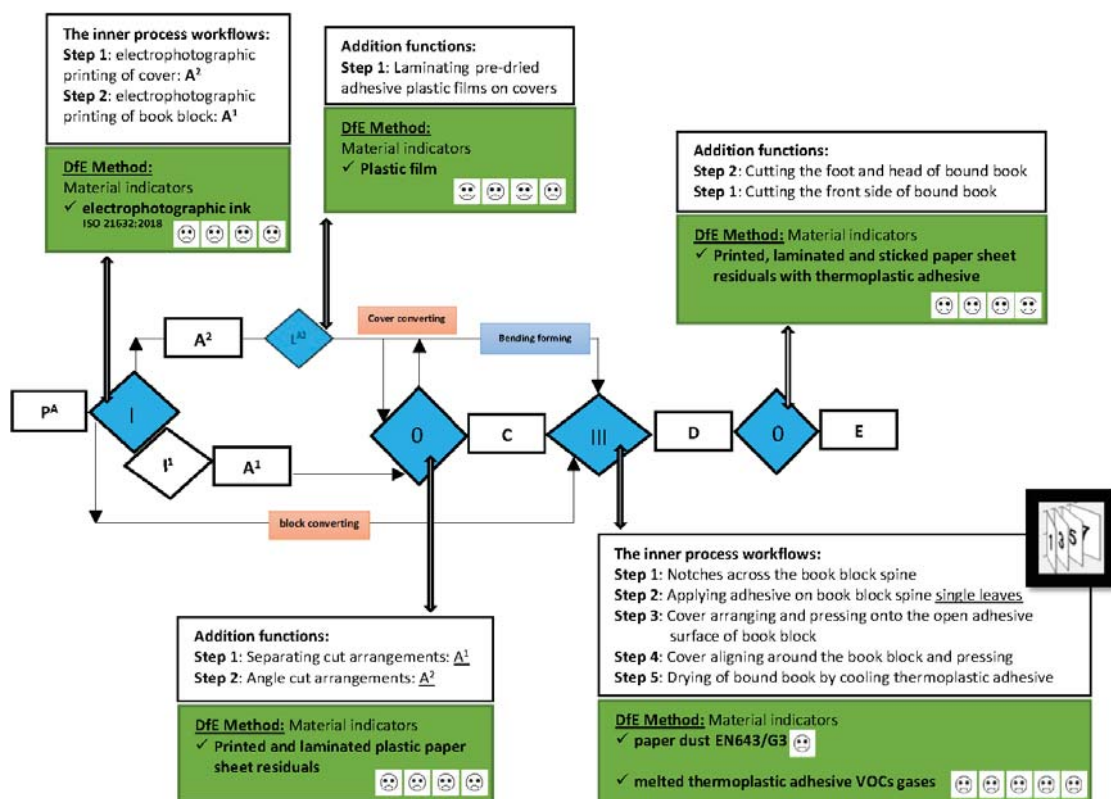


Figure 5: Processes (inputs, outputs) in digital printing and perfect binding workflow connected and captured through environmental impact of graphic art materials (on demand book production)

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 APPROACH

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, adhesion, 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. For 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 correlates 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

The authors are grateful for the financial support of the University of Zagreb, Grand under the title: “Characterization, durability and sustainability of advanced graphic materials and packaging”.

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