ISSN–2538–8622

INNOVATIONS IN PUBLISHING, PRINTING AND MULTIMEDIA TECHNOLOGIES

INOVACIJOS LEIDYBOS, POLIGRAFIJOS IR MULTIMEDIJOS TECHNOLOGIJOSE

Vol 1 No 2 (2025)

Kaunas, 2025

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STUDY OF OPTIMAL CONDITIONS FOR THE PRODUCTION OF PAPER BARRIER PACKAGING BY THE FLEXOGRAPHIC PRINTING METHOD

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Abstract

Increasing environmental pollution from plastic packaging, especially multi-layer films that are difficult to recycle, necessitates the search for effective ecological alternatives. Simultaneously, modern packaging requirements include enhanced barrier properties to meet global logistics needs and long-term product storage. A promising solution is the creation of paper packaging with functional coatings, particularly barrier coatings and heat seal varnishes. The study aimed to determine the optimal technological conditions for creating such packaging using flexographic printing.

The research was conducted on an Optima 2 flexographic printing press manufactured by Soma Engineering, using an additional IPU (Intelligent Printing Unit) section. Two types of paper with grammage of 70 g/m^2 and 80 g/m^2 from different suppliers were tested. A water-based heat seal varnish based on copolymer dispersion and a barrier primer were used to provide the paper with barrier and heat-sealing properties. The study included experiments with various combinations of functional varnishes, printing speeds (100-300 m/min), types of ink pumps, and forms of anilox roller cells. Parameters such as dry residue content, oil resistance, and heat-sealing strength at different temperature regimes and sealing conditions were evaluated.

It was determined that the best results are achieved with the combined application of barrier varnish followed by heat seal varnish at a speed of 100 m/min. Measurements showed that paper with lower grammage (70 g/m^2) and lower smoothness can accept more varnish during printing (2.8 g/m^2 vs 2.3 g/m^2 for barrier varnish and 5.9 g/m^2 vs 5.4 g/m^2 for heat seal varnish). The barrier varnish provided excellent oil resistance (5 points after 1 hour of exposure), which remained high (3 points) even after 24 hours of exposure. Heat sealing studies showed that optimal sealing is achieved at temperatures of 130–210 °C with a clamp width of 25 mm and a clamping time of 0.5 seconds.

It was established that using an anilox roller cell produced with GTT technology and a peristaltic pump significantly reduces foam formation and improves varnish transfer in the printing unit's ink system. It was determined that the quality of paper packaging sealing is significantly affected by the clamp width and sealing time, with an increase in both factors improving adhesion strength. The practical result of the research is the developed technology for creating environmentally friendly paper packaging with enhanced barrier properties against moisture and fats, which can also be effectively heat sealed. This approach allows for the replacement of multi-layer plastic packaging materials with ecological paper alternatives without losing functional properties.
Keywords: *barrier coating, flexographic printing, paper packaging, varnish.*

Introduction

The situation with environmental pollution by plastic packaging (especially multilayer films, which are difficult to recycle) requires the search for effective ecological solutions. At the same time, the fast pace of life, global logistics, and large warehouse residues require an increase in the barrier properties of packaging. One way to solve this problem is to create packaging from paper with the application of various functional varnishes. Paper is one of the oldest types of packaging material. Currently, paper and cardboard are the most common packaging materials, occupying the third place in the food packaging market (Netramai et al., 2016).

As varnishes, various barrier coatings are usually used, ensuring the tightness of the packaging – cold seal and heat seal. In most cases, the image is applied to this type of packaging using flexographic printing, which has proven itself best in small and medium runs. Flexographic printing is also used for heat seal application (Chiu et al., 2012). As for cold seal, sometimes flexographic printing does not allow to achieve a certain grammage of this coating, and therefore, in this case, rotogravure is a more effective method (Ilhan et al., 2021).

In (Aghamohammadi, 2023), the author shows that four main factors can influence the process of producing cardboard packaging using functional varnishes, namely: the chemical composition of the varnish, the amount of varnish applied to the cardboard, the weight and thickness of the reference cardboard, and the parameters of the welding equipment. In addition, the author argues that the heat sealability of varnishes depends not only on their chemical composition, but also on the increase in the number of varnish layers during flexographic printing, which can improve the water resistance and

heat sealability of products. The work shows that the choice of cardboard of the correct thickness and mass can positively affect the processability of the material during the production process. It should be noted that the author of the article does not fully disclose in his work the aspects of the factors influencing the amount of applied coating (primarily referring to the factors of the varnish application process) and does not take into account the influence of the paper structure on the heat-sealing properties in the paper-varnish system.

Methodology and equipment

This work investigated the technological conditions for creating paper packaging using barrier varnish and heat seal coating. Both functional varnishes were applied using flexographic printing on an Optima 2 flexographic press manufactured by Soma Engineering.

The coating was applied using the IPU (Intelligent Printing Unit) section, which is an additional option for a printing press with a central printing cylinder and consists of a small central printing cylinder and one or two flexographic printing sections (these can be either flexographic or rotogravure sections, as determined by the production tasks). This option in a printing press is typically used to apply various functional varnishes, including primers, finishing varnishes (matte, glossy, tactile (paper touch)), heat seal varnish and cold seal adhesive.

During the tests, a 4-color image was printed on one side of the paper simultaneously on the main printing sections of the press and functional varnishes were applied on the back side on the additional IPU section.

Two types of paper were taken from different suppliers with a grammage of 70 g/m^2 and 80 g/m^2. It should be noted that the 70 g/m^2 paper had less smoothness and more porosity. For application to paper materials for the manufacture of packaging, the studies used a water-based heat seal adhesive intended for direct contact with food products. This adhesive is fully recyclable. The coating, based on a copolymer dispersion and a stable vegetable wax emulsion, provides specific barrier properties. In particular, excellent grease resistance (OGR) combined with providing a certain level of water vapor transmission rate (MVTR), low values of water absorption capacity of paper Cobb and coefficient of friction of packaging (CoF). The ability to heat seal this adhesive occurs even at low temperatures (75–80°C) (Mostyka et al., n.d.).

It should be noted that the level of adhesion strength is related to the stability of the paper itself, since in all cases we have fiber breakage (Hishinuma, 2009). In addition, to reduce the porosity of the paper, it was decided to

apply an additional layer of the so-called primer, which not only smoothes out the paper's irregularities, but also performs an additional barrier function. This primer has the following characteristics: some resistance to oil and grease; some water resistance depending on the substrate and printing technology (it is often applied in two passes to cover all paper defects).

Since both varnishes (heat seal and primer) are water-based, as noted in the technical specification, better drying will be achieved if the airflow is increased and the drying temperature is reduced.

The following material and equipment parameters were selected for applying the first and second layers of varnish:

- Printing plate specification:
  - Printing plate type – digital.
  - Design type – solid plate.
  - Printing plate manufacturer – XSYS.
  - Printing plate thickness – 1.14 mm.
- Anilox roller specifications:
  - Anilox cell shape: 1st step – hexagonal; 2nd step (to increase ink transfer and reduce foam formation in the ink container) – GTT.
  - Cell volume – 25 cm^3/m^2 (2 IPU section) and 18 cm^3/m^2 (1 IPU section).
- Mounting tape specification: medium hardness (manufacturer 3M, series 1020).

Presentation of research results

As a result of several tests with changing combinations of two types of varnish, changing the printing speed, the amount of dry residue was monitored and the barrier properties of the resulting layers were determined (Table 1, 2). Also, Table 3 shows the results of the study of the quality of heat sealing. During the tests, it was decided to change the type of ink pump and the type of anilox cell in order to improve the conditions for applying varnishes.

As can be seen from the results of the conducted research optimal conditions for creating paper barrier packaging are achieved through the combined application of functional coating layers – first applying the barrier coating, followed by heat seal coating at a speed of 100 m/min, which provides the best dry residue mass (5,9 g/m^2).

Table 1. Test results with changing combinations of functional varnishes

No.	Mass of dry residue, g/m^2	Type of varnish on section 1, cell volume 18 cm^3/m^2	Type of varnish on section 2, cell volume 25 cm^3/m^2	Printing speed, m/min
1	2,6	Heat seal	X	100
2	5,9	Heat seal	Heat seal	100
3	4,9	Heat seal	Heat seal	200
4	5,9	Barrier varnish	Heat seal	100

Table 2. Results of applying functional varnishes at different speeds

No.	Substrate type	Coating	Printing speed	Mass of dry residue, g/m^2	Grease resistance (olive oil)		
					1 hour	4 hour	24 hour
1	Paper 70 g/m^2	without coating			0	0	0
2	Paper 80 g/m^2	without coating			0	0	0
3	Paper 70 g/m^2	Barrier varnish	100 m/min	2,8 g/m^2	5	4	3
4	Paper 80 g/m^2	Barrier varnish	100 m/min	2,3 g/m^2	3	2	2
5	Paper 70 g/m^2	heat seal	300 m/min	5,9 g/m^2	1	1	1
6	Paper 80 g/m^2	heat seal	300 m/min	5,4 g/m^2	1	1	1

0 – no grease resistance, 5 – excellent grease resistance

Table 3. Dependence of fiber strength on welding conditions

Sample type	Welding conditions	Tensile strength of fibers at different temperatures							
		70º	90º	110º	130º	150º	170º	190º	210º
70 g/m² paper with heat seal layer applied at a speed of 300 m/min	Welding equipment clamp width 25 mm, pressure time 0,5 s	0	1	3	4	5	5	5	5
	Welding equipment clamp width 5 mm, pressure time 0,2 s, cooling time 0,5 s	0	0	0	2	3	3	2	2
	Welding equipment clamp width 25 mm, pressure time 0,5 s, cooling time 0,3 s	0	2	3	3	3	2	0	0

0 – no welding (fiber breakage), 5 – maximum welding (complete fiber breakage)

The research demonstrated that paper with lower basis weight (70 g/m²) and smoothness can accept more coating during printing and shows better oil resistance (5 points in the first hour) compared to 80 g/m² paper. Using anilox rollers with a channel structure (GTT) and a peristaltic pump significantly reduces foam formation and improves coating transfer. Regarding heat sealing, the best results are achieved using clamps with a width of 25 mm and a clamping time of 0,5 seconds at temperatures above 150 °C, which ensures maximum bond strength (5 points out of 5).

Conclusions

During the tests, it was found that to apply the maximum amount of adhesive, ensure weldability and create the best barrier properties, the optimal solution would be to apply a layer of barrier varnish followed by application of heat-sealing varnish at a speed of 100 m/min. It was noted that the choice of an anilox roller cell manufactured using GTT technology and the use of a peristaltic pump reduces foaming and increases varnish transfer in the ink system of the printing press. It has been noted that paper with a lower grammage and smoothness is able to accept a greater amount of varnish during the printing process. It has been determined that the sealing quality is affected by the width of the clamp and the time of sealing the package, increasing both factors improves the adhesion strength.

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3D CAD AND 3D PRINTING-BASED PRODUCT DESIGN: CASE STUDY OF AN ARMCHAIR

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Abstract
Digital design is an efficient way of implementing furniture concepts. Advanced tools for rendering have a considerable effect on increasing their visibility via the use of sophisticated software that simulates the final appearance of furniture using appropriate textures, colors and environment. Although color plays an important role in the product's promotion, additional use of textures creates a more realistic appearance. The goal of this study was to develop an armchair using digital designing and physical prototyping. A variety of methodological and digital tools have been used to create a unique product, with effective application of 3D CAD and 3D printing technology in the design of an armchair. The present paper deals with the design of an armchair for children. Anthropometric shapes were used in the design process, thus digital sketches assisted in digitizing the armchair using an advanced Computer Aided Design (CAD) system. These models were enriched with colors and textures in order to convey the design concept, while providing a realistic view of the final solution. The prototype was built based on the CAD models created, in order to verify the incorporated specifications. Combining not only the effective geometry of the armchair but also its colorful appearance, a customized product for children was developed. Both the methodological and technological tools used supported the creative approach to the design of the armchair presented.

Keywords: *sculpting, CAD, product design, prototyping, 3D printing.*

Introduction

Digital 3D design technologies dominate product development. The needs of both customers and enterprises are served by professionals that combine methodological and technological tools in product and furniture design. A great deal of resources can be saved if all the available tools are used at the early stages of the design cycle i.e. the mind map (a conceptual map that gives the designer the opportunity to think out of the box), 2D

digital sketching (offers the opportunity to be creative in two dimensions and explore a number of design directions), CAD (Computer Aided Design, digitize the 2D sketched concepts in 3D models), rendering (creating real life-like digital appearance of the designed product), prototyping (with the use of a prototype technique the final concept is examined if meets all the requirements set, 3D printing technology offers additional advantages at this stage).

The longer the analysis and development process of the new product, the fewer errors the final product incorporates. For all industries, every error discovered later during the product development cycle results in higher cost for corrective actions. This is the basis for using all the available methodological and technological tools with the aim of avoiding making mistakes or spotting them as soon as possible during the design cycle.

Castellucci et al. points out that all the pieces of furniture should follow a series of guidelines based on anthropometrics and ergonomic principles, i.e. front tilted desks, high seat chairs. As a result, chairs can improve posture, academic performance and attention in the classroom (Castellucci et al., 2017). Jiang et al. dealt with young users and their preferences. They refer to the impact and choice of color by younger generations. Adults usually choose dark furniture while children's preferences include particular interest in white ones. In more detail, girls prefer red and white for chair colors, while boys prefer green, blue and yellow (Jiang et al., 2020). Sraiheen and Dalgin in their work on the importance of color, state that it can affect the consumer's overall perception of a product. Color is not perceived the same by men, women, and their country of origin. People emphasize color in specific product categories in different ways. Sraiheen and Dalgin provided a solid basis about the importance of color in clothes, shoes, and home related product colors. They even proved that a number of differences presented were related to genders. Men emphasized more on the digital colors they use, while women showed strong preferences to the colors and shades, they wear (Sraiheen, Dalgin, 2018). With respect to the combination and the colors importance, Lucius and Fuad stated that the color wheel can support and enrich the available data. This is achieved through the attractiveness created by the graphs and combinations that are proposed. Some of these are complementary, which consist of two colors that are opposite to each other on the color wheel. They also emphasize other harmonious combinations, i.e. equilateral triangle shape on the color wheel. The equilateral triangle on the color wheel can give combinations such as yellow, red and blue, which are the most powerful triad of colors and are called fundamentals (Lucius, Fuad, 2017). An alternative approach to product design is proposed by Manavis et al.,

when presenting the importance of product inspiration from nature. In this research, it is argued that nature is one of the oldest design methodologies, developing alternative illustrative examples inspired by nature thus providing new opportunities in marketing and product promotion. It is even argued that computational design tools can be used for designing highly complex geometries that are inspired by nature (Manavis et al., 2019).

People often emphasize the packaging and the way that it can attract the customers' attention. An unusual work for a toothpaste package was proposed by Malea et al. In this research, toothpaste packaging was developed, based on anthropocentric design and environmentally friendly principles. The development of the packaging was supported by different tools i.e. mind map, 2D digital sketches, 3D CAD modeling, rendering, prototyping (Malea et al., 2020). Ligka et al. developed a wearable headband for increased aesthetic purposes. It was developed based on both parametric design and biomimetic principles. Parametric design offers the opportunity to provide a great deal of alternatives and can satisfy different customer demands. At the same time, the product is customized for each user and can be 3D printed for prototyping or fabrication purposes (Ligka et al., 2024). In the present paper, a children's armchair was perceived and developed using a series of methodological tools, i.e. mind map, 2D digital sketching and technological media i.e. 3D CAD system for modeling and rendering purposes, 3D printing facility. The main idea was to have an armchair that can attract children's attention and be comfortable for use based on ergonomics.

Proposed methodology

In this study, a nature inspired armchair for children was proposed with an aim to combine biomimicry with ergonomic and a customer centered approach. The frame of the armchair was inspired by the branches of the trees and takes advantage of the familiarity that children have with them. Further to the product's definition and the initial 2D digital sketches, 3D CAD models were designed. The armchair was initially rendered with the appropriate colors and textures and then prototyped by a 3D printing facility (Figure 1). The design thinking principles were incorporated in this study by using methodological and technological tools together with the early involvement of the users. The users were able to provide an early evaluation of the proposed armchair design via the 3D printing prototype produced. At the same time, they felt satisfaction in contributing to the design process.

Workflow schematic		
Product Category	Interior Design Product	Children's Armchair
Design Concept	Inspiration	Natural colors & ergonomic design
Implementation Tools	CAD	Visualization & 3D CAD Modelling
3D Printing		

Figure 1. Workflow schematic to create products

Case study development

The first methodological tool used was the mind map. Through the mind map, the scope of solutions is expanded. In the case of the children's armchair, the most unusual ideas/proposals were promoted i.e. the imitation of the structure of tree branches and the balance of colors (Figure 2).

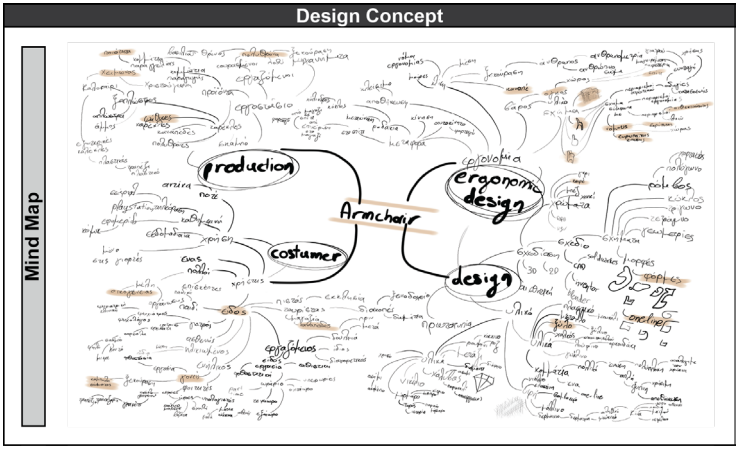

Figure 2. Mind map used for increased inspiration

Based on these ideas a great deal of 2D digital sketches were developed and captured the tree branch concept defined previously. A four-step approach was followed with different levels of sketching details (Figure 3):

- Process sketches: the inspiration used natural shapes and various seat geometries, i.e. car seats, school chairs, office chairs, children's seats, lounge/medical chairs, armchairs.
- Ideation sketches: a great number of chairs and armchairs shapes were examined.

- Explanatory sketches: A selection process was used to finalize the proposal in 2D sketched form and more detailed appearance of the proposed design was achieved.
- Persuasive sketches: a final sketch was created that captured the proposed armchair geometry and concept. It has included textures and colors.

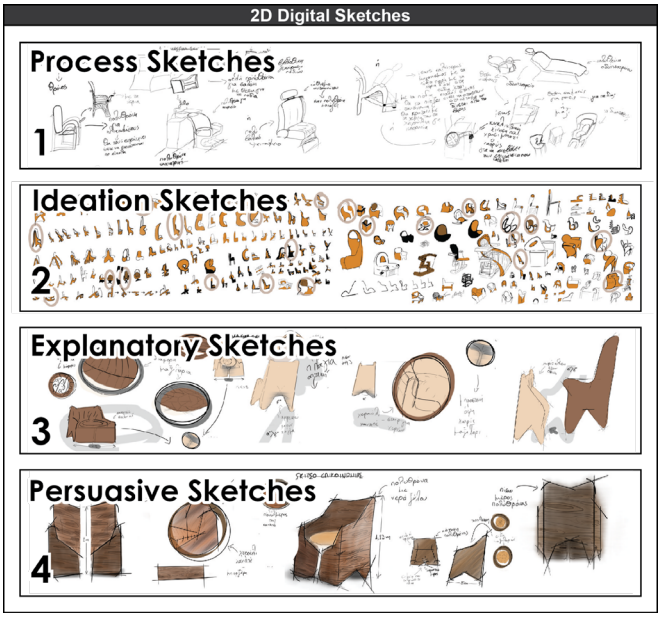

Figure 3. Sketching development in 4 stages

A 3D CAD modelling technique supported by sculpting was necessary due to the complexity of the geometry proposed. The mesh of the created geometry demanded a lot of attention in order to mimic the texture of a tree. Blender™ CAD software was used in this case because it is a powerful digital tool that at the same time is free and open accessed. Complex geometries can be modeled and provide high quality digital models for prototyping. During the armchair design anthropometric data and dimensions were taken into consideration, while at the same time filleting the geometry was necessary in order to avoid sharp corners for safety reasons. The main geometry of the armchair was a combination of a stool surrounded by a frame that

looked like a tree geometry. The tree geometry was modeled using CAD based sculpting techniques that provide a way to model unusual geometries. Blender™ has a specific module for this modelling approach.

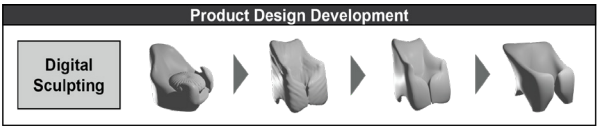

Figure 4. Design development using digital sculpting techniques

In more details, 3D CAD modeling resulted in shaping the armchair to look like tree with the appropriate branches, while the stool was positioned inside the surrounding geometry for easy transportation and use. The use of the appropriate color combinations was made based on the wheel of colors in order to attract the attention of the children. So, combining blue with shades of red, green with shades of red, and shades of blue with white, resulted in attractive selections from the user's point of view (Figure 5).

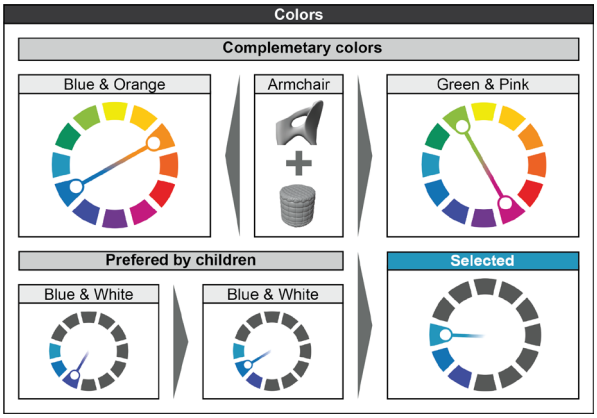

Figure 5. Color matches the rules and preferences of children

Figure 6 depicts the 3D CAD modeling workflow, and the three alternative colors used to satisfy the variety of users. The results present a detachable armchair inspired by the shape of trees. The shades were related to the preferences of children and the rules of the color wheel.

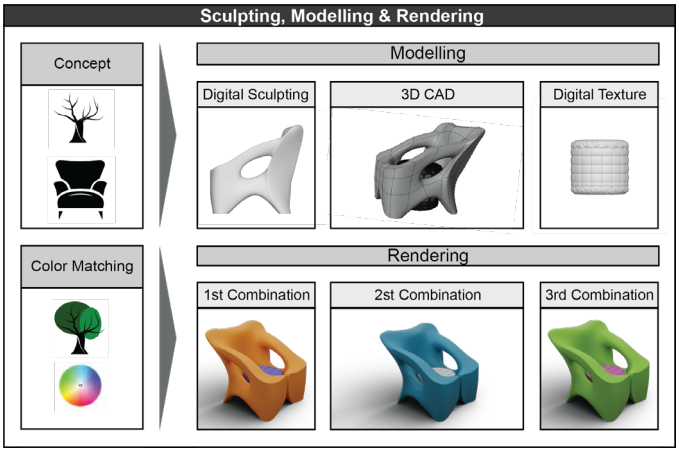

Figure 6. From concept to 3D CAD modeling

For the digital 3D model to be 3D printed for prototyping purposes, a series of guidelines should be followed. They concern the integrity of the surface in 3D printing and the quality of both the CAD based and 3D printed resulting surfaces (Table 1).

Table 1. Guidelines for the 3D printing procedure

Conditions	**Description**
Compatible files	STL are the compatible files that the CAD system exports to be compatible with the 3D printer.
Number of polygons	Using many polygons creates a better surface of the printed object but it can be difficult to manage large pieces of information.
Coordinate system	It is recommended that the designed object coordinate system assists in improved handling of the geometry within the 3D printing workspace.
Non-Manifold	Continuity of the model volumes is essential (closed geometry model).
Materials and methods	Depending on the material selection, the rest of the 3D printing manufacturing parameters are set (speed, temperatures, infill etc.).
Scale	The scale should be proportional to the requirements of the final model

Printer Size	It is necessary to have the size of the 3D printer checked. More specifically, the size of the object to be printed is required to be smaller than the size of the printer. Printing in scale can be an option.
Details	Emphasis should be placed on details. It is good to know that small details (geometrical characteristics) may not be visible when 3D printed.
Tolerance	The 3D printed object size can be considerably different from the dimensions set. More research work about the manufacturing parameters selected is usually needed.
File name	Simple name with English characters that is easily recognized should be used, when a lot of files are produced
Orientation	The object's orientation affects the mechanical properties of the final 3D printed item.

Following the proposed guidelines, the possibility of error during printing was reduced and the process of final prototyping was accelerated. Although there were a variety of 3D technologies available, Fused Filament Fabrication (FFF) was selected in this case study, mainly due to the size of the armchair. The CreatBot™ 3D printer was used (D600 Pro) with useful printing area dimensions of 0.6 m × 0.6m × 0.6 m. PLA EVO was selected in order to increase the printing speed to 50 mm/sec and reduce the printing time to 72 hours (Figure 7).

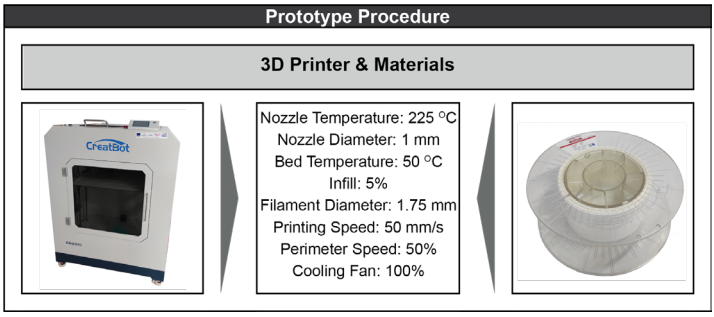

Figure 7. 3D Printer used and its settings

The volume of the final geometry resulted in an approx. 5 kg prototype. No problems occurred during 3D printing, and the surface quality was satisfactory for this application. Then, cardboard was used to create the seat. The

seat was placed inside the printed prototype for completing the product's final layout (Figure 8).

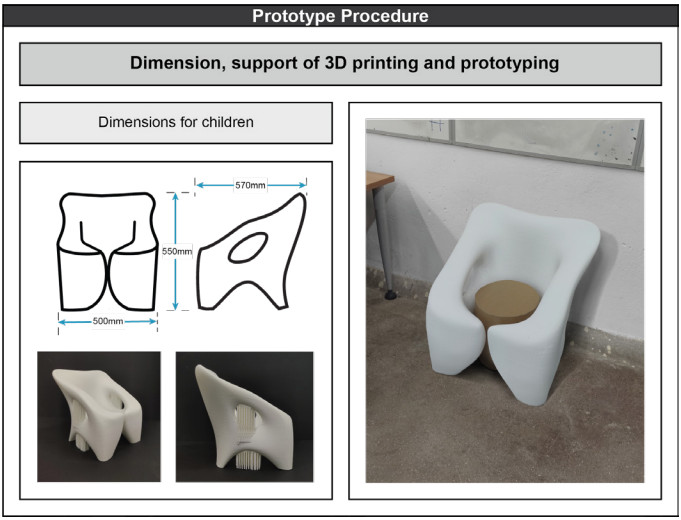

Figure 8. Dimensions, supports and the result of 3D printing

Results

An early evaluation was conducted based on the opinion of five couples of parents (10 people). Most of them (80%) expressed their approval for building customized armchairs for children with unusual geometries that can attract the user's attention. Although the 3D printing technology at the beginning was considered a positive issue by all the participants, at a later stage, there were concerns about the structural integrity of the products fabricated with this process (60%). All the participants (100%) expressed their satisfaction because their opinion was asked during the armchair unusual geometry design and they felt connected to the design process itself.

Conclusions

Through this research, a children's detachable ergonomic armchair was developed. The methodological and technological tools used were mind map, 2D digital sketching, 3D CAD modeling (sculpting), rendering and 3D printing. The mind map led to the primary idea regarding the imitation of the tree and its branches. The stool resembled the base of the tree. Then, with the help of the 2D digital sketches, a number of concepts were examined.

The proposed geometry was then digitized in 3D using a CAD system. The 3D CAD models were used for rendering and promotion purposes, taking into account the best practices for color selection, when children are involved as users. Finally, the prototype of the armchair was 3D printed on a 1:1 scale. The prototype was used for an early evaluation procedure and thus involving the customers well ahead in the product design lifecycle. During the 3D printing fabrication process, additional manufacturing guidelines were considered, and the final prototype was prepared with high surface quality delivered.

The prototype was detachable and could also be used as a stool for easier use and transportation. Combining not only an effective geometry of the armchair but also its colorful appearance, a very attractive product for children was developed. The creative approach to the design of the armchair opens new possibilities for its application.

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IMPLEMENTING PRODUCT DESIGN METHODOLOGY TOOLS: A DESK LAMP CASE STUDY

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Abstract
The product design process is used to develop new innovative products or to improve existing ones. The category of space decoration covers items that are mainly designed based on aesthetics and thus help users to enjoy an easier and more efficient lifestyle. Desk lamps are developed either for functional or aesthetic purposes. A large part of their use is in the workplace, and they aim to increase productivity. The contribution of the present work is to deal with the design of a prototype desk lamp that can combine both the functional and aesthetic characteristics required. In order to achieve this goal, a number of methodological and technological tools have been implemented in the development of the product itself i.e. mind-map, sketches, color selection process, a 3D Computer-Aided Design (CAD) modeling and 3D assembling, a high-quality rendering tool, and prototyping. A step-to-step approach was taken, starting with a search for similar works published, developing the design concept from scratch and finishing with a prototype using 3D printing technology available. The developed prototype provided a solid basis for an early evaluation of the users' perception of the designed product. A 3D CAD system has been used to achieve both the modeling and the prototyping of the product. Combining functionality and aesthetics, a design concept has been developed, a 3D printing prototype has been produced and finally an early evaluation of the outcome became available by experienced design engineers.
Keywords: *design thinking, design product, CAD, prototyping.*

Introduction

Desk lamps are divided into two main categories. The first category is the decorative desk lamps which offer a pleasant atmosphere at home. Utilizing such a decorative object in close spaces offers the opportunity to create a relaxing environment. The second category concerns desk lamps which have a more functional character and purpose (Zhang et al., 2019).

These lamps are used either at home or at the workplace. However, beyond that, desk lamps differ depending on the type. There are mainly 3 types of lamps. The first type includes the lamps whose base is placed on the desk with a clamp. The second type supports those that have enough arms and joints to have the appropriate adjustment. And at the last type belong the classic ones whose base is fixed. In addition, the intensity of the light plays a decisive role. Lighting can affect the user's performance in studying.

Lian et al., in their research published on the design of desk lamps, refers to a new system of smart lamps. These lamps differ in that they provide a camera and two servo motors that help the lamp lock the position of the book that the user studies as it moves. The design of the lamps includes a vision system as well as a servo motor control system. These lamps also have two tilt adjustment capabilities at 30 degrees and 60 degrees. Finally, the FPGA technology (Field-Programmable Gate Array) is used (Lian et al., 2021).

Su et al. in their article, refer to the correlation between the products of the modern era and the impacts they create on the environment. In addition, the research focuses on the tools and methods for properly creating a new innovative lighting product from scratch. It is worth noting that ecological design played a dominant role. Then, after the new product was completed, LED lamps were compared with the traditional lamps available on the market. The results showed that LED luminaire is superior in terms of product life cycle and lighting efficiency but mainly in terms of affecting the environment (Su et al., 2021).

Wang et al. state that, the product life cycle should not consist of just one phase but of two different ones. The first phase includes product development, which usually includes the initial designs and prototyping or otherwise manufacturing the product. The second phase concerns services, which usually involve sales, distribution, purchasing, maintenance and others. Both phases combined can lead to a successful product design and fabrication. According to a study conducted, LED luminaire was 46% less harmful to the environment and the resources saved were over 14% annually (Wang et al., 2020).

In the present study, a desk lamp was designed and 3D printed, with a stable base and unusual shape. All the characteristics introduced contribute towards combining both the successful aesthetics and their functional behavior. This was the main aim of this study in order to include advantages from both directions. During the design process the methodological tools provided increased inspiration and novel geometries. At the same time, the appropriate digital tools used 3D CAD (Computer Aided Design) based models that were fit for 3D assembling, rendering, prototyping and early evaluation.

Proposed methodology

The methodology followed was based on a design thinking approach that manages to utilize not only methodological tools for increased inspiration, but 3D CAD based technologies with a number of downstream applications. The mind map tool was used for documenting a number of different design directions. It was supported by words and images that could be used to spark new ideas that could be used towards the novel desk lamp design. Furthermore, they were based on demand and requirements for extra lighting features and geometrical forms.

2D sketches were the basis for exploring a series of ideas, improving the designer's perception of the product and documenting concepts that could be effectively implemented (Manavis et al., 2024a). Firstly, the customer needs and the technical specifications demands were used as the starting point for initiating the product development cycle. Then a great deal of 2D sketches were developed and assisted in exploring the design space in more detail (Manavis et al., 2024b). Finally, the selected idea was 2D sketched in detail and with the use of alternative features and geometrical characteristics.

Based on these 2D sketches provided, the 3D model was produced by using an advanced CAD system to which the product features and details were added. The proportions and dimensions of the product were included, and a detailed definition of the final product was delivered. The aesthetics and functional use of the product were tested via a 3D printing fabricated prototype (Figure 1).

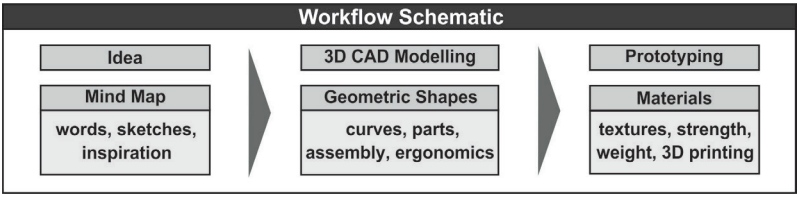

Figure 1. Workflow schematic (ideation, 3D modeling and prototyping)

Case study development

Following the different steps presented, a set of 2D sketches were prepared and developed the conceptual design steps based on the ideas revealed from the mind map. The ideation phase visualizes the designer's inspiration, and the ideas can be easily communicated within the design team and the customer/user. For this reason, it is important to follow a structured way

with an aim to use the sketching procedure effectively, which leads to a four-level approach described in the literature (Minaoglou et al., 2023).

Figure 2 depicts a simplified version of the mind map used. It contains the main directions proposed and the computer-aided based tools to be used. The figure also provides a detailed understanding of the 2D sketches four levels theory application. The first level develops basic concepts, the usage of the product and is an evolution and visual continuation of the mind map. The second level develops many different directions and inspirations for the product with the aim of creating novel geometries, characteristics and forms. In the third stage, the sketches focus on a particular design form. It can combine prior ideas or develop further an existing one, while analyzing in more detail the selected product's inspiration. Finally, in the fourth stage, the product is presented within its working environment.

The final proposal was to develop the desk lamp following the geometric combination of relatively simple shapes i.e. circle, triangle, square. As a result, the primary forms emerged, and the final proposal was to integrate geometrically a circle and a triangle. Combining sharp angles with fillets and curves provided an unusual geometry that could be produced only with the use of 3D printing technology.

The concept was 3D modeled using Autodesk™ Inventor™ advanced CAD system (Computer Aided Design). When the 3D modeling process finished, different colors and textures were incorporated in order to prepare a set of photorealistic images (Figure 3). Those images were able to facilitate the lighting effect and present the lamp very realistically. It was expected that the lamp would be basically metallic for increased durability (Myerson et al., 1990).

Regarding the preferred colors, for this concept brown, yellow and gray were selected. These colors are neutral, making them easier to be integrated into interior space decoration (Figure 4).

Although, a 3D printer was used in order to fabricate the prototype, the same technology could be used for producing the final product as well. For prototyping purposes and for assessing the desk lamp in real dimensions the PLA-EVO (Polylactic acid) by NEEMA3D™ was used, well known for its biodegradable nature (Figure 5). Furthermore, the proposed material for fabricating the final product could be the composite material Spartan Copper by NEEMA3D™. This material consists of 80% copper powder and 20% PLA. This would result in having an almost metallic desk lamp with the advantages of plastic material.

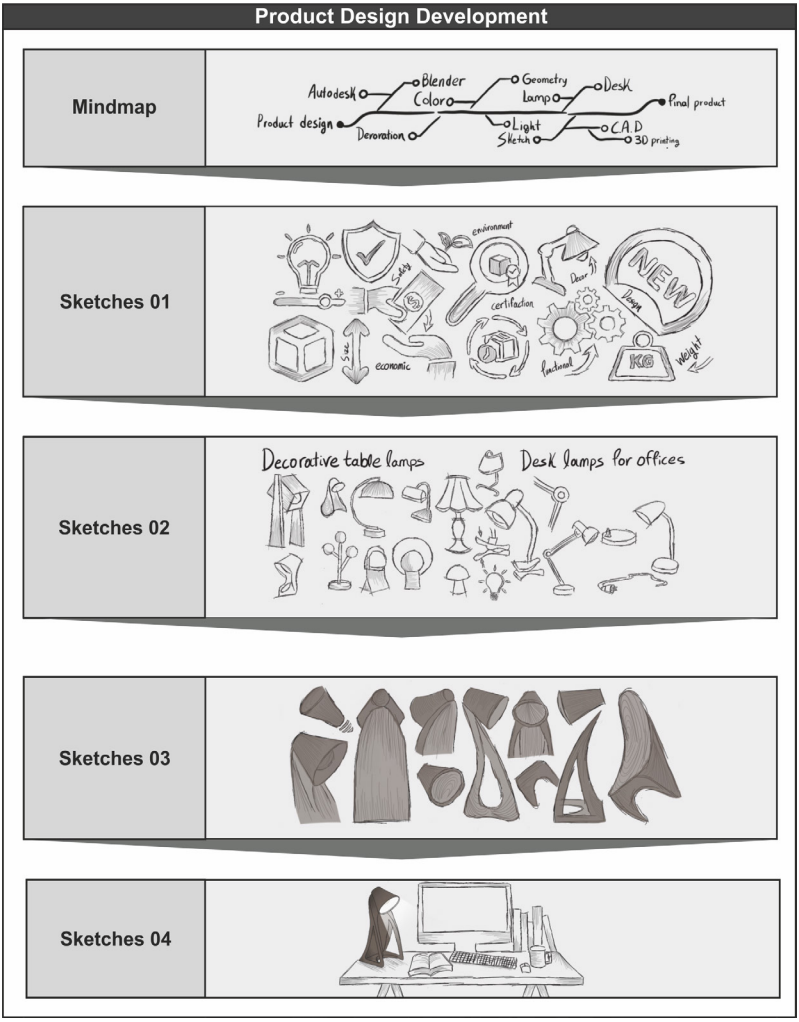

Figure 2. Product design development (mind map and sketches)

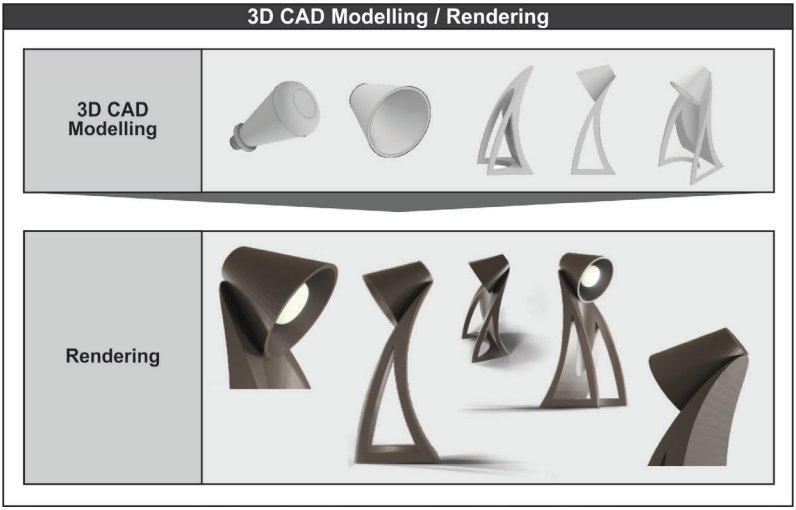

Figure 3. 3D visualization and Rendering

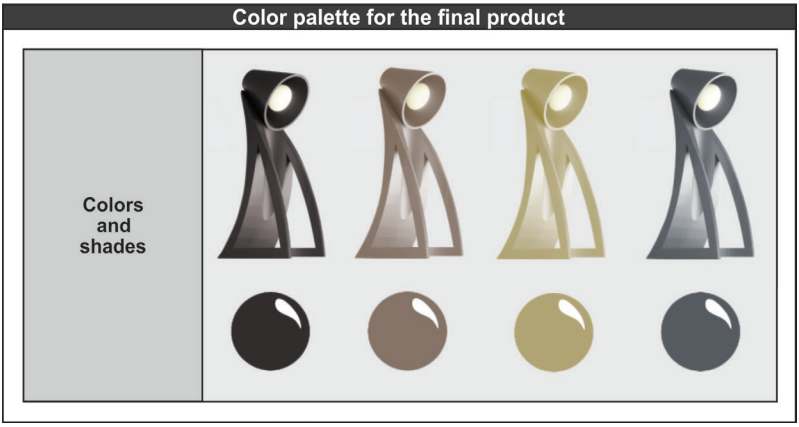

Figure 4. Application of colors to the product

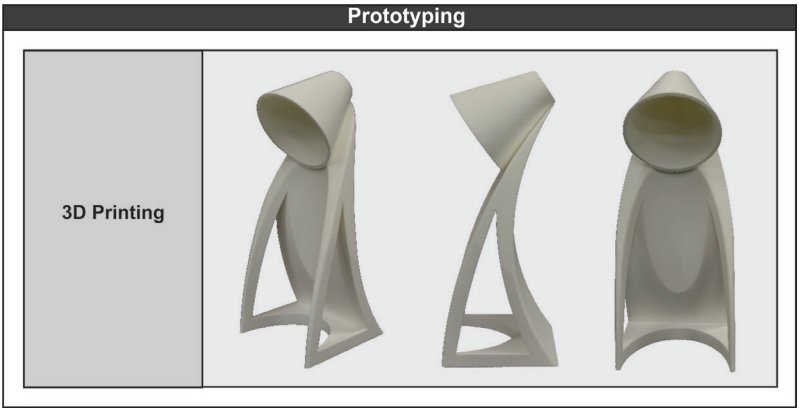

Figure 5. The prototype created by 3D printer

Results

The prototype was examined by three design engineers with more than 5 years of experience, and an early evaluation became available. Although they enjoyed having 3D printed prototypes of unusual geometry products early for evaluation, they expressed doubt if the same 3D printed fabrication could be used in a large-scale production due to time constraints. Nevertheless, based on their opinion the unusual geometry proposed for the desk lamp design is attractive. It can be a solid basis for designing customized lamps that will be fabricated by a variety of materials with 3D printing technology. Following this strategy both coloring and texturing can be implemented with most materials available with the fused filament fabrication (FFF) technology.

Conclusions

The presented work emphasizes the design and fabrication of a desk lamp, when combining methodological and digital tools for its development. Mind map and 2D sketching helped develop the geometrical characteristics of the product and 3D CAD modelling offered additional photorealistic images of the final product. Due to the unusual geometry of the desk lamp, 3D printing was proposed for both the prototyping and the final fabrication processes. For this reason, two separate materials were used and proposed. Especially the composite material Spartan Copper by NEEMA3D™, can offer increased durability of the metallic materials together with the advantage of light plastic. In addition, a series of alternative colors were proposed with the aim of offering an easy to incorporate product within the office interior design.

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AN OVERVIEW OF MULTIMEDIA INNOVATION IN THE WESTERN BALKANS

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Abstract

The Western Balkans is increasingly becoming a fertile ground for multimedia innovation. With rapid advancements in technology and a growing interest in digital transformation, the region is witnessing significant developments in multimedia, digital content creation, and innovative digital solutions. This study aims to explore the extent of multimedia innovation in the Western Balkans by addressing the following research question: How are multimedia industries developing in Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, and Serbia, and what factors influence their growth?

The methodology of this research is based on a qualitative approach, incorporating an extensive review of academic literature, policy documents, and industry reports. Secondary sources, such as reports from international organizations like the European Commission, World Bank, UNESCO, and UNDP, were analyzed to understand regional trends in multimedia innovation. Additionally, information from official government websites, film festivals, and multimedia industry stakeholders was included to ensure a comprehensive assessment of the sector.

Numerous initiatives and institutions are driving multimedia innovation in the Western Balkans. The Marubi Academy of Film and Multimedia in Albania stands out as a premier institution offering education and training in film, television, and digital media. Similarly, the Faculty of Dramatic Arts in Belgrade, Serbia, provides comprehensive programs in multimedia arts. Additional institutions such as the Academy of Arts in Novi Sad and the University of Sarajevo's Faculty of Performing Arts also contribute significantly to training future multimedia professionals. Sarajevo Film Festival and the Anibar International Animation Festival in Kosovo have become prominent platforms for showcasing multimedia works. Technological advancements such as augmented reality (AR), virtual reality (VR), and artificial intelligence (AI) are being integrated into multimedia projects in the Western Balkans.

Despite advancements, challenges remain, particularly in areas such as infrastructure development, access to high-quality equipment, and the

need for more specialized education programs in multimedia fields. Addressing these gaps will be crucial to unlocking the full potential of the region's creative economy. Governments across the Western Balkans have made significant strides in creating a favorable environment for digital innovation, but continued support, both financially and in terms of policy reforms, will be necessary to overcome existing barriers. Additionally, collaboration between countries in the region, as well as with international partners, will be key to creating a more sustainable and competitive multimedia ecosystem. Investment in digital education and training will be critical in nurturing talent and ensuring that the region will remain competitive in the future.
Keywords: *multimedia innovation, digital transformation, Western Balkans.*

Introduction

The region's unique blend of cultural diversity and historical richness provides fertile ground for multimedia storytelling, attracting local and international audiences alike. The Western Balkans have made considerable strides in building digital infrastructure, which is essential for fostering multimedia innovation (World Bank, 2023). Governments across the region have recognized the importance of digital transformation and have implemented various strategies to enhance internet connectivity, digital literacy, and access to technology (EBRD, 2022). Countries are investing in high-speed internet projects, 5G networks, and digital education programs to bridge the digital divide and support multimedia industries.

Technological advancements such as augmented reality (AR), virtual reality (VR), and artificial intelligence (AI) are being integrated into multimedia projects in the Western Balkans (Digital Serbia Initiative, 2023). Serbia, in particular, has seen a rise in VR and AR startups, with companies like VR Serbia and Digital Mind creating immersive multimedia experiences (VR Serbia, 2022). Additionally, blockchain technology is being explored for digital rights management in multimedia, ensuring creators are adequately compensated and protected.

This study aims to explore the extent of multimedia innovation in the Western Balkans by addressing the following research question: How are multimedia industries developing in Albania, Bosnia and Herzegovina, Kosovo, Montenegro, Serbia and North Macedonia, and what factors influence their growth? To answer this question, the paper examines key elements such as government policies, infrastructure investments, technological advancements, and the role of international collaborations in shaping digital creative industries in each country. Additionally, the study evaluates the challenges

and opportunities within the multimedia sector, identifying potential strategies for future development.

Methodology and equipment

The methodology of this research is based on a qualitative approach, incorporating an extensive review of academic literature, policy documents, and industry reports. Secondary sources, such as reports from international organizations like the European Commission, World Bank, UNESCO, and UNDP, were analyzed to understand regional trends in multimedia innovation. Additionally, information from official government websites, film festivals, and multimedia industry stakeholders was included to ensure a comprehensive assessment of the sector. By synthesizing insights from multiple sources, this study provides an in-depth evaluation of the current landscape and future prospects for multimedia innovation in the Western Balkans.

Presentation of research results

Albania has become a significant player in multimedia innovation, with a growing number of startups and institutions dedicated to digital media. The Marubi Academy of Film and Multimedia has played a crucial role in training professionals in film, animation, and digital storytelling (Marubi Academy, 2023). The government has also launched the Digital Agenda 2022-2026, focusing on expanding broadband access and integrating emerging technologies such as AI and blockchain in creative industries (European Commission, 2023). Additionally, Albanian filmmakers and content creators are gaining international recognition through participation in festivals such as the Tirana International Film Festival. However, challenges persist, including inadequate funding and the migration of skilled professionals to Western Europe in search of better opportunities (UNESCO, 2022). The Albanian government has introduced several incentives to support multimedia entrepreneurs and digital content creators. These include tax reductions for technology startups and grants for film and animation projects (World Bank, 2023). The National Center of Cinematography has also played a key role in financing independent films and digital media initiatives, helping local talent gain exposure in international markets (EBRD, 2023). Despite these efforts, there remains a need for greater investment in infrastructure, particularly in rural areas where access to high-speed internet and multimedia training programs is still limited.

Albania's multimedia industry is also benefiting from international collaborations and foreign investments. The European Union and private investors have supported various projects that enhance digital literacy and crea-

tive industry development (European Investment Bank, 2023). Additionally, major tech companies have begun exploring Albania as a potential outsourcing hub for animation, gaming, and digital content production, providing employment opportunities for skilled professionals. Local universities and technical institutions are beginning to integrate specialized courses on multimedia and digital content creation, ensuring that the next generation of professionals is equipped with cutting-edge skills (UNDP, 2023). While challenges such as brain drain and limited venture capital persist, continued government support and international partnerships could significantly boost Albania's role in the global multimedia industry.

Bosnia and Herzegovina (B&H) is making strides in multimedia innovation despite economic and political challenges. The Sarajevo Film Festival remains a key platform for multimedia content creators, offering opportunities for emerging filmmakers and digital artists to showcase their work (Sarajevo Film Festival, 2023). The country has seen increased interest in game development, animation, and digital storytelling, with initiatives like the Balkan Film and Digital Media Project providing mentorship and funding for young professionals (UNDP, 2023). However, the country faces obstacles such as outdated infrastructure and limited access to advanced digital technologies, which hinder the full potential of multimedia industries. The European Union has been supporting digital innovation programs to address these gaps and enhance B&H's role in the regional creative economy (EBRD, 2023).

In recent years, B&H has experienced growth in digital media production and interactive storytelling. Local studios are increasingly adopting cutting-edge animation techniques and virtual reality experiences, catering to both local and international markets. Additionally, partnerships with European and American production companies have helped Bosnian multimedia creators access larger audiences and funding opportunities (European Investment Bank, 2023). Despite these positive trends, challenges remain, including a lack of domestic investment in high-tech multimedia industries and limited government support for digital entrepreneurs.

In the future, B&H has the potential to become a regional hub for multimedia innovation, particularly in digital film production and virtual reality experiences. Government incentives, along with greater involvement from private sector investors, could drive further advancements in the industry. The adoption of artificial intelligence and automation in media production is also expected to reshape the sector, offering new possibilities for immersive storytelling and interactive entertainment (EBRD, 2023).

Kosovo's multimedia sector has grown, driven by a young, tech-savvy population and strong governmental support for digital entrepreneurship.

The Innovation and Training Park in Pristina has become a hub for startups specializing in animation, game design, and virtual reality (Western Balkans Digital Summit, 2022). Festivals like the Anibar International Animation Festival have placed Kosovo on the map as a center for animation and digital storytelling (Anibar Festival, 2022). Along with above mentioned advancements, Kosovo faces challenges such as limited access to high-end multimedia equipment and insufficient funding for large-scale digital projects. However, international partnerships, particularly with EU-funded programs, are helping to bridge these gaps and provide greater opportunities for content creators (European Investment Bank, 2022).

Montenegro's multimedia industry has also seen rapid development, driven by increased investments in digital technologies and creative industries. The country's government has collaborated with international organizations to enhance digital literacy and promote innovation hubs for startups in the multimedia sector (EBRD, 2023). Various educational programs have been launched to train young professionals in animation, film production, and game development, equipping them with skills that align with global industry standards (UNESCO, 2023). The gaming industry in Montenegro is gaining traction, with local developers working on independent projects and collaborating with international studios. Montenegro has hosted several gaming and digital art conferences, attracting industry experts and fostering networking opportunities for local creatives (Digital Serbia Initiative, 2023). The government's focus on building a robust IT infrastructure has also facilitated the expansion of digital content production, enabling Montenegrin firms to compete in global markets.

Serbia has positioned itself as a leader in multimedia innovation in the Western Balkans. The country is home to a thriving gaming industry, with internationally recognized studios like Nordeus and Mad Head Games contributing to its success (Digital Serbia Initiative, 2023). The Serbian government has invested in digital infrastructure and creative industries, fostering a strong ecosystem for game development, animation, and film production. Programs such as the "Serbia Creates" initiative provide funding and mentorship for young entrepreneurs in the multimedia sector (European Commission, 2023). The rise of digital content production has also been fueled by Serbia's strong education system in IT and multimedia. Universities in Belgrade and Novi Sad offer specialized programs in game design, animation, and virtual reality, ensuring a steady pipeline of talent for the industry (UNDP, 2023). With ongoing government support and private-sector involvement, Serbia is set to become a powerhouse for digital storytelling and creative media production (EBRD, 2023).

North Macedonia has made significant progress in multimedia innovation, with a growing ecosystem of creative industries and digital startups. The country has developed a strong foundation for digital media production, with several animation studios, film production houses, and gaming companies emerging in recent years. Skopje, the capital city, serves as the main hub for multimedia innovation, hosting events like the Skopje Film Festival and the Cinedays Festival of European Film, which provide a platform for local and international filmmakers to showcase their work (European Commission, 2023). Additionally, independent creators in North Macedonia have found success on global platforms such as YouTube and Twitch, producing digital content that reaches audiences worldwide. The government of North Macedonia has actively supported digital transformation and multimedia innovation through various initiatives. The country's Digital Agenda 2023-2027 aims to enhance digital literacy, improve access to high-speed internet, and provide funding for creative industries (World Bank, 2023).

Nevertheless, North Macedonia faces several challenges in fully realizing its multimedia potential. One major obstacle is the lack of specialized education programs tailored to multimedia and digital arts. While universities in Skopje and Bitola offer courses in IT and media studies, there is a need for more focused training in animation, game development, and virtual reality production. Additionally, access to funding remains a significant issue, as many startups struggle to secure investments to scale their businesses and develop high-quality content (European Investment Bank, 2023).

Western Balkans face several challenges in the realm of multimedia innovation. Limited funding and investment in digital and creative industries remain significant barriers (EBRD, 2023). Additionally, the region grapples with brain drain, as many talented multimedia professionals seek opportunities abroad. The lack of widespread access to advanced technology in rural areas further exacerbates the digital divide. Regional cooperation plays a crucial role in fostering multimedia innovation in the Western Balkans (European Commission, 2023). Initiatives like the Western Balkans Digital Summit bring together policymakers, industry leaders, and innovators to discuss and implement strategies for digital transformation (Western Balkans Digital Summit, 2022). Cross-border projects, supported by the European Union, provide funding and platforms for multimedia collaboration, enhancing the region's creative output. The future of multimedia innovation in the Western Balkans looks promising, with numerous opportunities for growth and development. Investment in digital education and training will be critical in nurturing talent and ensuring that the region remains competitive. Initiatives to foster gender diversity and inclusion in multimedia

industries are also gaining momentum, providing equal opportunities for all creators.

Conclusions

The Western Balkans is rapidly emerging as a hub for multimedia innovation, with countries like Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, and Serbia showing impressive growth in their digital media and creative industries. This transformation is fueled by both governmental support and private sector involvement, with initiatives aimed at improving digital infrastructure, promoting education and training in multimedia disciplines, and encouraging investment in creative startups. The region's rich cultural heritage offers a unique advantage for multimedia storytelling, fostering innovation in film, animation, game development, and digital art.

Despite these advancements, challenges remain, particularly in areas such as infrastructure development, access to high-quality equipment, and the need for more specialized education programs in multimedia fields. Addressing these gaps will be crucial to unlocking the full potential of the region's creative economy. Governments across the Western Balkans have made significant strides in creating a favorable environment for digital innovation, but continued support, both financially and in terms of policy reforms, will be necessary to overcome existing barriers. Additionally, collaboration between countries in the region, as well as with international partners, will be key to creating a more sustainable and competitive multimedia ecosystem.

Looking ahead, the Western Balkans has the potential to become a global leader in multimedia innovation, particularly in emerging fields such as virtual reality, augmented reality, and artificial intelligence. As more local startups gain international recognition and foreign investments continue to pour into the region, the multimedia industry is poised to reshape not only the economy but also cultural exchange and digital diplomacy. By fostering talent, encouraging entrepreneurship, and continuing to improve infrastructure, the region can leverage its creative potential and position itself as a driving force in the global digital economy. The future of multimedia innovation in the Western Balkans looks promising, with opportunities for growth, collaboration, and cultural exchange.

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INNOVATIONS IN PUBLISHING, PRINTING
AND MULTIMEDIA TECHNOLOGIES

INOVACIJOS LEIDYBOS, POLIGRAFIJOS
IR MULTIMEDIJOS TECHNOLOGIJOSE

Vol 1 No 1 (2025)

ISSN–2538–8622

Published by *Kauno kolegija Higher Education Institution*
Layout *Virginijus Valčiukas*