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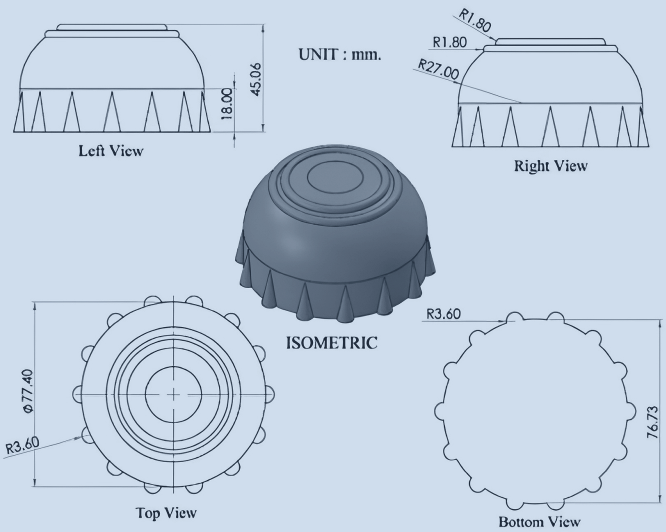

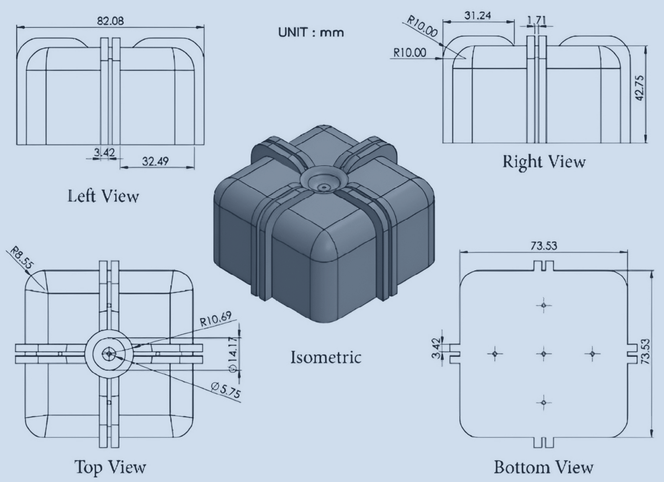

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Contents

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Translating cultural values into packaging design: The case of Ningxia eight treasures tea

ABSTRACT

'Eight Treasures Tea' (NETT), a unique herbal tea from Ningxia province, China, is renowned for its distinctive recipe, medicinal properties, and long history, yet public awareness of its cultural and nutritional value remains limited. Preliminary observations suggest that the current packaging design lacks the necessary visual and verbal elements to effectively convey NETT's cultural values (CVs). This study aimed to address this gap by translating NETT's CVs into creative packaging using a practice-based research approach, conducted in three phases. In the first phase, a visual analysis of 12 existing NETT gift packages revealed limited differentiation in terms of colour, graphics, and typography, with minimal communication of CVs. The second phase involved semi-structured interviews with five experts, identifying eight sub-themes related to NETT's historical, health, artistic, and spiritual dimensions: historical origin, historical context, health concept, dietary habits, brewing process, drinking method, emotional expression, and cultural interpretation. Findings highlighted the Yellow River as a key symbol of NETT's historical significance, the artistic merit tied to making and tasting the tea, and the spiritual value shaped by Ningxia's inclusive and diverse ethnic culture. In the third phase, creative and reflective practice was employed to explore and reconstruct the visual and verbal elements of NETT packaging, representing its multidimensional CVs. The study evoked the interconnectedness of research and practice, highlighting the critical role of the practitioner as a researcher. The creative process and outcomes offered new insights into packaging design, enhancing the communication of NETT's cultural values to potential consumers.

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Introduction

Eight Treasures Tea originated along the Silk Road during the Tang Dynasty and serves as a significant testament to the prosperity of trade and commerce in ancient China. Traveling traders would boil tea with dried fruits to combat fatigue, marking the beginning of Eight Treasures Tea's evolution. Over time, it has become an influential symbol and cultural legacy of Ningxia province, China (Cao et al., 2018b; Zhang, 2022). A unique formula has developed over the years, offering a wide range of nutritional benefits and flavours (Bai, 2010). Traditionally, the original Ningxia's Eight Treasures Tea (NETT) consisted of eight to ten ingredients, known for their edible and medicinal properties. It is prepared using a scientific approach, with tea leaves as the base and at least eight other ingredients, such as goji berries, walnuts, cinnamon, sesame seeds, raisins, jujubes, or rock sugar. Through the practical exploration of the people of Ningxia, additional ingredients like chrysanthemum and rose have been incorporated into various NETT brands to enhance both taste and health benefits (Wang, 1988; Huang, 2007; Bai, 2010). According to the NETT Industry Research Report (Zhang, 2022), Eight Treasures Tea, as a representative of Ningxia's Intangible Cultural Heritage, is one of the province's signature items. Cao et al. (2018b) noted that NETT has long been an integral part of local dietary habits, commonly served to guests and used in celebrations of major festivals.

Cultural objects can be defined as products, uses, and disseminations of media that communicate intangible values, such as financial, educational, or health benefits, through a process of 'objectification' (Mangone, 2018). Griswold (1994) proposed that "The cultural object may be defined as shared significance embodied in form. In other words, it is a socially meaningful expression that is audible, visible, or tangible, or that can be articulated" (p. 11). What sets cultural objects apart from ordinary objects is their 'cultural worth,' or what is referred to as 'cultural value' (Lipe, 1984). Cultural value is a multifaceted concept, meaning that different cultures will value individual items for various specific reasons (Lipe, 1984). According to previous studies (e.g., Lipe, 1984; Griswold, 1994; Mangone, 2018), these factors can be interpreted as: (1) historical importance; (2) health benefits; (3) artistic worth; and (4) spiritual significance. From these perspectives, the unique features of NETT, including its historical origins, rituals, customs, and health attributes, can be considered different dimensions of cultural value within the context of a cultural object.

State of the Art

Over the years, the importance of packaging has been recognized by many designers and experts across various fields. Packaging was described as 'the silent salesman' (Pilditch, 1961), creating a product's identity closely interconnected with its development. Attractive packaging helps differentiate products in the marketplace (Kuvykaite, Dovaliene & Navickiene, 2009). Lv, Shi & Yu (2006) proposed that packaging is a practical art, created by people to meet the needs of both production and daily life. Packaging design attracts consumer attention to a specific trademark, enhances brand image, and shapes consumers' perceptions of a product (Rundh, 2009). It represents the visual form that consumers will recognize, seek out, and be drawn to. As Ambrose & Harris (2018) noted, "Packaging provides a surface upon which to communicate information about the product" (p. 10). In other words, packaging creates a unique visual image that helps consumers identify the product among hundreds of other brands (Ranjbarian, Mahmoodi & Shahin, 2010).

Packaging is a significant visual tool that not only conveys a product's identity through unique visual forms but also enhances product recognition through different design elements and influences consumer perceptions. Some literature emphasizes that differentiated packaging can be used to gain consumer preference by portraying and communicating a culture (Underwood, Klein & Burke, 2001; Silayoi & Speece, 2004; Stewart, 1994). This suggests that culture also offers more opportunities for packaging design. Mirzoeff (2002) mentioned that visual culture is a means of interpreting the world visually, and the artistic model of culture relies on distinguishing the culture of one ethnicity, nation, or people from another. This implies that packaging, as an artistic model of culture, can also represent the cultures of different nations. These perspectives suggest that packaging and culture can interact with one another. Based on this, packaging design can potentially serve as an effective medium to visually convey cultural values (CVs) and features of specific 'cultural objects.'

Packaging design elements have garnered interest from both customers and designers. Several studies have highlighted that the components of packaging are diverse. The theoretical model proposed by Silayoi & Speece (2004) categorized packaging design elements into two main groups that influence consumer purchasing decisions. The first is the visual component, including layout, colour, photography and illustration, typography, and pack size and shape. The second is the informational component, which includes product information and package technology. Similarly, Dovaliene & Navickiene (2009) argued that packaging design elements are divided into visual elements—such as colour, form, size, material, and graphics—and verbal elements, including the brand, manufacturer, and country of origin.

The colour element is one of the visual components that has received extensive attention. Strong associations created by colour combinations help shape the image of the product (Garber, Burke & Jones, 2000; Gofman, Moskowitz & Mets, 2010). Barchiesi, Castellan & Costa (2018) study revealed that colour elements enhance packaging attractiveness and convey a clear and credible message. Packaging design should incorporate colour codes that relate to specific product categories (Stewart, 1994). Kauppinen-Räisänen & Luomala (2010) emphasized that the colour of packaging can influence consumers' expectations and perceptions of food products. It is important to fully consider colour preferences developed in different cultural contexts when designing the visual elements of packaging (Madden, Hewett & Roth, 2000). Silayoi & Speece (2004) noted that graphics can influence decision-making for both high- and low-involvement products. Since graphics represent the product to varying degrees and add value to the packaging, they can drive consumer choices (Ksenia, 2013). Graphic elements, such as product photographs and illustrations, stimulate consumers' perceptions and encourage them to try the product (Silayoi & Speece, 2007).

The combination of creative colours and well-designed graphics creates an emotional appeal to consumers (Ksenia, 2013). According to Velasco & Spence (2019), typography is an essential component of multi-sensory packaging design. Not only is it a ubiquitous feature of product packaging, but in some cases, the choice of typeface can even influence the consumer's experience of the product. The shape and size of packaging also impact purchasing decisions, with consumers concerned about convenience and usability (Silayoi & Speece, 2004; Krishna, Cian & Aydınoğlu, 2017). Consumers can judge a product's volume by combining the elements of shape and size, reflecting whether the packaging is easy to use and carry. Effective packaging shapes can subtly communicate messages and generate expectations through design (Ksenia, 2013).

Kuvykaite, Dovaliene & Navickiene (2009) found that the verbal elements of packaging, such as product information, brand, and country of origin (COO), were most important to consumers' purchase decisions, even more so than visual elements, especially when consumers are pressed for time. It was difficult for consumers to identify product attributes when most visual elements of packaging shared similar styles or sizes (Ambrose & Harris, 2018). Therefore, verbal elements often serve as the entry point for consumers when observing packaging. General product information includes details like weight and measurements, ingredients, and recyclability (Ambrose & Harris, 2018). The country of origin signifies where the product was originally made (Yeong et al., 2007) and is a powerful marketing tool for building the image of a regional or national product (Tseng & Balabanis, 2011). Kamaruddin, Mokhlis & Othman (2002) noted that consumers often prioritized the COO over information about the manufacturer. However, both Hausman (2000) and Silayoi & Speece (2007) argued that it is consumers' 'experiences' that simplify their product choices based on verbal elements. Although visual messages in advertisements generally attract more attention and are noticed before verbal messages (Bolen, 1984), empirical evidence in marketing suggests that images are often more accessible or usable than verbal stimuli (Underwood & Klein, 2002). As a result, it can be challenging to determine whether visual or verbal elements are more important in packaging design. However, it can certainly be argued that both types of elements must be carefully considered in packaging design studies and practice.

Semiotics is commonly employed to analyse information recorded in various forms of expression, such as a combination of signs (e.g., text and images). The essence of this expression can be understood through the physical materials of the medium, including photographs and printed material. The use of these mediums has significant implications for influencing the meaning potential of signs. As a research method in packaging, semiotics principally interprets packaging as a subject (Ni Luh Desi In Diana Sari, 2016). This subject embodies practical functions, techniques, production, and economic aspects, while also encompassing informational and communicative elements as a medium (Piliang, 2010). Visual and verbal signs are interpreted separately and then categorized and explored for interpretive links through the semiotic process of the Peirce semiotic model (Tinarbuko, 2009). Ni Luh Desi In Diana Sari (2016) argued that the use of visual and verbal elements in packaging—the signifiers that attract consumers—constitutes a process of communication and semiotic phenomena. The presence of semiotics suggests that the rich information or specific meanings of a product can be conveyed to the target consumer through the symbolism of design elements in the packaging (Cavassilas, 2007).

Culture and packaging design interact to establish the unique visual identity of a cultural object. Indeed, integrating cultural elements into the visual and verbal components of packaging design has gained increasing attention over the last decade. Numerous studies have demonstrated that a 'cultural concept' plays a significant role in shaping the visual style and information presented in packaging (Min & Idris & Yusoff, 2018; Yang, 2018; Wan & Razali, 2019; Celhay et al., 2020; Hu, 2020). Packaging can stimulate the interest of potential consumers when various cultural characteristics and information are depicted (Silayoi & Speece, 2004). Different cultures can be communicated to consumers through the visual and verbal elements of unique packaging design (Ambrose & Harris, 2018).

A considerable amount of literature has focused on investigating the application of the 'cultural concept' in packaging design. These studies have advanced the understanding of the creative process and the impact of applying cultural values (CVs) and related elements in packaging design, contributing new marketing insights to product promotion. In a study by Wan & Razali (2019), a meaningful packaging solution was offered by combining indigenous Malaysian cultural elements with traditional graphics, utilizing a contemporary style. This packaging was created for a Malaysian medicinal bath product brand. Hu's (2020) study developed a practice-led process for visualizing traditional cultural symbols.

According to Hu (2020), this practical approach to incorporating traditional Chinese symbols into the design elements of tea packaging effectively represents cultural identity in contemporary visual communication design. Several researchers (e.g., Min & Idris & Yusoff, 2018; Celhay et al., 2020) have suggested that conveying desired cultural meanings and aesthetic styles using visual symbols in packaging can eliminate linguistic and cultural barriers. This means that consumers from different regions or cultures can more easily comprehend meanings through visual symbols, even if they are unfamiliar with the cultures depicted.

Chinese Health Concerns Big Data (2019) indicated that wellness has become a popular issue, with significant potential for wellness products, especially in China's post-90s and post-80s consumer markets. Similarly, a report by Yu & Yang (2018) suggested that the total sales of NETT exceeded 300 million yuan in 2018. Despite the increasing popularity of NETT in the market, Cao et al. (2018a) noted that the general public in Ningxia and other regions of China has an insufficient understanding of NETT. In light of this, several experts (Cao et al., 2018b; Yu & Yang, 2018) recommended exploring more effective promotional channels to highlight the unique cultural characteristics of NETT as a potential solution to enhance public awareness.

In relation to the above, a report by CBNData & Tmall Tasty (2020) indicated that packaging was ranked as the third most important factor, following quality and taste, when people select tea products. This suggests that packaging could be strategically utilized to promote the CVs of NETT to potential consumers. Supporting this view, previous studies (e.g., Silayoi & Speece, 2004; Siwei, Cheng & Zhe, 2019; Hu, 2020; Celhay et al., 2020) have suggested that packaging design can serve as a crucial vehicle for conveying the cultural characteristics of cultural heritage. If the visual elements (e.g., shapes, sizes, materials, graphics, colours, typography, and layout) and verbal elements (e.g., product information, brand information, and country of origin) are properly designed, packaging can potentially enhance a product's recognizability and distinctiveness.

However, a preliminary observation conducted by the authors of this study indicated that the visual representations of the existing NETT packaging designs were relatively similar in terms of the choice of visual elements, such as colour and graphics. Moreover, only basic information was included on the packaging. In other words, the cultural values of NETT have yet to be adequately explored and integrated into the visual and verbal elements of its packaging design. Consequently, both Yu & Yang (2018) and Zhang (2022) highlighted that the competitive advantages of NETT are not distinctively represented in local and international markets today. Therefore, there is a need for an in-depth investigation into how the cultural values of NETT could be more effectively reflected in its packaging.

Furthermore, to the best of the authors' knowledge, there is limited literature on the different dimensions of NETT's CVs, which creates difficulties and challenges for successful integration. It is therefore imperative to gather additional insights from relevant stakeholders to gain a better understanding of NETT's cultural values before initiating the creative process.

Given the gaps in the existing literature, the overall purpose of this study is to effectively translate the multidimensional cultural values of NETT into its packaging design. Correspondingly, the specific research questions addressed by this study are:

1. How are the visual and verbal elements represented in the existing packaging design of Ningxia's Eight Treasures Tea?
2. What cultural values related to the historical, health, artistic, or spiritual dimensions of Ningxia's Eight Treasures Tea are identified from the perspectives of selected experts?
3. In what ways can the cultural values of Ningxia's Eight Treasures Tea be effectively translated into the visual and verbal elements of its packaging design?

Practice-based research was employed as the overall research methodology for this study. Muratovski (2016) stated that practice-based research is distinctly different from qualitative and quantitative research in terms of its purpose. This methodology is intrinsically oriented toward refining creative practice and outcomes and serves as a powerful tool for initiating change (Crouch, 2012). In practice-based research, a wide variety of data collection methods can be utilized flexibly to achieve research objectives meaningfully (Meyer, 2000). Hu (2019) developed a practice-oriented research design by applying mixed methods in his study to investigate the contemporary visualizations of traditional Chinese symbols. To answer the research questions posed in this study, Hu's (2019) research design was adapted. Specifically, the study was divided into three phases: visual research, semi-structured interviews, and creative and reflective practice. This approach aimed to explore more effective means of translating the CVs of NETT into its packaging design.

Phase One: Visual Research

Visual research is the process of interpreting objects and evaluating the quality of works through connoisseurship of the visual information presented. It plays an invaluable role in understanding the meaning of images and their ability to convey information (Muratovski, 2016). Also referred to as compositional interpretation, this research method relies primarily on the researchers themselves to describe the visual appearance of selected image samples using relevant terms (Rose, 2022). For practitioners, this approach is grounded in the knowledge and experience of the researchers (Muratovski, 2016).

In the first phase of this study, visual research was conducted to analyse both the visual elements (shape, size, material, graphic, colour, typography, layout) and verbal elements (brand information, product information, country of origin) of existing packaging designs for NETT.

This analysis aimed to determine whether the current packaging designs effectively represent the characteristics of NETT through the application of diverse elements and whether they offer a differentiated visual representation. Additionally, the visual research process sought to validate the findings from the preliminary observations conducted by the authors.

As noted by Muratovski (2016), the sampling process in visual research can be quite subjective, allowing researchers to identify and select the most relevant visual samples to meet their research objectives. In the Ningxia market, there are over 200 NETT manufacturers and brands. To identify the most relevant visual data, field visits were conducted at four supermarkets, three teahouses, and three tea boutiques in the Ningxia region (see Table 1). Brief conversations and observations with customers and staff indicated that a total of 30 gift packaging designs of NETT were currently preferred by consumers. The ideal purposive sampling situation involves identifying objects with target features and then randomly selecting a sample of these objects (Hibberts, Burke Johnson & Hudson, 2012). Consequently, a random sample of 12 packaging designs was selected from the 30 purposive samples for final visual analysis.

A set of photos was utilized to document the finalized samples for visual analysis. This phase concentrates on analysing the visual and verbal elements of the existing packaging design for NETT. Consequently, collecting relevant photographs or images was an essential prerequisite for conducting the visual analysis (Gray & Malins, 2004). The profiles of the selected packages are detailed in Table 2 and Table 3.

The analysis of the 12 NETT gift packages (P1 to P12) reveals consistent patterns in their visual and verbal elements, focusing on shapes, materials, graphics, colours, typography, and layout. The packaging comes in both square and rectangular boxes, with sizes varying according to the product quantity. Larger packages can hold more tea bags, which are individually sealed in plastic to prevent spoilage. Most packaging (e.g., P1, P2) uses high-quality cardboard, providing good protection during transport and practical usability.

Graphically, some packages, such as P4, P5, and P6, incorporate simple illustrations with motifs inspired by the Gaiwan (teacup) and the ancient Silk Road to reflect the origins of Eight Treasures Tea. However, the designs of P1, P2, P5, P8, and P9 are relatively homogeneous, with similar graphic elements that lack differentiation and fail to convey the tea's multi-dimensional cultural values.

Traditional Chinese motifs, such as clouds and cranes, are prevalent in designs like P1, P2, and P3, but they do not create a unique cultural identity for NETT. While P6 and P7 attempt to visually present the health benefits of the tea, the graphics are often limited in richness and integration with artistic and spiritual values.

Colour schemes across the packages are dominated by highly saturated red, often paired with gold, black, or white, as seen in P1, P2, P5, P6, P10, and P12. Red is a favoured choice in Ningxia, symbolizing tradition, but its frequent use can lead to visual fatigue. However, P4 and P6 demonstrate successful diversification of colours, creating richer cultural contexts and enhancing the emotional experience for the consumer.

Typography in the packaging emphasizes the product name, typically presented in large, bold Chinese calligraphic fonts, complemented by Song font (e.g., P1, P2, P4, P5, P6, P8, P9) and Hei font (e.g., P7, P10, P11, P12) for additional information. This combination reflects Chinese tradition and improves readability. Most designs, such as P1, P3, P4, P5, P6, P7, P10, P11, and P12, maintain a vertical layout, aligning with traditional Chinese writing practices. These designs also tend to be symmetrical, achieving visual balance and ensuring a clear hierarchy of information.

Table 1

A Summary of Sites for the Field Research

Field Research Sites		Remarks
Supermarkets	1. Hyper Market	The largest local supermarket chain in Ningxia.
	2. Vanguard Mart	One of the largest retail chains in China.
	3. Wu Mart	The first Chinese chain to have 100 supermarkets in the northern region.
	4. Metro	Retain and wholesale supermarket group from Germany with supermarkets in 32 countries.
Teahouses	1. Ma Yixin Teahouse	One of the most popular teahouses in Ningxia's busy business district.
	2. Liu Sandu Teahouse	Ningxia's first NETT experience hall.
	3. Ma Yi Teahouse	A well-known traditional NETT teahouse.
Tea Boutiques	1. Ma Yixin Babaocha	A popular tea boutique in the local shopping centre of Ningxia.
	2. Liu Sandu Babaocha	The brand with the largest number of the NETT of tea boutiques in China.
	3. Fei Yi Babaocha	A new tea boutique that has opened in recent years with a full range of products.

Textual elements on the packaging usually cover basic product details, such as names, brands, weights, and ingredients. Some packages, like P4, P7, and P9, also highlight the product's origin and its health benefits. However, most packaging does not provide comprehensive textual content, particularly regarding NETT's cultural values.

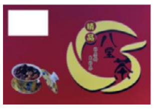
Only P5 and P6 include limited bilingual information, suggesting that future designs should incorporate more detailed and bilingual descriptions to better communicate NETT's cultural significance.

Table 2 (part 1)

The Profile of the Selected Packaging on Visual Elements

Code	Image	Visual Elements								
		Shape	Size (L x W x H) cm	Materials	Graphics	Colours	Typography			Layout
							Chinese Calligraphic Fonts	Song Font (Serif)	Hei Font (Sans Serif)	
P1		Rectangular	38 x 26 x 10	Paper Cardboard Cloth	Illustration of a Gaiwan (a set of teacups) with simplified auspicious cloud patterns as the background.	Gold Red Black	√	√	-	Vertical orientation: from top to bottom, exhibiting vertical symmetry.
P2		Rectangular	42 x 28 x 12	Cardboard	Illustration of a Gaiwan bordered with auspicious cloud motifs.	Red Green Beige	√	√	-	Horizontal orientation: from left to right, demonstrating a tendency towards vertical symmetry.
P3		Rectangular	40 x 24 x 10	Paper Cardboard Plastic	Crane illustrations accented with simplified auspicious cloud motifs.	Gold Red White Blue	√	√	√	Vertical orientation: from top to bottom, exhibiting vertical symmetry.
P4		Rectangular	40 x 20 x 8	Paper Plastic	Camel illustrations featuring Silk Road motifs in a circular pattern.	Beige Black Blue	√	√	-	Vertical orientation: from top to bottom, displaying asymmetry.
P5		Rectangular	28 x 28 x 10	Cardboard	Simplified outline of the Gaiwan alongside a simplified outline of the Silk Road.	Red Golden	√	√	-	Vertical orientation: from top to bottom, displaying asymmetry.
P6		Rectangular	38 x 28 x 8	Cardboard	Vivid colour illustration of an open-lid Gaiwan, complemented by landscape illustrations.	Red Golden Black	√	√	-	Vertical orientation: from top to bottom, showing a tendency towards vertical symmetry.

Table 2 (part 2)
The Profile of the Selected Packaging on Visual Elements

Code	Image	Visual Elements								
		Shape	Size (L x W x H) cm	Materials	Graphics	Colours	Typography			Layout
							Chinese Calligraphic Fonts	Song Font (Serif)	Hei Font (Sans Serif)	
P7		Rectangular	24 x 16 x 7	Paper Plastic	Background illustration of the ingredients with rectangular line patterns.	Gold Black White	√	√	√	Horizontal orientation: from left to right, demonstrating a tendency towards vertical symmetry.
P8		Rectangular	38 x 24 x 10	Cardboard	Photo of a Gaiwan, surrounded by circular lines and patterns.	Red Yellow Black	√	√	-	Vertical orientation: from top to bottom, displaying asymmetry.
P9		Rectangular	34 x 26 x 10	Cardboard Plastic	Photo of a Gaiwan with decorative circular patterns.	Black Red Beige	√	√	-	Vertical orientation: exhibiting asymmetry.
P10		Rectangular	33 x 24 x 5	Paper	Simplified scalloped patterns combined with circular lines.	Red Golden Black	√	√	√	Vertical orientation: showing a tendency towards vertical symmetry.
P11		Rectangular	30 x 22 x 5	Paper Plastic	Background illustration of the ingredients featuring auspicious cloud pattern lines and circular patterns.	Yellow Grey Black	√	√	√	Vertical orientation: showing a tendency towards vertical symmetry.
P12		Rectangular	26 x 18 x 12	Cardboard	Auspicious cloud pattern lines arranged in a rectangular pattern.	Red Gold Black	√	√	√	Vertical orientation: showing a tendency towards vertical symmetry.

Phase Two: Semi-structured Interviews

The second phase of this study utilized semi-structured interviews (SSI). In this approach, conversations were centered around predetermined themes, incorporating a mix of closed and open-ended questions (Adams, 2015). This method allowed for relevance to the topic while avoiding overly standardized questions. SSI enabled researchers to explore unanticipated issues while maintaining high participant engagement (Merton & Kendall, 1946; Morse & Field, 1995; McIntosh & Morse, 2015). Participants had the freedom to respond to open-ended questions in their own way, and researchers could probe these responses with follow-up questions. This flexibility is a distinctive feature of the semi-structured interview approach. According to Adams (2015), SSI is particularly useful when researchers have a solid understanding of the topic's domains and components but cannot predict all possible responses. The SSI aimed to gather insights from five purposively selected experts regarding the specific CVs of NETT and to obtain new perspectives on the existing packaging design.

This facilitated an in-depth exploration of the unknown and unanticipated characteristics of NETT, supplementing the data collected in the first phase of the study. Table 4 presents the profiles of the informants.

Table 3

The Profile of the Selected Packaging on Verbal Elements

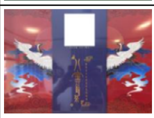
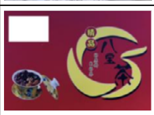
Code	Image	Verbal Elements							
		Brand Information		Product Information					Place of Origin (Ningxia)
		Brand Name (Logo)	Brand Slogan	Quantities	Ingredients	Health Instructions	Historical Introduction	Brewing and Drinking Methods	
P1		√	-	√	√	-	√	-	√
P2		√	√	√	-	-	√	-	√
P3		√	-	√	√	-	√	-	√
P4		√	√	√	√	-	√	-	√
P5		√	√	√	-	-	-	-	-
P6		√	√	√	√	-	-	-	-
P7		√	√	√	√	√	√	-	√
P8		√	√	√	√	-	-	-	-
P9		√	-	√	√	√	√	-	√
P10		√	-	√	√	-	-	-	-
P11		√	-	√	√	-	-	-	-
P12		√	-	√	√	-	-	-	-

Table 4
Experts' Profile

Code	Position	Work Location	Experience	Relevant Achievement
P	University Professor	North Minzu University	Teaching and research in the subject of tourism management for nearly 15 years.	Published two papers on NETT
D	Director of the Cultural Centre	Ningxia Cultural Centre	Nearly 25 years in the promotion of cultural heritage projects	Responsible for over twenty Ningxia cultural heritage products
H	Head of the Department of Commerce	Ningxia Commerce Department	Engaged in the promotion of Ningxia commodities to the public for nearly 30 years	Represented the Ningxia government at over a hundred international trade conferences
F	Founder and Manufacturer of the local NETT Brand	Ningxia's Eight Treasures Tea Co.	Almost twenty years in the NETT industry	Building the brand into Ningxia's highest selling NETT
M	Tea Master of NETT	Ningxia's Eight Treasures Tea Co.	Over 10 years as a NETT master	Attended hundreds of NETT brewing demonstrations throughout China

Seven (7) questions were developed based on the four dimensions of cultural values (CVs) of Ningxia's Eight Treasures Tea (NETT), adapted from Lipe (1984), Griswold (1994), and Mangone (2018). Following the guidelines of Brinkmann & Kvale (2015), the interview questions were phrased in everyday language to ensure comprehensibility for the participants. Since the participants were non-English speakers, the questions were translated into Chinese. To ensure content validity, the questions were reviewed by three experts from the academic field who provided feedback and guidance based on their backgrounds and work experiences.

Thematic analysis was employed to analyse the data with the assistance of NVivo software. The findings from the semi-structured interviews were organized according to the themes generated from the interview questions. A total of 153 raw statements and 38 related concepts were produced during the open-ended and axial coding processes in NVivo. As illustrated in Table 5, selective coding further identified eight subcategories, or sub-themes, grouped according to the frequency of occurrence of the data and aligned with the four dimensions of the CVs.

Table 5
The selective coding of developing the 8 sub-themes in Nvivo

Core Dimension	Sub-dimensions	Frequency
Historical Importance	Historical Origin	12
	Historical Context	12
Health Benefits	Health Concept	12
	Dietary Habits	17
Artistic Worth	Brewing Process	19
	Drinking Method	11
Spiritual Significance	Emotional Expression	16
	Cultural Interpretation	23

The sub-dimensions extracted from the four dimensions of the CVs of NETT were reviewed and reconfirmed by the experts. Achieving their consensus was essential to ensure the accuracy of the findings before proceeding with the creative practice.

Phase Three: Creative and Reflective Practice

In professional and academic fields, 'creative practice' combines the act of creating novel things with the essential processes and techniques inherent to a particular discipline (Candy & Edmonds, 2018). Design output is central to creative practice and plays a crucial role in generating new understandings (Candy, 2006; Candy & Edmonds, 2018). Insights gained from creative practice can directly inform the design itself (Candy & Edmonds, 2018). Thus, creative practice is characterized not only by the focus on producing something new but also by the process of making, which leads to shifts in ideas and practices resulting in continually renewed outputs (Candy & Edmonds, 2018).

For practice-based researchers, the insights gained through reflection significantly contribute to the outcomes of creative practice (Candy & Edmonds, 2018). When practitioners engage in reflection, the object of reflection encompasses a diverse system of knowledge. This reflection may involve strategies and theories implicit in patterns of behaviour, feelings toward the practice, and approaches taken to solve problems (Schön, 1983).

Reflection-in-action is a reflective form of knowing-in-action. Action and reflection are complementary; 'doing' extends 'thinking,' while 'reflection' facilitates both 'doing' and its results (Schön, 1983).

Moreover, reflective practice serves as a highly applicable structured self-evaluation method that can be deployed throughout the design process (Thompson, 2008). This process can produce unexpected shifts in practice, adding new perceptions and enabling responses to emerging issues. Reflective practice often leads to greater achievements than anticipated or described in advance (Schön, 1983).

Based on the above arguments, creative and reflective practice were employed in the third phase, with findings presented as creative outputs. This method encourages thinking, reflecting, and practicing an understanding of the CVs of NETT, which continually feeds back into the visual representation and allows for developments in packaging design for specific themes.

In the second phase, the consensus among experts validated the key elements within the four dimensions of NETT's CVs and reaffirmed its long evolutionary journey into becoming an authentic cultural object of Ningxia. The distinctive historical development, geographical location, humanistic sentiments, and artistic atmosphere of Ningxia Province have collectively contributed to the cultural background and significance of Eight Treasures Tea. Consequently, the finalized design concept was 'Tea Trip to Ningxia.' This concept aims to convey the CVs of Eight Treasures Tea by shaping the identity of a unique tea product that represents the Ningxia region. Additionally, the process of perceiving the CVs embedded in the packaging is framed as a tea trip, providing a sense of scenario and experience that enhances interaction with potential consumers.

The Creative Processes of Translating of Cultural Values into Verbal and Visual Elements

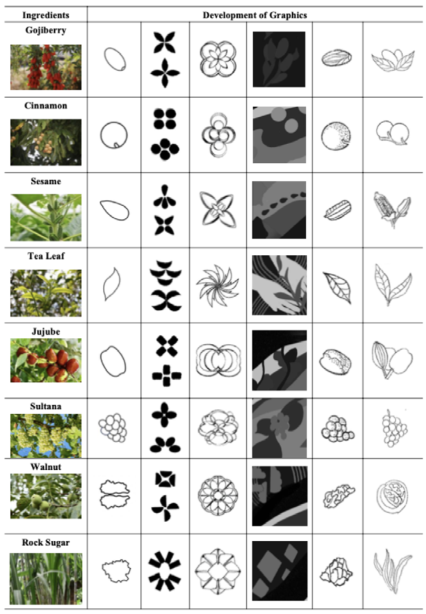
According to previous studies (Silayoi & Speece, 2004; Kuvykaite, Dovaliene & Navickiene, 2009), the verbal elements considered in the packaging creative process include brand information, product information, and country of origin. In this section, the majority of these elements are expressed bilingually to ground the design in a broader international perspective.

Corporate branding or identity is the primary concern that designers or researchers must address when embarking on any packaging design. The packaging of NETT, which conveys CVs, should align with its brand identity. A dummy brand named 'Yuncha' was created to facilitate the creative process and outcomes of the study. In Chinese, 'Yun' signifies containment, often embodying deep cultural and emotional connotations. Accordingly, 'Yuncha' was envisioned as a local Ningxia brand dedicated to raising awareness and understanding of Ningxia's renowned cultural heritage, particularly through Eight Treasures Tea.

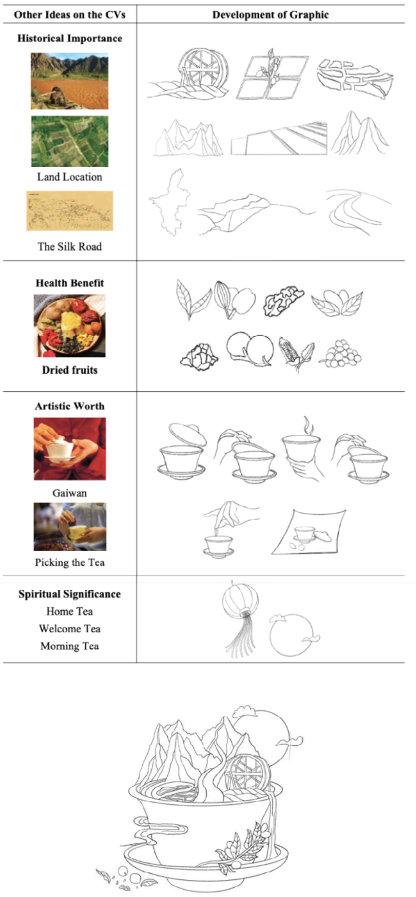
In the first phase of the study, visual analysis findings indicated that existing NETT packaging typically included product information such as size, weight, content details, ingredient lists, efficacy, and product type. As a result, product information was prioritized in the creative process. However, since the packaging design aimed to convey the multidimensional CVs of NETT, it was essential to tell a meaningful story about the product. Consequently, the slogan 'Experiencing the Cultural Value of Ningxia's Eight Treasures Tea' was developed. This narrative, which encompasses the four dimensions of CVs, is presented as a 'Tea Trip Guide.' To enhance the experiential significance of the packaging, additional instructions describing the brewing and drinking methods of NETT were included. Furthermore, the introduction of 'Gaiwan' and 'Picking Joy' illustrates an artistic approach to making a cup of tea.

Ningxia Province, China, recognized as an influential origin and development site for Eight Treasures Tea, has been repeatedly validated in this study. Therefore, the label 'NINGXIA materials & made' was incorporated throughout the packaging design.

On the other hand, the development of the visual elements of the packaging primarily focused on size, material, shape, graphics, color, typography, and layout (Silayoi & Speece, 2004; Kuvykaite, Dovaliene & Navickiene, 2009). The creative process was documented through diagrams, tables, sketches, and computer-aided prototypes. Simultaneously, it involved a reflective process of continuous integration, execution, evaluation, and modification. Highlights of how the identified CVs were translated into graphic elements, style, color, font selection, and other aspects are illustrated in Figures 1 to 4.

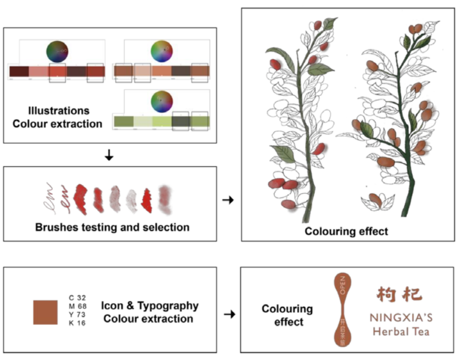


» **Figure 1:** *Development of Graphic and Style on Different Ingredients*



» **Figure 2:** *Development of Supporting Graphics*

» **Figure 3:** *Colour Inspirations*



» **Figure 4:** *Colours and Fonts Testing Process*

The Creative Output

As illustrated in Figure 5, the outer packaging is primarily constructed from wood. The design features an illustration inspired by the CVs of NETT, alongside verbal elements such as the origin and slogan.

These visual and verbal components are crafted to emphasize the concept of 'Tea Trip to Ningxia.' When consumers encounter the outer packaging, it signifies the beginning of their journey to explore the CVs of NETT.

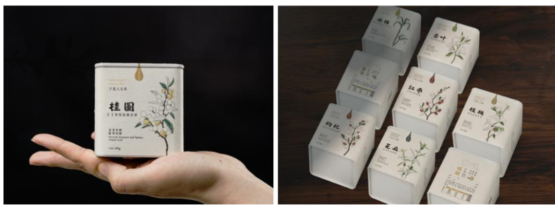
» **Figure 5:** *The Outer Look of the Packaging Design*

Upon opening the outer packaging, the introduction to the tea journey immediately captures the consumer's attention. As shown in Figure 6, it summarizes the four dimensions of the CVs of NETT: history, health, art, and spirituality. Following this introduction are the product packages containing the ingredients for NETT.

» **Figure 6:** *The Intermediate Packaging Design*

The ingredients are housed in metal tins, each labeled with one of eight distinct illustrations (see Figure 7).

In addition to the essential product and brand information, the tins display the slogan 'Experience the Cultural Values of Ningxia's Eight Treasures Tea.'



» **Figure 7:** *The Inner Packaging Design*

One of the most striking features is the travel guide presented in the form of a letter. As depicted in Figure 8, a stamp design on the front enhances the travel theme. Upon opening the envelope, consumers will find four different cards, each specifically describing the CVs of the eight teas, accompanied by rich graphics.

» **Figure 8:** *The Design of the 'Tea Trip Guide'*

As illustrated in Figure 9, Pickingjoy is crafted from cloth and features graphics of the eight ingredients printed on it. Consumers can easily measure different amounts of ingredients based on the size of the graphics. This packaging also includes specific instructions, while the Gaiwan is securely encased within Pickingjoy.

» **Figure 9:** *The Design of 'Gaiwan' and 'Pickingjoy'*

Additionally, Figure 10 showcases the eco-friendly bag, which offers enhanced protection for the packages and is designed for easy portability.

» **Figure 10:** *The Design of the Eco-friendly Bag*

Discussion

The Visual and Verbal Elements of the Existing NETT Packaging Design

Past studies (Huang, 2007; Cao et al., 2018b; Yu & Yang, 2018) have indicated that NETT is a cultural object unique to the Ningxia region. However, its cultural characteristics have not been deeply explored or effectively communicated to the general public through promotional channels (Cao et al., 2018b).

Some studies (Yu, 2018; Wan & Razali, 2019) suggest that the appeal and communicative ability of packaging can be enhanced by leveraging visual representations, such as graphic and colour elements related to cultural factors. In this context, this study distinguishes itself by aiming to create more effective packaging for NETT that integrates visual and verbal elements to better convey its CVs.

To achieve this, it was essential to evaluate existing packaging in Ningxia's market to assess their effectiveness in communicating cultural characteristics. Visual analysis was employed in the first phase of the study. Overall, the visual and verbal elements of the current packaging were found to be relatively incomplete in articulating the four dimensions of NETT's CVs. This one-sided consideration poses challenges for the public to fully understand the cultural characteristics and connotations of NETT through the existing packaging design.

The findings indicated that the existing packaging designs of NETT shared similar visual presentations in terms of colour schemes, graphical styles, and typography. While some designs addressed the historical and health values of NETT, they often lacked rich imagery and context, making it challenging for potential consumers to appreciate the cultural significance of NETT in its entirety.

According to Silayoi & Speece (2007), graphics and colour elements are crucial in packaging design. The analysis revealed a predominant use of red in the existing NETT packaging. While a large plain colour background can create a neat and orderly visual effect, allowing for easy access to product information, the overuse of a single colour may fail to generate sufficient appeal and could lead to visual fatigue. Additionally, the excessive repetition of one colour may diminish the distinctiveness of a particular package compared to others. A well-considered colour palette in packaging should build a harmonious visual atmosphere while reflecting the cultural context and characteristics of the product.

Out of the twelve packaging designs examined, seven drew inspiration from the Silk Road and tea cups, which have been repeatedly validated as important expressions of NETT's historical dimension.

However, the relatively singular design style fails to evoke an emotional atmosphere or transport the consumer back to the historical origins of NETT, leading to a potential homogenization of visual imagery. Four designs represented the health benefits of NETT, yet their presentation was straightforward, often relying on simple photographs or textures. Six of the packages incorporated traditional Chinese motifs, such as auspicious clouds, fans, and cranes. However, these motifs are common across various Chinese products, and there is limited evidence to prove their specific relevance to the cultural identity of NETT. The spiritual and artistic values associated with NETT were also underrepresented or neglected, resulting in graphics that provided minimal information.

The primary function of packaging is to protect its contents (Kotler & Pfoertsch, 2010). It is noteworthy that the visual elements, such as shape, material, and size, of the existing packages performed well in safeguarding the products, with most cardboard-based outer packaging being convenient for shipping and recycling. However, these packages contained all eight ingredients in one packet for ready-to-drink purposes, potentially overlooking the unique experience and artistic value that NETT offers during the brewing process.

As Squire, Willberg & Forssman (2006) noted, typography is fundamentally about communicating information. Typography design is crucial in conveying product messages, as it transforms verbal elements into powerful visual representations. The visual analysis revealed that traditional Chinese calligraphic and Song fonts were used across all packaging. While these fonts effectively differentiate primary and secondary message aspects based on size and boldness, the limited use of typography may not sufficiently create an orderly visual structure.

The analysis indicated that most packaging effectively conveyed verbal elements, covering essential brand and product information. However, considering the specificity of this study, the effective use of verbal elements is also vital in evaluating the relevance of existing packaging in conveying NETT's CVs. The examination found that only four existing packages addressed health and historical values through verbal elements, but the brief content may not be deeply accessible to the general public. Furthermore, the packaging did not utilize bilingual expressions to create a more diverse or international perspective.

Experts Views on Cultural Values of NETT

Based on the findings from the SSI in the second phase of the study, it can be confirmed that NETT possesses significant CVs in four key areas: history, health, art, and spirituality. The Ancient Silk Road and the Yellow River emerge as pivotal icons that underscore NETT's historical significance. The health benefits are emphasized through the natural and medicinal properties inherent in the eight ingredients. Additionally, a cohesive brewing and drinking process reflects the artistic value of NETT, while its spiritual significance is rooted in the customs and social environment of the local people in Ningxia.

These findings are partially consistent with previous studies (Huang, 2007; Cao et al., 2018b; Yu & Yang, 2018) and elucidate the CVs embodied in four specific aspects of NETT as a cultural object. While these meaningful insights suggest that a design concept for the packaging has begun to take shape, it is crucial to recognize that the emergence of these design ideas does not imply that the 'right' design approach has been identified. Rather, they represent the aggregation of perceptions gathered from a group of experts regarding the CVs of NETT.

Translating CVs into NETT Packaging Design

In this context, the researchers aim to explore their dual role as both researchers and practitioners in this study. It is crucial not only to continuously reflect on the multi-dimensional connotations of NETT's CVs but also to consider its visual externalization in packaging design through a more comprehensive creative practice.

The semiotic analysis was employed to examine the signs and use visual signifiers to express specific meanings to interpreters (Ni Luh Desi In Diana Sari, 2016; Celhay et al., 2020). Given that semiotics has been extended to graphic design, it can similarly be applied to packaging design (Celhay et al., 2020). The integration of various visual signifiers—such as colour, graphics, typography, and text—can effectively convey meaningful concepts related to the product. Bobrie (2018) argued that all elements of the text are simultaneously embedded within the viewer's visual field, contributing to the overall meaning of the brand. However, initial findings from the creative practice indicated that the complexity of NETT's four dimensions made it challenging for the packaging design ideas to encompass all CVs. To address this, perspectives from five experts were extracted and summarized, revealing that the text could be systematically integrated with several visual signifiers across the four dimensions. These verbal and visual elements worked together to create a meaningful sign and communicate it to the perceiver.

According to the findings, the design concept of 'Tea Trip to Ningxia' could be layered throughout the packaging, allowing consumers to perceive the CVs of NETT as they open each layer. Furthermore, the importance of interactive packaging design in conveying the CVs was emphasized by three experts in the second phase of the study.

The types of packaging can be classified based on their functions: outer, intermediate, and inner packaging.

The shape, size, and materials of each type serve essential characteristics of protection, convenience, circulation, and preservation. Ambrose & Harris (2018) noted that packaging is used to wrap, secure, and store products while also identifying and differentiating them. Several rounds of evaluation revealed that wooden outer packaging effectively demonstrated the natural and medicinal characteristics, particularly the health value, of NETT. Additionally, the hermeticity of the product packaging plays a vital role in preserving the ingredients. This design differs from existing ready-to-drink gift packs of NETT, as it allows for the separate packaging of ingredients along with a tea grasping tool. This design choice invites customers to enjoy the artistic and pleasurable aspects of NETT while grasping different ingredients, thereby creating a more sensory drinking experience. The 'Tea Trip Guide,' presented in the form of a letter attached to the packaging, echoes the design concept and provides extensive information. Through this interactive process, consumers can empathize with and experience the unique appeal of NETT.

Andrea (2016) pointed out that colour is the most emotionally responsive element in packaging design. Participants suggested a shift in the application of colour for NETT packaging. Findings indicated that a colour palette derived from the eight ingredients of NETT could better highlight its health values. Moreover, this colour scheme diverges from the predominant red palette currently used in existing packaging designs.

Stewart (1994) argued that packaging design should utilize various colour codes related to specific product categories, as colour elements contribute to consumer recognition of the packaging (Barchiesi, Castellan & Costa, 2018). The findings suggest that illustrations featuring a rich colour palette are expected to enhance the visibility of NETT packaging in the consumer market. The visual effects created by the graphics, combined with the extracted colours, help to effectively demonstrate the four dimensions of NETT's CVs.

According to Dabner, Calvert & Casey (2012), typographic decisions relate to the hierarchy of information; in any design, some information must be prioritized over others. The findings indicate that classifying verbal elements into primary, secondary, and tertiary categories based on their importance facilitates typography that effectively isolates information and defines the visual structure.

Textual information was distinguished by different Chinese calligraphic handwriting, serif, and sans serif fonts in the creation of verbal elements. More importantly, in addition to the basic information present in existing packaging designs, textual material on the CVs was integrated throughout the graphic elements, which benefits customers by deepening their understanding of the culture of NETT through visual cues and flows.

Additionally, the specific challenge of bilingual systems remains for designers to create layouts that enrich the global dialogue while preserving local cultural identities (Baki, 2013). Riaz et al. (2015) revealed that labels featuring a foreign language capture consumer attention and significantly impact purchase intention. Reflecting on these findings, this study argues that the use of bilingual forms enhances the understanding of packaging design as a form of communication or an intercultural tool. This approach opens new possibilities for expressing the CVs of NETT in international markets.

Implications of the Study

Limited literature and resources are available on the CVs of NETT within the context of China. This study provides a comprehensive and systematic review and analysis of NETT's CVs, summarized into four dimensions: historical, health, artistic, and spiritual values.

This summary aims to identify factors for cultural research in the tea industry. Specifically, the study addresses the lack of awareness about NETT's culture within academic circles while effectively communicating the core CVs of this cultural object in a manner that is more relevant to contemporary society.

The contribution of this study lies in providing theoretical knowledge about semiotics as a method to express the relationship between thematic packaging design and CVs (signs) in determining the object (NETT) and the interpreter (customers). Packaging design serves as a visible signifier that combines visual and verbal elements organized on a surface to convey specific meanings to consumers. The study implies that NETT can be perceived as a cultural object embedded within the visible field of the interpreter (consumers) through its packaging design, thereby influencing consumers' perceptions.

The creative outcome of this study is a set of original packaging designs for NETT, which provides a platform for promoting Ningxia's regional culture and local heritage products. For manufacturers, incorporating cultural attributes into packaging innovation enhances market competitiveness and brand visibility.

Thematic packaging designs that reflect CVs are expected to attract consumers' attention, thereby increasing purchase intentions. For consumers, NETT is presented with a more vibrant image through concepts such as 'Picking Joy' and 'Eating Tea.' The study strives to create designs imbued with experiential elements that narrate the story of this tea to a broader audience. In particular, the packaging design encourages the younger generation to appreciate the charm of this traditional cultural object, thereby fostering public recognition of the unique tea culture and preserving traditional customs.

Limitations and Recommendations

Although this study provides valuable insights and design outcomes for various stakeholders, several limitations warrant consideration. The first limitation concerns the samples used for visual research in the initial phase of the study. To evaluate whether the existing packaging design of Eight Treasures Tea in the Ningxia market effectively conveys the four aspects of CVs, visual analysis was employed to assess the visual and verbal elements of 12 popular gift packaging items available on the market.

However, these selected samples were insufficient to illustrate the broader issues associated with the existing packaging of NETT. A larger sample should be visually analysed to refine the findings from phase one and provide a more meaningful background for subsequent phases. Additionally, the findings derived from the SSI were limited by the small sample size. While the insights provided by five participants regarding the four dimensions of CVs were extensive, Creswell (2014) notes that a larger participant pool enhances the reliability and comprehensiveness of findings. Furthermore, the SSIs were conducted in Chinese. Despite efforts to accurately translate the collected data into English, minor translation inaccuracies may have occurred.

Another limitation pertains to the research methodology employed in the study. The 'practitioner-researcher' role is complex, and challenges may arise due to limited time and potential lack of research experience and confidence. In this study, the researchers were required to function as reflective practitioners, collecting and analysing data while translating CVs into appropriate visual and verbal elements for packaging design. This reflection involved diverse systematic knowledge, including the multidimensional CVs, visual representations, and design strategies that needed to be considered throughout the cycles of evaluation, modification, adaptation, and refinement before achieving the final outcome. Although reflection is central to being a practitioner-researcher, it presents challenges, including the potential for one-sided views or a lack of absolute objectivity during the design process.

Future research should include consumer and client engagement, as they are significant stakeholders in the NETT industry. While the SSI captured insights from experts in the Eight Treasures Tea field regarding the CVs and thematic packaging concepts, the researcher did not interact with consumers to gain insight into their needs in the consumption market for these cultural objectives. For example, Borgman, Mulder-Nijkamp & Koeijer (2018) employed conjoint analysis to determine the specific design elements upon which consumer decisions about packaging are based.

Therefore, it is strongly recommended that future research adopt quantitative methods such as questionnaires or conjoint analysis to examine consumer perceptions and preferences for packaging designs with cultural attributes. Specifically, future studies could compare different design elements that convey CVs in packaging, allowing for testing of purchase intentions in various contexts and realistic market environments to enhance existing findings.

Moreover, it would be intriguing to explore how CVs from different cultural heritages can be incorporated into visual representations to convey broader dimensions of cultural characteristics through innovative design means, thus contributing to the development of traditional cultures across different countries.

Ranjbarian, Mahmoodi & Shahin (2010) noted that packaging serves as a unique visual image of a product, helping consumers identify it among numerous brands. Wan & Razali (2019) considered packaging design as a distinctive visual and verbal representation of a brand, analyzing selected brands according to Kapferer's (2004) Brand Identity Model, in which culture represents the origin of the product.

Consequently, it would be meaningful for future research to verify whether the enriched CVs expressed through packaging design can confer a unique identity to a brand and cultivate respect and loyalty among target consumers.

Conclusion

In conclusion, thematic packaging design that incorporates cultural elements has gained significant attention from designers and researchers (Yang, 2018; Hu, 2019; Wan & Razali, 2019).

However, the cultural characteristics of NETT, as a signature cultural object from Ningxia province, have not been adequately reflected in its packaging design, limiting the public's understanding of its rich cultural connotations. The various phases of this study aimed to develop a fresh and meaningful packaging solution for NETT, focusing on effectively conveying its cultural values through visual and verbal elements. It is hoped that this research will contribute to the development of the Eight Treasures Tea industry in Ningxia, promoting its growth, expanding its influence, and enhancing public recognition in the future.

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References

Adams, W. C. (2015) Conducting semi-structured interviews. In: Newcomer, K. E., Hatry, H. P. & Wholey, J. S. (eds.) *Handbook of Practical Program Evaluation. 4th Edition*. New York, John Wiley & Sons, Inc. Available from: doi: 10.1002/9781119171386.ch19

Ambrose, G. & Harris, P. (2018) *Packaging the brand.* Worthing, AVA Publishing.

Andrea, F. (2016) *Positioning Sustainable Packaging: How can the design of packaging affect the consumer to think and buy more sustainably?.* Penryn, Falmouth University.

Bai, X. (2010) The development of Eight Treasure Tea beverage. *Modern Food Science and Technology.* 26 (6). Available from: doi: 10.13982/j.mfst.1673-9078.2010.06.020

Baki, R. A. (2013) Bilingual design layout systems: cases from Beirut. *Visible Language.* 47 (1). 39-66

Barchiesi, M. A., Castellan, S. & Costa, R. (2018) In the eye of the beholder: communicating CSR through color in packaging design. *Journal of Marketing Communications.* 24 (7), 720–733. Available from: doi: 10.1080/13527266.2016.1224771

Bobrie, F. (2018) Visual representations of goods and services through their brandings: the semiotic foundations of a language of brands. *Recherche et Applications en Marketing (English Edition)*. 33 (3), 122–144. Available from: doi: 10.1177/2051570718791784

Bolen, W. H. (1984) *Advertising*. 2nd Edition. New York, John Wiley & Sons.

Borgman, I., Mulder-Nijkamp, M. & Koeijer, B. D. (2018) The influence of packaging design features on consumers' purchasing & recycling behaviour. *The 21st IAPRI World Conference on Packaging, 19-22 June 2018, Zhuhai, China.* Available from: doi: 10.12783/iapri2018/24397

Brinkmann, S. & Kvale, S. (2015) *Interviews: learning the craft of qualitative research interviewing.* Thousand Oaks, SAGE.

Candy, L. & Edmonds, E. (2018) Practice-based research in the creative arts: foundations and futures from the front line. *Leonardo*. 51 (1), 63–69. Available from: doi: 10.1162/LEON_a_01471

Candy, L. (2006) *Practice-based research: A guide.* CCS Report. Report number: 2006-V1.0 November

Cao, X., Ma, Y., Long, D. & Jing, X. (2018a) Research on the excavation and promotion of the art of Ningxia's Eight Treasures Tea. *China Industry and Technology Forum.* 17 (6).

Cao, T., Wang, W., Du, W., Guo, G., Cheng, C., Long, D. & Jing, X. (2018b) Research on the culture and promotion of Eight Treasures Tea for health. *China Industry and Technology Forum.* 17 (5).

Cavassilas, M. (2007) *Clés et codes du packaging: sémiotique appliquée.* Paris, Hermes Lavoisier.

CBNData & Tmall Tasty (2020) 2020 *Tianmao chahangye xiaofei qushi baogao [2020 Tmall Tea Industry Consumer Trend Report].* Available from: https://www.cbndata.com/report/2507/detail?isReading=report&page=1 [Accessed 21st February 2025].

Celhay, F., Cheng, P., Masson, J. & Li, W. (2020) Package graphic design and communication across cultures: an investigation of Chinese consumers' interpretation of imported wine labels. *International Journal of Research in Marketing.* 37 (1), 108–128. Available from: doi: 10.1016/j.ijresmar.2019.07.004

Chinese Health Concerns Big Data (2019) *2019 guomin jiankang guanzhu dashuju chulu [2019 National Health Concerns Big Data is out]*. Available from: http://health.people.com.cn/n1/2019/1202/c14739-31485724.html [Accessed 21st February 2025].

Creswell, J. W. (2014) *Research design: qualitative, quantitative, and mixed methods approaches.* 4th Edition. Thousand Oaks, SAGE.

Crouch, C. (2012) *Doing research in design.* Oxford, Berg.

Dabner, D., Calvert, S. & Casey, A. (2012) *The new graphic design school: A Foundation Course in Principles and Practice.* 5th Edition. New York, John Wiley & Sons.

Garber, L. L. Jr., Burke, R. R. & Jones, J. M. (2000) *The role of package color in consumer purchase consideration and choice.* Marketing Science Institute. Report number: 00-104.

Gofman, A., Moskowitz, H. R. & Mets, T. (2010) Accelerating structured consumer driven package design. *Journal of Consumer Marketing.* 27 (2), 157–168. Available from: doi: 10.1108/07363761011027259

Gray, C. & Malins, J. (2004) *Visualizing research: a guide to the research process in art and design.* Farnham, Ashgate.

Griswold, W. (1994) *Cultures and societies in a changing world.* Newbury Park, Pine Forge Press.

Hausman, A. (2000) A multi-method investigation of consumer motivations in impulse buying behavior. *Journal of Consumer Marketing.* 17 (5), 403-426. Available from: doi: 10.1108/07363760010341045

Hibberts, M., Burke Johnson, R. & Hudson, K. (2012) Common survey sampling techniques. In: Gideon, L. (ed.) *Handbook of Survey Methodology for the Social Sciences.* Berlin, Springer. Available from: doi: 10.1007/978-1-4614-3876-2_5

Hu, B. (2020) Exploring contemporary visualizations of traditional Chinese symbols: a case of tea packaging design. *The Design Journal.* 23 (2), 309–320. Available from: doi: 10.1080/14606925.2019.1699763

Huang, Z. (2007) *Zhongguo cha wenhua [Chinese Tea Culture]*. Hangzhou, Zhejiang University Press.

Kamaruddin, A. R., Mokhlis, S. & Othman, M. N. (2002) Ethnocentrism orientation and choice decisions of Malaysian consumers: the effects of socio-cultural and demographic factors. *Asia Pacific Management Review.* 7 (4), 555–573.

Kapferer, J. N. (2004) *The new strategic brand management: creating and sustaining brand equity long term.* London, Kogan Page.

Kauppinen-Räisänen, H. & Luomala, H. (2010) Exploring consumers' product-specific colour meanings. *Qualitative Market Research: An International Journal.* 13 (3), 287–308. Available from: doi: 10.1108/13522751011053644

Kotler, P. & Pfoertsch, W. (2010) *Ingredient branding: making the invisible visible.* Berlin, Springer.

Krishna, A., Cian, L. & Aydınoğlu, N. Z. (2017) Sensory aspects of package design. *Journal of Retailing.* 93 (1), 43–54. Available from: doi: 10.1016/j.jretai.2016.12.002

Ksenia, P. (2013) *Packaging design as a marketing tool and desire to purchase.* BSc thesis. Saimaa University of Applied Science.

Kuvykaite, R., Dovaliene, A. & Navickiene, L. (2009) Impact of package elements on consumer's purchase decision. *Economics & Management.* 14, 441-447.

Lipe, W. D. (1984) Value and meaning in cultural resources. In: Green, G. L. (ed.) *Approaches to the Archaeological Heritage.* Cambridge, Cambridge University Press.

Lv, S., Shi, Y. & Yu, F. (2006) The idea of primordium in the virtual packaging design. In: *2006 7th International Conference on Computer-Aided Industrial Design and Conceptual Design, 17-19 November 2006, Hangzhou, China.* New York, IEEE. Available from: doi: 10.1109/CAIDCD.2006.329339

Madden, J. T., Hewett, K. & Roth, M. S. (2000) Managing images in different cultures: a cross-national study of colour meaning and preferences. *Journal of International Marketing.* 8 (4), 90–107. Available from: doi: 10.1509/jimk.8.4.90.19795

Mangone, E. (2018) *Social and cultural dynamics.* Berlin, Springer.

McIntosh, M. J. & Morse, J. M. (2015) Situating and constructing diversity in semi-structured interviews. *Global Qualitative Nursing Research.* 2. Available from: doi: 10.1177/2333393615597674

Merton, R. K. & Kendall, P. L. (1946) The focused interview. *American Journal of Sociology.* 51 (6), 541–557.

Meyer, J. (2000) Using qualitative methods in health related action research. *BMJ.* 320 (7228), 178–181. Available from: doi: 10.1136/bmj.320.7228.178

Min, T. S., Idris, M. Z. & Yusoff, S. O. S. (2018) Exploring small and medium enterprises (SMEs) food packaging as a touchpoint to promote nation branding at Kuala Lumpur International Airport (KLIA). *International Journal of Academic Research in Business and Social Sciences.* 8 (10), 1349–1360. Available from: doi: 10.6007/IJARBSS/v8-i10/5303

Mirzoeff, N. (2002) Ghostwriting: working out visual culture. *Journal of Visual Culture.* 1 (2), 239–254. Available from: doi: 10.1177/147041290200100206

Morse, J. M. & Field, P. A. (1995) *Qualitative research methods for health professionals.* 2nd Edition. Thousand Oaks, SAGE.

Muratovski, G. (2016) *Research for designers: a guide to methods and practice.* Thousand Oaks, SAGE.

Ni Luh Desi In Diana Sari (2016) Poleng as a creative concept of awani packaging design. In: *Proceedings of the 1st International and Interdisciplinary Confernce on Arts Creation and Studies, Paradigms in art creations and art studies, IICACS, 24-25 August 2016, Solo, Indonesia.* ISI Press. pp. 78-91.

Pilditch, J. (1961) *The silent salesman: how to develop packaging that sells.* London, Business Books Limited.

Piliang, A. Y. (2010) *Semiotikadan hipersemiotika, kode gaya dan matinya makna.* Bandung, Matahari.

Ranjbarian, B., Mahmoodi, S. & Shahin, A. (2010) Packaging elements and consumer buying decisions. *International Journal of Business Innovation and Research.* 4 (4), 376–390. Available from: doi: 10.1504/IJBIR.2010.033353

Riaz, S., Wasif, S., Nisar, W., Farwa, U. & Rashid, A. (2015) Impact of packaging designs of cosmetics on female consumer buying behavior. *Academic Research International.* 6 (5), 130–142.

Rose, G. (2022) *Visual methodologies: an introduction to researching with visual materials.* Thousand Oaks, SAGE.

Rundh, B. (2009) Packaging design: creating competitive advantage with product packaging. *British Food Journal.* 111 (9), 988–1002. Available from: doi: 10.1108/00070700910992880

Schön, D. A. (1983) *The reflective practitioner: how professionals think in action.* New York, Basic Books.

Thompson, S. (2008) *The critically reflective practitioner.* New York, Palgrave Macmillan.

Silayoi, P. & Speece, M. (2004) Packaging and purchase decisions: an exploratory study on the impact of involvement level and time pressure. *British Food Journal.* 106 (8), 607–628. Available from: doi: 10.1108/00070700410553602

Silayoi, P. & Speece, M. (2007) The importance of packaging attributes: a conjoint analysis approach. *European Journal of Marketing.* 41 (11-12), 1495–1517. Available from: doi: 10.1108/03090560710821279

Siwei, W., Cheng, D. & Zhe, Y. (2019) The new concept of visual communication in brand packaging design in contemporary internet context. In: *3rd International Conference on Economics, Management Engineerring and Education Technology, ICEMEET 2019, 18-19 May 2019, Suzhou, China.* London, Francis Academic Press. pp. 1299-1304. Available from: doi: 10.25236/icemeet.2019.264

Squire, V., Willberg, H. & Forssman, F. (2006) *Getting it right with type.* London, Laurence King Publishing.

Stewart, B. (1994) *Packaging design strategy.* Letterhead, Pira International Ltd. Available from: doi: 10.1002/pts.2770070609

Tinarbuko, S. (2009) *Semiotika komunikasi visual.* Yogyakarta, Jala Sutra.

Tseng, T. H. & Balabanis, G. (2011) Explaining the product-specificity of country-of-origin effects. *International Marketing Review.* 28 (6), 581–600. Available from: doi: 10.1108/02651331111181420

Underwood, R. L., Klein, N. M. & Burke, R. R. (2001) Packaging communication: attentional effects of product imagery. *Journal of Product & Brand Management.* 10 (7), 403–422. Available from: doi: 10.1108/10610420110410531

Underwood, R. L. & Klein, N. M. (2002) Packaging as brand communication: effects of product pictures on consumer responses to the package and brand. *Journal of Marketing Theory and Practice.* 10 (4), 58–68. Available from: doi: 10.1080/10696679.2002.11501926

Velasco, C. & Spence, C. (2019) The role of typeface in multisensory packaging. In: Velasco, C. & Spence, C. (eds) *Multisensory packaging.* Cham, Palgrave Macmillan. Available from: doi: 10.1007/978-3-319-94977-2_4

Wan, S. S. A. & Razali, N. M. (2019) Brand identity on local Malay herbal toiletries' packaging designs as potential tourism products. *International Journal of Art & Design.* 1 (1), 46-53. Available from: doi: 10.24191/ijad.v1i1.2656

Wang, Z. (1988) *Zhongguo nongye baike quanshu [Encyclopaedia of Chinese agriculture].* Beijing, China Agricultural Press.

Yang, W. (2018) *Packaging design development for Taiwanese souvenirs.* Ames, Iowa State University.

Yeong, N. C., Mohamad, O., Ramayah, T. & Omar, A. (2007) Purchase preference of selected Malaysian motorcycle buyers: the discriminating role of perception of country of origin of brand and ethnocentrism. *Asian Academy of Management Journal.* 12 (1), 1–22.

Yu, X. & Yang, D. (2018) *Ningxia babaocha chanye nian yingshou yu 3 yi yuan [Ningxia's Eight Treasures Tea annual revenue exceeds 300 million yuan].* Available from: https://www.sohu.com/a/283766238_120044782 [Accessed 22nd March 2022].

Zhang, T. (2022) *Ningxia feiyi zhanfang xiandai zhi mei [Ningxia's cultural heritage blossoms into modern beauty].* Available from: https://www.sohu.com/a/557560752_121106869 [Accessed 3rd March 2022].

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UV light in graphic technology: Usage, effects and safety measures

ABSTRACT

The introduction of ultraviolet (UV) light technologies to the graphic arts industry has revolutionised printing by offering better print quality, faster curing times and the ability to print on a variety of substrates. Despite these advances, UV light and UV-curable materials pose significant health risks to workers. This paper examines the potentially harmful effects of UV light on workers in the graphics technology sector and outlines key safety measures to mitigate these risks. The UV spectrum (100–400 nm) is categorised as UVA, UVB and UVC. While UVA and UVB are partially absorbed by the atmosphere, UVC is almost completely absorbed by the ozone layer. In graphics technology, however, artificial UV light sources can expose workers to harmful radiation. The increasing use of UV light in UV printing and UV curing requires a closer look at occupational hazards. Harmful effects include skin damage (erythema, skin ageing, pigmentation changes, skin cancer) and eye damage (photokeratitis, cataracts, retinal damage). UV-curable inks and coatings also contain photoinitiators and chemicals that pose health risks (irritation, allergic reactions and respiratory problems) and require comprehensive safety protocols. Key safety measures include personal protective equipment (PPE) such as protective clothing, goggles and respirators. Technical measures such as UV-blocking shields, covers and adequate ventilation reduce exposure. Comprehensive training, the use of PPE, safety protocols and regular inspections ensure the safety of employees. By addressing the risk of UV exposure, the industry can protect its employees while continuing to innovate.

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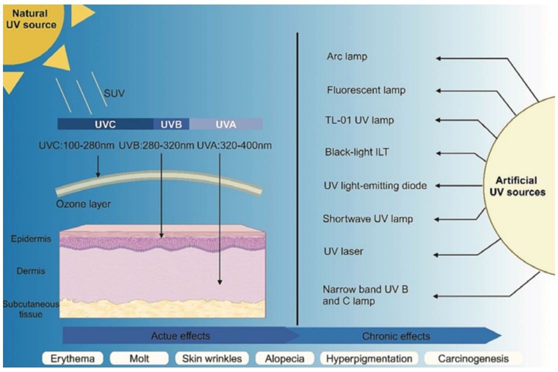
Introduction

Due to its high energy density, UV radiation has become an integral part of modern technological progress and is therefore ideal for processes that require efficient and fast curing or treatment. In practice, the use of high-energy radiation is often limited to UV light or electron beams, as both provide the necessary intensity to effectively initiate and maintain chemical reactions or material transformations. Decades of extensive research have expanded our understanding of this segment of the electromagnetic spectrum and provided deep insights into its mechanisms and applications. This growing knowledge has enabled ever more precise and innovative use of UV radiation in various industries, including the graphic arts industry.

UV radiation comes from both natural and artificial sources (Figure 1) and spans the electromagnetic spectrum between 100 and 400 nm.

It is usually divided into three ranges: UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). More recently, the UVA and UVB spectra have been further subdivided into specific subcategories: Narrowband UVB (311–313 nm), UVA2 (320–340 nm) and UVA1 (340–400 nm), allowing a more detailed understanding of their different effects and applications (Ahmad, Christensen & Baron, 2017).

In the case of naturally occurring UV radiation, e.g. that of the sun, UVA and UVB are partially absorbed by the earth's atmosphere, while UVC is almost completely blocked by the ozone layer. While the effects of UV light, both beneficial and harmful, are well researched, the widespread and often unquestioned reliance on artificial UV sources in industrial processes harbours a number of potential risks.



» **Figure 1:** *Comparison of natural and artificial UV light sources and their biological effects (Tang et al., 2024)*

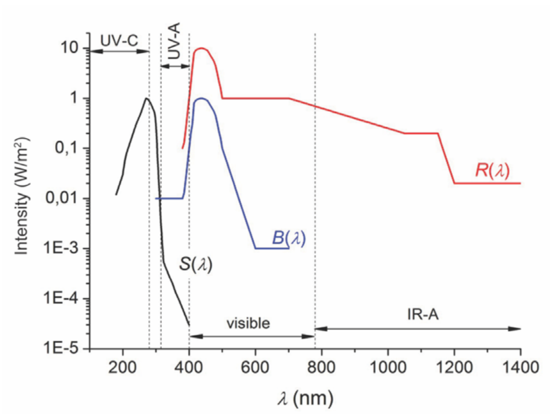
Prolonged exposure to UV light can have a number of harmful effects, particularly on the skin. These include erythema (similar to sunburn), accelerated skin ageing, pigmentation changes and, more importantly, an increased risk of skin cancer. The carcinogenic potential of UV radiation emphasises the need for strict protective measures. In addition to these skin problems, UV exposure also poses a significant risk to the eyes. Acute exposure can lead to photokeratitis, while chronic exposure increases the risk of cataracts and retinal damage, which can lead to visual impairment or, in severe cases, loss of vision. But these are not the only effects, as the WHO published a report in 2006 on the harmful effects of exposure to artificial UV radiation and skin cancer, which even mentions DNA and cell damage (IARC Working Group on Risk of Skin Cancer and Exposure to Artificial Ultraviolet Light, 2006).

In addition, UV curing inks and coatings commonly used in UV printing contain photoinitiators and various chemicals that pose additional health risks. Direct contact with these substances or inhalation of their vapours can lead to irritation, allergic reactions and respiratory problems. The complexity and toxicity of these chemicals requires the implementation of comprehensive safety protocols to adequately protect workers.

The harmful effects of incoherent optical radiation are quantified with three spectral weighting functions – *S(λ)*, *B(λ)* and *R(λ)* (Figure 2). These functions represent the risk of the radiation interacting with the tissue and potentially causing damage based on the spectral distribution and energy of the exposure. They are defined in the regulation as *„spectral weighting functions"* that help to assess the specific risks posed by different wavelengths of radiation and their potentially harmful effects on biological tissue.

The *S(λ)* function, also known as the *actinic UV hazard function*, represents the effectiveness of UV radiation in damaging the skin and eyes. It is defined in the range of 180–400 nm and peaks at 270 nm, with its effectiveness falling below 0.01 at 321 nm. Put simply, this function shows how dangerous UV light is for the skin and eyes – especially at short wavelengths where the energy is at its highest. The *B(λ)* function, or blue light hazard function, measures the photochemically induced retinal damage caused mainly by blue light between 400–500 nm. This means that it quantifies how prolonged exposure to blue light – such as from some LEDs – can damage our eyes, especially the retina.

Finally, the *R(λ)* function describes the thermal effects of visible and IR-A radiation, covers wavelengths from 380–1400 nm and considers risks such as IR-induced cataract and thermal retinal damage, including photoretinitis. In other words, this function indicates how much the heat from intense light sources can damage the eye tissue or skin, similar to a burn.



» **Figure 2:** *Risk functions for optical radiation sources: UV radiation – S(λ), visible light – B(λ) and visible and IR-A radiation – R(λ) (European Union, 2006; Commission Internationale de l'Eclairage, 1998)*

In industrial practice, e.g. in printing plants, the intensity and biological risk of UV radiation is measured using portable spectroradiometers or UV hazard metres. These devices record the spectral power distribution of the UV source directly at the nearest point of human exposure. In UV curing systems, for example, the probe is placed at the exit of the lamp housing or near areas accessible to the operator to determine the effective irradiance.

The device then applies the appropriate spectral weighting functions (e.g. *S(λ)* for skin and eye hazards) to calculate the Biologically Effective Dose (BED). If the measured values exceed the exposure limits mandatory in standards such as IEC 62471 or ICNIRP guidelines, technical and organisational measures — such as shielding, limiting the duration of exposure or prescribed PPE — must be taken to ensure the safety of the operator.

In 2002, the International Commission on Illumination (CIE) introduced standardised methods for assessing the radiation hazards of different lamps and lamp systems, with a focus on non-coherent radiation sources – ***CIE S 009/E:2002/IEC 62471:2006*** (Commission Internationale de l'Eclairage, 2002). These guidelines provide a framework for assessing the risks associated with the different types of radiation emitted by lamps, thus ensuring safety in the use of these lamps. In addition, ***Directive 2006/25/EC*** of the European Parliament and of the Council defines the spectral weighting functions and lays down minimum requirements for the protection of the health and safety of workers from artificial optical radiation (European Union, 2006).

Directive 2006/25/EC sets minimum standards for the prevention of skin and eye damage due to exposure to artificial optical radiation. It sets exposure limit values, defines the employer's obligations and establishes penalties for non-compliance. These limits aim to protect most people from harmful effects, even from repeated exposure. However, the Directive does not take into account people with increased photosensitivity or photosensitisers, nor does it address exposure to natural sunlight, which means that it does not impose any restrictions on outdoor activities. Manufacturers' data on radiation levels must be used for exposure assessment, although all devices require proper risk assessment and inclusion in comprehensive risk assessments. (European Union, 2006; Klanjšek Gunde, 2010; Commission Internationale de l'Eclairage, 1998).

In addition to the EU and CIE legislation mentioned above, there are several other important documents that regulate the harmful effects of ultraviolet (UV), infrared (IR) and non-ionising radiation (NIR). Directive 2006/25/EC, adopted as a part of the overarching ***framework Directive 89/391/EEC***, requires employers to assess the risks and take safety measures to protect workers from radiation, including UV and IR radiation. In addition, ***Directive 2013/35/EU*** addresses the health and safety requirements for exposure to electromagnetic fields (EMF), which include certain wavelengths of infrared and UV radiation.

The ***European Optical Radiation Directive*** is supported by EN standards that set safe limits for exposure to optical radiation, particularly in industries such as printing and manufacturing where UV radiation is often used for curing. In addition, ***ISO 15858:2016*** sets safety standards for UV-C devices used for air and surface disinfection to prevent human exposure.

CEN (European Committee for Standardisation) provides further safety guidelines for exposure to optical radiation in the workplace, such as ***EN 14255-1***, which outlines measurement and assessment protocols for artificial optical radiation.

Many CEN standards are in line with the ***recommendations*** of the ***ICNIRP*** (International Commission on Non-Ionising Radiation Protection) and set limits to reduce the harmful effects of optical radiation in industrial environments such as UV curing, welding and laser use. Standards such as ***EN 170*** ensure that PPE such as goggles, face shields and clothing fulfil the required safety criteria, especially for UV protection.

In addition, standards such as ***EN 12198*** provide methods for measuring radiation emissions and assessing their effects on workers to ensure compliance with safe exposure levels. CEN often develops harmonised standards that complement European regulations and help companies comply with Directive 2006/25/EC. Industries that rely on UV, IR or visible light sources must follow specific safety standards, such as ***EN 62471***, which assesses the photobiological safety of lamps and high-intensity light sources, including LEDs and lasers, which are often used in the printing and manufacturing industries.

In addition, national regulations should also be considered. Namely, EU member states also implement their own national regulations, which are often based on EU directives. In Germany, for example, there is the ***Ordinance on Artificial Optical Radiation (OStrV)***, which mandates detailed risk assessments and safety measures to protect workers from exposure to artificial UV and IR radiation. In combination, these directives and standards form a comprehensive regulatory framework that aims to minimise the health risks associated with exposure to optical radiation in the workplace.

The CIE has continuously updated and revised the ***CIE S 009/E:2002/IEC*** guidelines for the Photobiological Safety of lamps and Lamp Systems since the original standards. Whilst ***IEC 62471:2006*** remains the core standard for the assessment of photobiological safety, there have also been some developments. In particular, ***IEC TR 62471-2 (2009)*** provides guidance on the application of ***IEC 62471***, especially for LED sources, to improve compliance by manufacturers and authorities. The ***IEC 62778 (2014)*** standard focuses specifically on the hazards of blue light and targets the risks to the retina from LEDs and high-intensity light sources.

The ***CIE 231:2019*** standard emphasises the hazards of blue light and its potential impact on human health and addresses the concerns associated with the proliferation of LED and solid-state lighting.

These directives and standards underline the importance of accurate risk assessments, compliance with exposure limits and the implementation of protective measures to minimise health risks in industries heavily dependent on optical radiation. This comprehensive legal framework is essential to ensure the safety of workers in various industries.

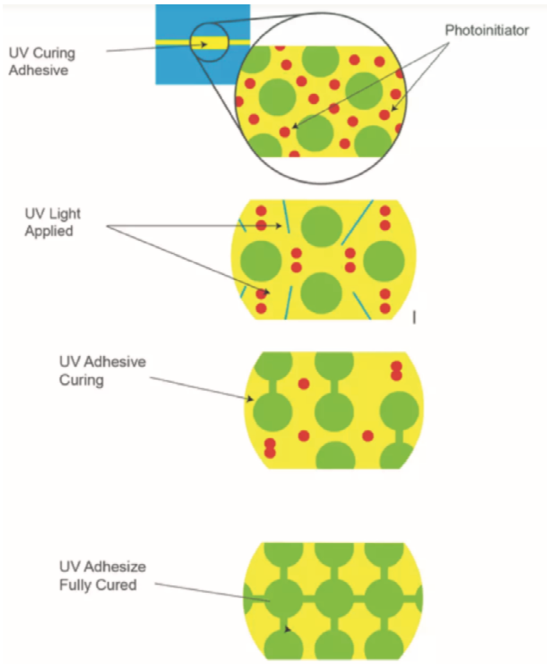
Applications of UV radiation in graphic technology

UV radiation is mainly used in processes such as drying, cross-linking, curing and (photo)polymerisation. In graphic arts technology, it plays a crucial role in UV printing, curing (Figure 3) and the production of printing plates for offset and flexographic printing through photopolymerisation or photoengraving.

Compared to conventional drying methods, UV radiation consumes significantly less energy, eliminates the need for organic solvents and ensures compliance with VOC guidelines. The efficiency of these processes is controlled by the spectral distribution of the UV light, the activation energy of the photoinitiator and the exposure time, which optimises both volume and speed (Klanjšek Gunde & Urbas, 2007; Excelitas, 2014).

An efficient UV-curable system must contain several key components: a photoinitiator that generates free radicals when exposed to UV light, a monomer that provides viscosity and flexibility, an oligomer that creates the essential coating properties, and additives to fine-tune performance. The photoinitiator decomposes into free radicals and initiates the curing process.

Monomers combine chemically with other molecules to form polymers, while oligomers are short-chain polymers or resins that affect the structure of the material. Finally, additives such as pigments, fillers and wetting agents are added to give the coating certain properties (Excelitas, 2014).



» **Figure 3:** *Curing process (Excelitas, 2014)*

During polymerisation, UV light sources are used to cure photopolymers. The areas containing photopolymer are cured and the unexposed areas are washed away. In addition, modern computer-to-plate (CTP) systems typically use UV laser or UV LED technologies so that the design can be transferred directly to the printing plate without the need for conventional film exposure.

UV applications in specific printing techniques

UV radiation in flexographic printing

In flexographic printing, UV curing is generally used with photopolymer printing plates and UV curing inks. The plates consist of light-sensitive polymers that are selectively cured by UV radiation. UV LED curing systems are increasingly being used instead of traditional mercury lamps due to their lower energy consumption, compactness and precise wavelength control. These systems allow immediate curing at lower temperatures, which is particularly beneficial for heat-sensitive substrates such as thin films or self-supporting labels (Gómez, Orme & Simmons, 2019).

UV radiation in screen printing

Screen printing relies on UV curing inks and varnishes, especially for printing on non-absorbent substrates such as plastics, metals, and glass. UV coatings are used for both protective and decorative purposes, including gloss, tactile or matt effects. As screen printing usually involves the application of thicker layers of ink, powerful UV lamps or controllable UV LED systems are used to ensure complete curing. These systems enable durable and resistant prints even on difficult surfaces. (Klanjšek Gunde et al., 2011)

UV radiation in offset printing

UV offset printing is often used to print on non-porous materials such as plastic cards, packaging foils or metal-coated papers. The UV inks used in this process contain photoinitiators that polymerise quickly when exposed to UV light. This eliminates the drying time, reduces emissions of volatile organic compounds (VOCs) and improves print sharpness and durability. Modern offset presses are increasingly utilising LED UV systems for greater energy efficiency, longer lamp life and improved print stability (Excelitas, 2014; Light Adviser, 2024b).

Each of these printing processes utilises the benefits of UV curing – fast drying, high durability and environmental friendliness – while adapting the type of light source, ink formulation and process parameters to the specific technological requirements.

UV light sources technologies and graphic applications

There are different types of UV sources/lights that can be used in graphics technology.

Mercury vapour lamps, which are frequently used in graphics technology, are available in both medium and high pressure versions. These lamps emit a broad spectrum of UV light (UVA, UVB and UVC) and are therefore ideal for curing UV-curing inks, varnishes and coatings as well as for the production of printing plates. High pressure mercury vapour lamps provide a more intense UV output and are suitable for applications that require fast curing, especially with thicker or more difficult substrates. Medium-pressure mercury vapour lamps, on the other hand, are mainly used in exposure systems, where their broad UV spectrum effectively cures photopolymer materials in printing plates.

Today, UV LED technology is mainly used because it is more energy-efficient, emits less heat and has a longer service life than conventional mercury lamps. UV LEDs emit mainly in the UVA range and offer precise wavelength control, making them ideal for curing inks and coatings in printing processes. Their precision and energy efficiency are also beneficial in the production of printing plates, where UVA light is used to cure photopolymer plates for digital printing. UV LED systems also offer an instant-on function that speeds up plate production. These environmentally friendly and mercury-free systems operate at cooler temperatures, maintaining the integrity of the photopolymer materials during exposure and improving sustainability without compromising quality.

Metal halide lamps are another viable option for UV curing applications, especially when substrates or inks require specific wavelengths for curing. These lamps emit a broad spectrum of light, similar to mercury vapour lamps, but can be adjusted for greater precision. In some cases, they are also used in UV exposure units for printing plate production, as they provide a balanced spectrum of UVA and UVB light.

This makes them ideal for curing photopolymer plates where accuracy is important. This combination of broad spectrum and finely tuned control ensures effective curing and exposure processes.

Xenon arc lamps emit a complete spectrum of UV radiation, with a particularly high intensity in the UVA range. They are often used for high-precision exposure and offer excellent resolution for imaging in printing plate production. In addition, xenon arc lamps are used in test environments where UV exposure and weathering tests are performed on printed materials to ensure their durability and performance.

Their ability to deliver consistent, high-intensity UV light makes them ideal for applications that require detailed imaging and rigorous testing.

Fluorescent UV lamps are typically used for low intensity applications such as quality control and inspection. Although they are not normally used for curing processes, they are very effective in the inspection of UV-reactive inks and coatings, enabling the accurate detection of defects or inconsistencies in printed materials. Their use in inspection processes ensures the quality and consistency of UV-sensitive materials without the need for high-intensity curing.

Laser-based UV systems are an essential part of CTP technologies, where laser diodes are used to selectively expose precise areas of photopolymer plates. This method enables highly detailed imaging and provides excellent control over the plate production process. Widely used in modern print workflows, laser-based UV imaging ensures the creation of offset printing plates with exceptional precision and consistency, making it a favoured technology for accurate and reliable results in professional printing environments.

Although less common in traditional printing, Excimer UV lamps are used in specialised printing processes or in areas where extreme precision in curing is required, such as microprinting or electronic printing. These lamps provide the high level of accuracy required for intricate applications, making them ideal for advanced production processes where detail and precision are essential. (Gálvez et al., 2022; Bahria & Erbil, 2016; Maloney, 2006; Klanjšek Gunde et al., 2011, Klanjšek Gunde & Urbas, 2007; SCENIHR, 2012; Light Adviser, 2024a; FDA, 2022; European Committee for Electrotechnical Standardization, 2008).

In summary, UV light sources play a crucial role in the production of printing plates, especially in photopolymerisation and laser-based imaging processes. Mercury vapour lamps and UV LEDs dominate in this area, but xenon arc and metal halide lamps also contribute in certain applications.

UV light sources are widely used in 3D printing, whether in subtractive or additive manufacturing technologies such as the polyjet process.

UV light is also critical in the printing of industrial coatings and in the graphics market for coatings on electronic and automotive components, overprint varnishes and various printing processes using inks such as flexographic, screen and lithographic inks. UV light also plays a role in laminating, pressure-sensitive adhesives, wooden furniture and flooring. It is also used for printing displays, touchscreens, solar cells, batteries, fuel cells and flexible electronics.

System design considerations: housing, ventilation and curing speed

Modern UV printing systems often use semi-enclosed or fully enclosed configurations to ensure safe operation of UV lamps and control emissions. High-pressure mercury lamps, for example, can reach temperatures in excess of 850°C, which poses a significant fire risk when printing on sensitive substrates. To minimise these risks, the systems are usually equipped with active cooling (either air or water-based), automatic shutters and paper jam detection sensors that immediately deactivate the UV lamp in the event of a malfunction (RiskStop, 2023).

Ventilation systems are also an important component of UV printing systems. These include local exhaust fans and ducts to remove ozone and vapours generated during the curing process and to supply the working environment with fresh air. Proper air management reduces the risk of photochemical smog formation and increases operator safety (Uvitron, 2023).

Curing speed is another important factor in the development of machines. Modern UV LED systems — especially for flexographic printing applications — can dynamically adjust the light intensity to the web speed (e.g. 150–200 m/min) and offer an instant on/off function. Water-cooled LED heads enable efficient curing with minimal thermal stress, enabling high-speed production with lower operating costs and better substrate compatibility (CureUV, 2023; Flint Group, 2024).

Guidelines addressing the use of UV light in graphic technology

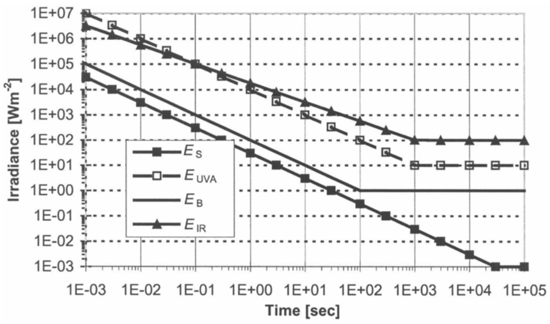
Several publications and guidelines deal with the use of UV light in the field of graphic arts technology, focussing on health risks and safety measures. Regulatory frameworks, industry standards and certifications aim to minimise the impact of UV light in the printing sector on health and the environment. This includes compliance with national and international regulations, an emphasis on worker protection, the handling of hazardous materials and the use of safe UV inks.

Health and environmental aspects point to exposure to harmful UV radiation and the release of volatile organic compounds (VOCs) from conventional UV inks. Safer alternatives such as UV LEDs and bio-based UV inks are becoming increasingly important due to their lower environmental and health risks.

Best practices for UV curing emphasise the use of proper light intensity to avoid under or overexposure, which can damage the material. Neglecting safety measures, such as wearing protective clothing or ensuring adequate ventilation, exacerbates these risks (SCENIHR, 2012; Commission Internationale de l'Eclairage, 2002; European Union, 2006).

IEC 62471:2008 specifies exposure limits for UV light based on intensity and duration. It specifies that at a light intensity of 1,000,000,000 W/sr/m² the safe exposure time is 1/1000 of a second. At a lower intensity of 100 W/sr/m², the permissible exposure time is 10,000 seconds, which corresponds to 2.78 hours (Figure 4). These limits contribute to safety by regulating the duration and intensity of exposure to prevent possible damage from UV light wavelengths.

The BED of UV radiation measures the amount of radiation an organism receives, taking into account the spectral distribution of the light source (e.g. a lamp) and the action spectrum of biological effects (e.g. skin damage). To calculate the BED, the spectral output of the lamp is measured at the nearest point of human exposure and then weighted with the corresponding spectrum of action. The resulting BED is compared to the maximum permissible exposure limits set by the ICNIRP, a scientific organisation that provides guidance on the risks of non-ionising radiation, including UV light and electromagnetic fields (EMF), which are adopted by regulatory authorities around the world (FDA, 2022; Klanjšek Gunde & Urbas, 2007).



» **Figure 4:** *Weighted radiation exposure limits as a function of time with constant exposure (E_s – for skin and eyes, E_{UVA} – for eyes in the UVA range, E_B – for blue light and EIR – for skin in the IR range) (FDA, 2022)*

The photobiological safety of UV lights can be measured with portable devices, using a three-step procedure:
1. Measure the spectral distribution of the selected lamp, taking into account factors such as the filter system and projection optics, at the nearest point to which a person could be exposed;
2. Weight the measured spectral distribution with the corresponding action spectrum to calculate the BED;
3. Compare the calculated BED with the maximum permissible exposure limits set by the ICNIRP to ensure safety.

The safety protocols for UV printing, curing and printing plates production emphasise the importance of using PPE such as UV-blocking goggles, protective clothing (gowns), protective gloves and ensuring adequate ventilation to prevent the build-up of harmful chemicals.

The protective properties of textile materials (clothing, including gloves, headgear (e.g. hats, caps)) against UV radiation are defined by the Ultraviolet Protection Factor (UPF), which indicates the ratio between the time when erythema appears on human skin when human skin is protected by textiles and the time when it does not.

It is defined by standards (such as the European standards EN 13758-1, EN 13758-3, 183 and UV STANDARD 801, the Australian/New Zealand standard AS/NZS 4399, the American standard AATCC TM). The protection values are listed in Table 1 (Urbas, 2005). Protection by textile material is simple and very effective.

In printing environments, protective clothing such as gloves, gowns, long-sleeved lab coats or visors with a high UPF rating is often worn by operators working near open UV curing equipment or during maintenance, where incidental exposure to UV radiation is more likely.

Table 1

UPF rating

UPF	UV protection	Blocking of UV radiation (%)
15 - 20	good	93.3 - 95.8
25, 30, 35	very good	95.9 - 97.4
40, 45, 50, 50+	excellent	>97.9

To protect the eyes from UV radiation, it is recommended to wear UV-blocking sunglasses that filter 99–100% of UVA and UVB rays, as well as a wide-brimmed hat for additional protection. Special safety goggles are also essential in industrial environments with UV exposure.

In a study investigating the effectiveness of laboratory protective clothing – laboratory gowns, gloves (such as latex PFE, nitrile latex free) and goggles – against UV radiation, Klanjšek Gunde et al. (2011) concluded that only goggles provide adequate protection, while gloves and gowns do not provide all-day protection. This emphasises the need for constant innovation in materials and products to improve UV resistance. As protective technologies are constantly evolving, it is crucial to carefully select laboratory equipment that fulfils the high requirements for adequate UV protection to ensure maximum safety during prolonged exposure (Klanjšek Gunde et al., 2011).

Conclusion

While the use of UV radiation in the graphic arts industry increases productivity and print quality, it also requires comprehensive safety protocols. All UV light sources pose a significant health risk, and without the proper use of PPE, these risks cannot be mitigated. It is imperative that the use of PPE is considered mandatory to protect workers from the harmful effects of UV exposure.

Employers have a major responsibility to ensure the safety of their employees from artificial optical radiation. They must evaluate the exposure of workers and assess the associated health risks. To this end, the radiation levels in the working environment must be measured and calculated. If exposure exceeds the safe limits, employers are obliged to take measures to reduce the risks, including adapting work processes, using alternative equipment, providing protective clothing or limiting the duration of exposure. Particular attention must be paid to sensitive groups of workers and the interaction between optical radiation and photosensitive chemicals. In addition, any work area where radiation exposure exceeds safe limits must be clearly labelled and access should be restricted. Workers must be trained and receive appropriate medical examinations to protect their health.

Despite numerous laws, regulations and directives dealing with UV protection, many critical questions remain unanswered. Questions such as whether UV-induced damage is fully regenerative, the potential effects of long-term exposure (which are still largely unexplored), the accumulation of non-regenerative damage and its possible consequences need further investigation. These complex questions can probably only be answered by a multidisciplinary approach involving photobiology, photochemistry, dermatology and ophthalmology.

Only by further improving our understanding of the biological effects of UV light, while adhering to strict safety standards, can we ensure that UV radiation remains a sustainable and safe tool in graphics technology.

Future developments and research perspectives

As UV technology continues to evolve, future developments in graphic arts printing are likely to focus on further improving energy efficiency, curing speed and substrate compatibility — particularly using modern UV LED systems. The move away from mercury-containing sources is likely to accelerate due to environmental regulations and safety concerns. However, challenges remain in ensuring uniform curing on complex substrates and scaling UV systems for high-speed industrial applications without compromising quality or safety.

Further research is needed to optimise ink formulations for low-energy curing, understand long-term material interactions with UV irradiation and develop intelligent control systems that dynamically adjust curing parameters in real time. In addition, interdisciplinary studies combining materials science, photochemistry and occupational health and safety are critical to the development of safe, efficient and sustainable UV printing processes tailored to flexo, screen and offset printing technologies.

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References

Ahmad, S. I., Christensen, L. & Baron, E. (2017) History of UV lamps, types, and their applications. In: *Ahmad, S. (ed.) Ultraviolet Light in Human Health, Diseases and Environment. Advances in Experimental Medicine and Biology, vol 996.* Cham, Springer. Available from: doi: 10.1007/978-3-319-56017-5_1

Bahria, H. & Erbil, Y. (2016) UV technology for use in textile dyeing and printing: Photocured applications. *Dyes and Pigments.* 134, 442–447. Available from: doi: 10.1016/j.dyepig.2016.07.042

Commission Internationale de l'Eclairage. (2002) S 009/E:2002 / IEC 62471:2006. *Photobiological safety of lamps and lamp systems.* Vienna, Commission Internationale de l'Eclairage.

Commission Internationale de l'Eclairage. (1998) CIE S 007/E-1998. *Erythema reference action spectrum and standard erythema dose. ISO 17166:1999(E).* Vienna, Commission Internationale de l'Eclairage.

CureUV. (2023) *350×25mm UV LED Curing System for Flexo Printing with Water Cooling*. Available from: https://www.cureuv.com/products/350x-25mm-uv-led-curing-system-forr-flexo-printing-with-water-cooling [Accessed 24th July 2025].

European Committee for Electrotechnical Standardization. (2008) EN 62471:2008. *Photobiological safety of lamps and lamp systems.* Brussels, European Committee for Electrotechnical Standardization.

European Union. (2006) Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation). *Official Journal of the European Union.* 114, 38-59. Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0038:0059:EN:PDF [Accessed 25th September 2024].

Excelitas. (2014) *Delivering superior optics and lighting for highest quality printing*. Available from: https://www.excelitas.com/application/industrial-manufacturing/printing [Accessed 25th September 2025].

FDA – Food and Drug Administration. (2022) *The Case for Regulation of Light Emitting Diode Products*. Available from: https://www.softlights.org/wp-content/uploads/2022/10/FDA-Update-to-Petition-to-Regulate-LEDs.pdf [Accessed 25th September 2025].

Flint Group. (2024) *EkoCure® F – UV LED Inks for Flexographic Printing*. Available from: https://www.flintgrp.com/media/tlxamfk1/ekocure-f_ver1_a4.pdf [Accessed 24th July 2025].

Gálvez, E. N., Aguilera, J., Solis, A., Gálvez, M. V., Andrés, J. R., Herrera-Ceballos, E. & Gago-Calderon, E. (2022) The potential role of UV and blue light from the sun, artificial lighting, and electronic devices in melanogenesis and oxidative stress. *Journal of Photochemistry and Photobiology B: Biology.* 228, 112405. Available from: doi: 10.1016/j.jphotobiol.2022.112405

Gómez, J., Orme, M. & Simmons, T. (2019) *LED UV Curing for Narrow Web Flexo Printing*. RadTech Europe.

IARC Working Group on Risk of Skin Cancer and Exposure to Artificial Ultraviolet Light. (2006) *Exposure to artificial UV radiation and skin cancer.* Available from: https://publications.iarc.fr/Book-And-Report-Series/Iarc-Working-Group-Reports/Exposure-To-Artificial-UV-Radiation-And-Skin-Cancer-2006 [Accessed 25th September 2024].

Klanjšek Gunde, M. (2010) Fotobiološka varnost nekoherentnih optičnih sevanj – določila nove uredbe. *Vakuumist.* 30 (3), 12–16. Available from: https://www2.arnes.si/~ljdvts/arhiv/2010/2010_3/2010_3_3_100dpi.pdf [Accessed 25th September 2024].

Klanjšek Gunde, M., Urbas, R., Sever Škapin, A. & Friškovec, M. (2011) Photobiological safety of radiation curing lamp sources applied for printing. In: *10th Seminar in Graphic Arts, 19–21 September 2011, Pardubice, Slovakia*. Pardubice, University of Pardubice, Department of Graphic Arts and Photophysics. pp. 37–42.

Klanjšek Gunde, M. & Urbas, R. (2007) Učinki UV svetlobe v organskih snoveh in njihovo izkoriščanje. In: A. Orgulan (ed.) *Svetloba in arhitektura – Zunanja razsvetljava.* Maribor, Slovensko društvo za razsvetljavo.

Light Adviser. (2024a) *5 Common Mistakes in Best Practices for Using UV Curing Lights Effectively*. Available from: https://lightadviser.com/5-Common-Mistakes-in-Best-Practices-for-Using-UV-Curing-Lights-Effectively/ [Accessed 24th September 2024].

Light Adviser. (2024b) *LED UV Curing System vs. Mercury UV System: Key Differences*. Available from: https://goodiuv.com/th/innovation-of-uv-technology/uv-curing-system-tips/led-uv-vs-mercury-uv-curing-system-key-differences/ [Accessed 24th July 2025].

Maloney, D. L. (2006) Choosing the right UV-curing lamp can brighten your future: Implementing UV technology can prove to be both productive and profitable. *Metal Finishing.* 104 (4), 57–59. Available from: doi: 10.1016/S0026-0576(06)80098-X

RiskStop. (2023) *UV Drying in the Printing Industry: Technical Bulletin*. Available from: https://www.riskstop.co.uk/technical-bulletins/uv-drying-in-the-printing-industry [Accessed 25th July 2025].

SCENIHR – Scientific Committee on Emerging and Newly Identified Health Risks. (2012) *Health Effects of Artificial Light*. Available from: https://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_035.pdf [Accessed 24th September 2024].

Tang, X., Yang, T., Yu, D., Xiong, H. & Zhang, S. (2024) Current insights and future perspectives of ultraviolet radiation (UV) exposure: Friends and foes to the skin and beyond the skin. *Environmental International.* 185, 108535. Available from: doi: 10.1016/j.envint.2024.108535

Urbas, R. (2005) *Analiza zaščitnega učinka tekstilij pred negativnimi vplivi ultravijoličnih žarkov na kožo.* PhD thesis. University of Ljubljana, Faculty of Natural Sciences and Engineering.

Uvitron. (2023) *UV Curing Safety 101: How to Protect Your Employees*. Available from: https://www.uvitron.com/blog/uv-curing-safety-101-how-to-protect-your-employees [Accessed 25th July 2025].

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The role of 3D printing in original printmaking and graphic production

ABSTRACT

This study explores the functional role of 3D printers in original printmaking, a graphic production technique. Traditional methods like linocut, engraving, and intaglio have limited integration with modern digital manufacturing technologies. This research examines how 3D printers can be effectively combined with these techniques. The main goal is to show how 3D printing can be integrated into the printmaking process and what benefits it brings to design and production. The study focuses on converting digitally designed models into physical printing plates via 3D printing, highlighting how this enables the creation of complex surfaces and detailed forms difficult to achieve traditionally. This offers designers both creative freedom and technical advantages. Additionally, the research discusses how digital design and customization of printing plates and stencils improve flexibility, speed, and cost-efficiency in printmaking. Especially in linocut and engraving, the precision, scalability, and detail of 3D printing introduce new production paradigms. In conclusion, the study shows that 3D printers are not only technical tools but also creative elements transforming graphic production in original printmaking, providing artists and designers new opportunities to exceed traditional boundaries and expand artistic expression.

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Introduction

Original printmaking remains a foundational technique in visual art, enabling the transfer of designed compositions onto various surfaces through methods such as linocut, woodcut, and engraving. These techniques, while rooted in manual craftsmanship, have persisted as important modes of artistic expression due to their tactile qualities, aesthetic diversity, and reproducibility. Each method offers a distinct material language, determined by the interaction between surface, tool, and hand. The expressive power of these processes lies not only in their visual outcomes but also in the physical engagement they demand from the artist.

Despite their historical and artistic value, traditional printmaking techniques pose significant challenges in modern production workflows. These include extended production times, difficulty in correcting errors during plate preparation, and limitations in achieving high-resolution or repeatable detail, especially in mass production or iterative design processes. In contemporary creative industries, where rapid prototyping and flexible design adaptation are critical, such constraints have motivated a search for new methodologies that can preserve artistic intent while improving production efficiency.

With the rise of digital technologies, especially in design and fabrication, artists and designers have begun to explore alternative approaches that blend traditional techniques with digital processes. Among these, three-dimensional (3D) printing stands out as a transformative technology capable of bridging the gap between virtual modeling and tangible outcomes.

In the context of printmaking, 3D printing provides an opportunity to rethink the production of printing plates through digitally controlled additive manufacturing. This process allows for the construction of complex surface geometries, consistent repeatability, and the integration of non-traditional materials into the printmaking workflow.

Unlike relief or intaglio methods which rely on subtractive interventions such as carving, etching, or engraving 3D printing operates through an additive process that builds forms layer by layer. This fundamental difference enables greater precision and control in plate fabrication, particularly for intricate or experimental designs that may be difficult to achieve by hand. Furthermore, 3D printing facilitates the customization of plates for specific artistic objectives, offering possibilities such as variable line depths, surface textures, and dimensional layering that enrich the final print. In addition to formal benefits, the incorporation of 3D printing into printmaking introduces new methodological opportunities. Digital fabrication allows for rapid iteration, versioning, and archival of plate designs, ensuring consistency across multiple prints. Moreover, the ability to simulate and visualize models before fabrication supports intentional decision-making in design stages. These advantages align well with the principles of original printmaking while expanding its technical and creative scope.

This study investigates the integration of 3D printing into the context of original printmaking, not as a replacement for traditional methods but as a complementary tool that enhances artistic versatility. By employing digital modeling software and desktop FDM (Fused Deposition Modeling) printers, the research evaluates the use of both flexible (thermoplastic polyurethane, TPU) and rigid (acrylonitrile butadiene styrene, ABS) filaments in printing plate production.

These materials were chosen for their contrasting physical properties, allowing for a comparative examination of detail resolution, surface response, and print durability. Through this practice-based exploration, the study aims to contribute to the ongoing dialogue between craft and technology, offering insights into how digital tools can reshape established visual traditions in contemporary printmaking.

Overview of Original Print Types: Woodcut, Linocut, and Engraving Techniques

Original printmaking is a traditional method in which each print is handcrafted and typically produced in limited editions. Throughout art history, these techniques have served as significant tools of visual expression and cultural dissemination. Relief printing, particularly woodcut, originated in East Asia and was employed for both artistic and communicative purposes. For instance, early Taoist monks used woodblock prints to ward off evil spirits (Kıran, 2016), and woodcut forms can be traced back to as early as 1120 BCE in China (Emerson, 1881). Prior to the printing press, woodblock printing played a vital role in replicating religious texts and illustrations.

In Europe, prior to the 15th century, works such as the Biblia Pauperum were produced using woodcut techniques to combine imagery with text, aiding in public understanding. Woodcut became one of the most widely adopted techniques in book illustration and visual storytelling throughout the Middle Ages and Renaissance. The process involves carving into prepared wooden blocks with simple tools, where uncut surfaces transfer ink to paper. While woodcut provides a natural texture that contributes to its aesthetic value, the carving process is labor-intensive and requires significant precision (Gök & Taş, 2023).

Linocut, a more modern relief technique, emerged in the 20th century and remains widely practiced. It utilizes linoleum, a softer and more workable material than wood, enabling smoother cuts and finer line control (Tekcan, 1997). This method involves removing non-printing areas to leave raised surfaces for inking. Linoleum's adaptability and clarity in design reproduction have made linocut a common technique in contemporary art education and professional studios (Turani, 1975). Artists like Picasso and Matisse explored linocut's artistic potential, employing it in their original works (Figure 1).

» **Figure 1:** *Henri Matisse, Teeny, 1938, linocut, 30.1 × 22.8 cm. Fogg Museum, Cambridge (Matisse, 1938)*

The linocut process involves several stages: design preparation, carving, inking, and printing. The artist creates a reversed design, considering that the print will appear as a mirror image. The linoleum material is carved using cutting tools, leaving raised areas that are inked with a roller (brayer) and pressed onto paper, either by hand or with a printing press (Nemlioğlu, 2021).

Negative areas are carved away, while uncarved surfaces receive ink. Advantages of linocut include ease of material use and suitability for mass production, although carving intricate details can be limiting.

Engraving, categorized as an intaglio method, involves incising detailed lines into metal plates. This technique produces a wide tonal range and exceptional line clarity, but it also demands considerable manual skill and time investment. Each print made through engraving captures the artist's hand yet offers limited flexibility in terms of rapid reproduction and experimentation.

While traditional techniques such as woodcut, linocut, and engraving maintain cultural and artistic significance, they also present challenges in precision, repeatability, and production efficiency. These constraints have led contemporary artists and researchers to explore digital tools as complementary resources. Among these, 3D printing has emerged as a transformative method that allows digital designs to be fabricated as physical printing plates with high accuracy.

Unlike subtractive methods such as carving or etching, 3D printing operates through additive manufacturing, constructing forms layer by layer. This facilitates the replication of intricate surfaces and supports the use of alternative materials tailored to specific design goals. The integration of 3D printing into printmaking introduces consistent reproducibility, expanded material experimentation, and digital archiving capabilities. As such, understanding the historical and technical context of original printmaking lays the foundation for assessing how digital fabrication can enhance, rather than replace, traditional production methods.

Fundamentals of 3D Printing Technology

Three-dimensional (3D) printers are additive manufacturing technologies that convert digitally designed models into physical objects by building them layer by layer (Akbaba & Akbulut, 2021). Typically working with materials such as plastic, resin, metal, ceramic, or composites, these systems directly transform digital models created via computer-aided design (CAD) software into physical forms.

Compared to traditional manufacturing, 3D printing offers a highly flexible and customizable production process. It serves as a tool for turning imaginative ideas into tangible results, especially beneficial in education and for activities that are otherwise resource-intensive or unfeasible within formal settings (Özsoy & Duman, 2017). Advantages such as low-cost prototyping, rapid production, and ease of manufacturing complex geometries have expanded its applications across fields from engineering and medicine to architecture and art. Particularly for limited-run designs, 3D printing caters to unique production needs rather than mass manufacturing.

3D printers employ various production techniques and materials. Filaments and materials significantly affect print quality and process. PLA, a biodegradable material available in various colors, contrasts with the more durable, heat-resistant ABS plastic. Soluble support materials like PVA and composite filaments—such as wood, copper-bronze mixes, and nylon—are used for aesthetic and functional purposes. Resin and ceramic materials are preferred for high-detail productions (Yıldırım, Yıldırım & Çelik, 2018). The most common methods include FDM (Fused Deposition Modeling), SLA (Stereolithography), and SLS (Selective Laser Sintering). FDM melts thermoplastic filament and deposits it layer by layer, favored for user-friendliness (Figure 2). SLA cures liquid resin with a laser, while SLS fuses powdered material with a laser.

Each method offers distinct advantages in precision, surface finish, durability, and material versatility.

» **Figure 2:** *Image of a printing FDM-type 3D printer (HLHRapid, 2023)*

3D printing technology has a transformative impact not only in technical manufacturing but also in artistic and design processes. For artists and designers, this technology has evolved beyond production into a new mode of thinking and expression.

"3D printing technology enables artists to rapidly and precisely transform complex and original designs into physical objects. By overcoming the limitations of traditional craftsmanship and manufacturing methods, it bridges the gap between digital design and physical production. Through 3D printing, artists can experiment with structural and formal possibilities previously unattainable, thereby expanding their creative processes" (Scott, 2018).

In this new production environment that merges traditional handcraft with digital fabrication, the structural logic of the art object is also transformed.

Design processes become more experimental, multilayered, and reproducible, while the concept of originality gains new dimensions through digital modeling.

Particularly in fields such as sculpture, ceramics, jewelry design, and architectural modeling, the use of 3D printers provides artists with greater control over materials, forms, and structures, while also increasing production speed and repeatability. Thus, artists can reinterpret traditional forms and produce innovative, experimental works.

In conclusion, 3D printing technology is not merely a manufacturing tool but a contemporary creative platform that enables ideas to take tangible form. In the digital age, such technologies play a crucial role in shaping the direction of art and design practice. With the flexibility, speed, and diversity it offers from design to production, 3D printing has become an indispensable part of today's creative industries.

Integration of 3D Printing into Traditional Printmaking Techniques

Historically, printing plates used in original printmaking have been handcrafted through labor-intensive processes. In linocut printing, plate creation directly depends on the artist's manual skill. The linoleum surface is carved by hand using specialized cutting tools to produce a negative image (Figure 3). This technique emphasizes the artist's tactile engagement with the material throughout all stages of printing. However, the process is time-consuming and technically limited; applying highly detailed patterns is challenging, and plates risk deformation after limited print runs.

» **Figure 3:** *Carved linoleum prepared for printing (Owen, 2023)*

At this point, 3D printing technology emerges as an alternative method for producing printing plates in original printmaking processes. Patterns created in digital design environments can be converted into physical printing plates through 3D printers. This method offers surface textures and depths comparable to those achieved in linocut printing. Operating on an additive layering principle, 3D printers enable the modeling of details with millimetric precision. Thus, visual complexity limited in traditional linocut can be easily attained through digital production.

Moreover, 3D-printed plates provide significant advantages in terms of reproducibility during the design process. Material modeling allows accurate simulation of complex geometries, playing a critical role in enhancing efficiency during design iterations in digital product development (Scotti et al., 2023). The same plate can be produced repeatedly, facilitating both experimental work and consistency in the printing process. Digital archiving of plate files enables artists to revisit previous works or produce new versions by modifying existing designs.

In this context, integrating 3D printers into original printmaking techniques is not merely a technical innovation but a transformation of the creative process. The control artists gain through digital design tools adds a new dimension to printmaking practice, bridging traditional craftsmanship and digital production into a novel form of expression.

Digital Preparation of the Design

The transformation of digital designs into physical objects has become increasingly accessible and efficient with recent advancements in 3D printing technologies. This process encompasses the steps involved in transferring a digitally created model into the physical world. The three-dimensional model of the object to be printed is created using design software or 3D scanners. The generated model file is then transferred to the 3D printer. Subsequently, slicing software divides the model into layers. Using a thin filament material, known as three-dimensional ink, digital models are converted into tangible objects (Sönmez, Kesen & Dalgıç, 2018). 3D printers enable designers to materialize creative ideas and have broad applications ranging from industrial manufacturing to the arts.

In traditional original printmaking, the process begins with designing the artwork to be printed, followed by carving the design onto materials such as linoleum or wood to create the printing plate. For the digital equivalent, the design must be created digitally.

In the digital environment, both bitmap and vector-based images can be edited, and designers can create original designs from scratch using digital illustration tools.

Digital hardware and software, combined with input devices such as graphic tablets and a mouse, allow artists to produce digital illustrations. These tools provide similar outcomes to traditional illustrations, differing only in the medium used (Topbasan, 2013).

Graphic tablets and digital pens allow artists to directly translate hand movements into digital form, bridging traditional drawing experience with digital workflows. Widely used by visual designers, architects, and artists, these devices enable interaction with the digital canvas as naturally as drawing on paper.

These technologies make the design process more flexible and reversible; artists can easily revise each step, experiment with compositions, and maintain extensive control over the color palette.

Additionally, image editing software such as Adobe Photoshop, Illustrator, and Procreate supports layered workflows, allowing artists to conduct their production process in a controlled and organized manner. These tools empower artists to produce work that is high quality not only aesthetically but also technically.

In the sample study, the design to be printed was prepared in layers using digital illustration techniques. After creating a rough sketch, contour lines and tonal values were finalized using a drawing tablet (Figure 4). The design was tailored for original printmaking by focusing on distinct tonal areas rather than color gradients. This facilitates easier differentiation between raised and recessed areas on the printing plate.

» **Figure 4:** *Design sketch and completed digital illustration. Produced by the author*

After the design is finalized, the process moves to 3D modeling. However, to accelerate modeling in CAD and CAM software with technical drawing capabilities, the design must be converted into vector-based graphics. Vector graphics are preferred because their resolution-independent nature allows for clear, scalable, and technically precise drawings.

While bitmap (pixel-based) images lose quality when zoomed, vector graphics maintain clarity at any scale due to their mathematical definitions. Adobe Illustrator's image trace feature was used to convert the pixel-based design into vector format. The software calculates spots and tonal values to generate vector paths. Although some shapes and forms may be lost depending on tonal variations, the overall structure is preserved. For the print design, the focus was on spot-based work rather than gradual color or tone transitions to ensure a healthy vector graphic. This enabled a vector conversion with minimal detail loss (Figure 5).

» **Figure 5:** *Fill and stroke view of the vector-converted design. Produced by the author*

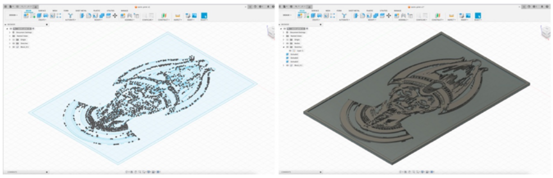
Vector-based graphics can be used as fills or strokes, with lines defined by X and Y coordinates similar to technical drawing software. This resolution-independent nature allows vector graphics to be exported in widely supported formats such as DWG and DXF. Developed by Autodesk, DWG and DXF are commonly used in software like AutoCAD and Fusion 360 for transferring 2D drawings to production and creating 3D models (Autodesk 2024).

Parametric modeling software like Fusion 360 can import SVG, DWG, or DXF files prepared in programs such as Illustrator or CorelDRAW and convert them into 3D objects using solid modeling operations like extrude, revolve, and loft.

This process enables digital illustrations to be transformed into technical models ready for 3D printing, facilitating an interdisciplinary approach in original print design. The choice of modeling software depends on user needs, with simpler models suited for Tinkercad and more complex ones for AutoCAD, SolidWorks, or Blender (Nemec, 2017).

Parametric modeling offers automated updates throughout the model when changes are made, increasing design consistency (Pradhan, 2019). Cloud-based platforms like Fusion 360 further enable collaboration and accessibility across devices (Pradhan, 2019).

In this study, Fusion 360 was used to import the vector graphics in DWG format. The two-dimensional drawings were converted into a three-dimensional model at exact scale, and surfaces were extruded to add volume, preparing the model for physical production (Figure 6).



» **Figure 6:** *3D model with added volume after extrusion. Produced by the author*

The relevant modeling process began with the transfer of vector drawings into the CAD environment. Graphics prepared in Adobe Illustrator were exported in vector format and processed within Autodesk Fusion 360. During this process, vector graphics were utilized in the .DXF format to enable transfer into the 3D modeling software. Subsequently, the two-dimensional drawings were converted into three-dimensional forms using the extrusion method.

Study: 3D Printed Printing Plates

The obtained three-dimensional models were exported in both .OBJ and .STL file formats, with the STL format preferred for printing preparation due to its widespread support in 3D printer software.

To prepare the models for printing, a slicing process was applied using the slicing software of the 3D printer employed (Zaxe X1). Printing parameters such as layer height, infill density, printing temperature, and support structures were optimized based on the model's geometry and the filament type used.

For the production of the printing plate, TPU (Thermoplastic Polyurethane) filament was selected due to its flexible and shock-absorbing properties. The flexibility of TPU was considered advantageous for replicating the characteristics of linoleum printing plates. Printing parameters for TPU included a heated bed temperature of 60°C and a nozzle temperature of 240°C. Given the instability of flexible filaments at high speeds, the printing speed was limited to 25 mm/s.

To assess the impact of different filament materials on print quality, a second plate was printed using a different design while following the same 3D modeling procedures (Figure 7). The design was based on the Vegvisir, a runic compass symbol, arranged in a circular composition. For this model, ABS (Acrylonitrile Butadiene Styrene) filament was chosen to achieve rigidity and sharp edge definition.

Thanks to ABS's durability and shape retention, fine linear motifs and detailed edges were clearly rendered. Printing parameters for ABS were set to a nozzle temperature of 240°C and a heated bed temperature of 90°C.

» **Figure 7:** *Layer preview of sliced printing plates and final printed molds. Produced by the author*

Both models were produced using desktop 3D printers operating with Fused Deposition Modeling (FDM) technology. Throughout the production process, printer movement accuracy, filament flow balance, and the placement of support structures were carefully monitored to preserve the details of the printing plates. After production, the plate surfaces were cleaned, removing any burrs and residual filament waste generated during printing to prepare them for printing use. Subsequently, printing ink was applied onto the surface of the plates using a brayer. The ink was evenly spread over the raised areas of the plates while the recessed parts remained ink-free (Figure 8).

» **Figure 8:** *Ink application on the surface of the printing plates. Produced by the author*

All impressions were produced using a manually operated flatbed press. During printing, a medium level of pressure estimated at approximately 1.5 to 2 bar was applied for a duration of about 15 seconds per print. This pressure level and time interval were selected to ensure that the ink adequately transferred from the raised surfaces of the 3D-printed plate to the paper substrate. For all impressions, a 250 gsm (grams per square meter), textured, and highly absorbent fine art paper was used. A felt layer was placed between the plate and the press to minimize slippage, promote even ink distribution, and prevent deformation or damage to the printed surface.

The applied printing pressure was optimized in accordance with traditional linocut printing standards to achieve a satisfactory aesthetic result while protecting the structural integrity of the 3D-printed plates. Furthermore, due to the manual nature of the press, pressure was not applied mechanically at a fixed rate, but rather controlled by hand, allowing the user to make precise adjustments during each impression.

After pressing, the paper was carefully removed, and prints were left to dry. Plates made with TPU showed smoother and more continuous detail transfer due to their flexible surface adaptation. However, ink distribution on the paper was uneven, and some areas experienced ink bleeding and loss of fine details. In contrast, ABS plates produced sharper lines and higher contrast owing to their rigid structure (Figure 9). Nevertheless, deformation on the ABS plate surface was observed after several prints due to the material's hardness.

» **Figure 9:** *Prints made using the 3D printed plates. Left: Osiris TPU plate; Right: Vegvisir ABS plate. Produced by the author*

The key factors affecting print quality in this process include the uniformity of ink application, the paper-plate interaction, and the balance of press pressure. All prints were repeated under the same technical conditions to allow an objective evaluation of material-based differences (Table 1).

Table 1 presents the mechanical and thermal properties of the materials used in the production of 3D-printed plates, namely thermoplastic polyurethane (TPU) and acrylonitrile butadiene styrene (ABS). These values were not obtained from the regular tests maintained for this study; instead, they were obtained from manufacturer technical documentation. According to the Ultimaker TPU 95A specifications, the material exhibits a tensile modulus of approximately 23–39 MPa, a tensile strength exceeding 560%, and a Shore A hardness of 95 (Ultimaker, 2022).

Similarly, the ABS filament used in the study, as reported in the BCN3D ABS datasheet (BCN3D, 2018), exhibits a tensile modulus of approximately 2,300 MPa, a flexural strength between 60–70 MPa, and a Vicat softening temperature of approximately 95°C.

These values were taken into account during material selection and process storage, particularly for the durability of the printed plates and for planning surface images.

Table 1

Technical specifications of TPU and ABS filaments used for printing plate fabrication. Data obtained from manufacturer datasheets (Ultimaker, 2022; BCN3D, 2018)

Criteria	TPU (Thermoplastic Polyurethane)	ABS (Acrylonitrile Butadiene Styrene)
Material Structure	Flexible	Hard
Nozzle / Bed Temperature	240 °C / 60 °C	240 °C / 90 °C
Detail Transfer	Moderate; ink smearing may ocur due to flexibility	High; clear edges and distinct surface separation
Ink Distribution	Soft transition, homogenity may be low	Homogeneous, controlled surface transfer
Post Press Printing	Soft, linoleum-effect surface	Sharp, engraving-like result
Mold Strength / Durability	Maintains its from in multiple uses	Hard structure may Show surface deformation during repeated use
Artistic Effect	More organic, similar to classic high print	More graphic, clearly contorured

The Osiris motif contains a high level of detail, including numerous fine lines and intricate structures, making it one of the most complex designs tested in this study. An attempt was made to fabricate a printing plate for this motif using ABS filament via 3D printing.

However, during the printing process, several small and delicate features of the plate fractured under the applied pressure, compromising the integrity of the design. Although ABS has the potential to yield sharper lines due to its rigidity, this same property rendered the material less tolerant to fine structural elements, increasing the risk of breakage.

As a result, thermoplastic polyurethane (TPU) was selected as a more suitable material for this specific motif. The flexibility of TPU provided greater tolerance during pressing, allowing the plate to absorb mechanical stress without losing structural fidelity. Nevertheless, test prints with less detailed motifs showed that ABS could indeed deliver higher resolution and cleaner line quality, making it appropriate for simpler and bolder designs. Therefore, material selection was directly influenced by the complexity and structural delicacy of the motif being reproduced.

Observations regarding the durability of the printing plates revealed distinct differences depending on the filament material used. Plates produced with thermoplastic polyurethane (TPU) maintained their structural integrity under the applied printing pressure and conditions, showing no visible signs of deformation or loss of detail even after approximately 20 to 30 consecutive impressions. This performance can be attributed to TPU's flexible nature, which allows it to absorb mechanical stress during the printing process without fracturing.

In contrast, although plates fabricated from acrylonitrile butadiene styrene (ABS) yielded sharper and more precise lines, they exhibited lower durability. Noticeable surface wear, edge deformation, and loss of fine detail were observed after approximately 10 impressions. These issues likely stem from the brittle nature of ABS, which, despite its rigidity, is less resistant to compressive stress during repeated use.

Therefore, for extended use and multiple print runs, TPU filament proved to be a more reliable material for printing plate production.

Conclusion

This study experimentally examined the integration of digital fabrication technologies into traditional graphic printmaking techniques. The reproducibility of handcrafted plate-making processes was tested through 3D printing, converting vector-based digital designs into physical models. Printing applications were conducted using plates produced with different filament materials.

Throughout the workflow, each stage from digital modeling to print output was reconsidered at the intersection of traditional printmaking and digital technology. The use of TPU and ABS filaments yielded distinct technical and aesthetic outcomes. TPU's flexibility allowed organic surface textures resembling linocut prints, while ABS provided sharp edges and high-contrast details typical of graphic prints.

Key variables affecting print quality, such as slicing settings, printing temperature, surface contact, and ink application, were optimized according to material properties. Pressing pressure, duration, and contact balance were also critical in defining print results. This controlled experimental setup enabled objective evaluation of filament effects on print quality.

Findings demonstrate that 3D-printed plates are functionally viable in graphic production, transforming not only technical workflows but also offering designers new modes of thinking and expression. Digital production makes plate fabrication more predictable, repeatable, and experimental, extending traditional printmaking limits.

Thus, 3D printing should be seen not as an alternative but as a complementary and enriching tool in original print practice. Its accessibility and low cost make it valuable in education, artistic production, and individual applications. This study lays groundwork for future research into complex forms, alternative materials, and multi-layered printing systems.

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References

Akbaba, A. İ. & Akbulut, E. (2021) 3D printers and areas of usage. *ETU Synthesis Journal of Economic and Administrative Sciences.* 3, 19–46. Available from: doi: 10.47358/sentez.2020.13

BCN3D (2018) *BCN3D Filaments – ABS Technical Data Sheet.* Available from: https://3dprint.pe/wp-content/uploads/2018/09/TDS_BCN3D_Filaments_ABS.pdf [Accessed 30th November 2025].

Emerson, W. A. (1881) *Hand-book of wood engraving.* Boston, Lee and Shepard.

Gök, A. & Taş, M. (2023) Comparison of the application of woodblock printing techniques on various materials (paper, fabric, leather, wood, ceramic). *İdil Sanat ve Dil Dergisi.* 12 (110), 1743–1761. Available from: doi: 10.7816/idil-12-110-12

HLH Rapid (2023) *What is FDM 3D printing?*. Available from: https://hlhrapid.com/knowledge/what-is-fdm-3d-printing/ [Accessed 30th November 2025]

Kıran, H. (2016) A general overview of contemporary printmaking art. *Sanat ve Tasarım Dergisi.* 6 (1), 54–77. Available from: doi: 10.20488/www-std-anadolu-edu-tr.291232

Matisse, H. (1938) *2007.155: Teeny.* Available from: https://harvardartmuseums.org/collections/object/319230 [Accessed 30th November 2025].

Nemec, R. (2017) Using and citation of 3D modeling software for 3D printers. *International Journal of Education and Information Technologies.* 11, 160–170.

Nemlioğlu, M. (2021) Original Printmaking and Linoleum. *Aydin Sanat.* 7 (13), 77–83. Available from: doi: 10.17932/IAU.SANAT.2015.015/sanat_v07i13007

Owen, A. (2023) *MegaLilyDesign Linocut*. Folksy. Available from: https://folksy.com/shops/MegaLilyDesign [Accessed 30th November 2025].

Özsoy, K. & Duman, B. (2017) Applicability of additive manufacturing (3D printing) technologies in education. *International Journal of 3D Printing Technologies and Digital Industry.* 1 (1), 36–48.

Pradhan, R. S. (2019) Industrial design and cloud-based 3D visualization tool – Autodesk Fusion

360. *International Journal of Engineering Applied Sciences and Technology.* 4 (4), 74–78.

Scott, C. M. (2018) *Exploring "The use of 3D printing in art and design practice".* Master's thesis, Ulster University.

Scotti, L., Basoalto, H., Moffat, D. & Cogswell, D. (2023) Review of Material Modeling and Digitalization in Industry: Barriers and Perspectives. *Integrating Materials and Manufacturing Innovation.* 12, 397–420. Available from: doi: 10.1007/s40192-023-00318-2

Sönmez, S., Kesen, U. & Dalgıç, C. (2018) 3 Dimensional Printers. In: *6th International Printing Technologies Symposium, 1-3 November 2018, Istanbul, Turkiye*. Istanbul, İstanbul University–Cerrahpaşa. pp. 471–481.

Tekcan, S. S. (1997) Original print. In: *Eczacıbaşı Encyclopedia of Art 3*. İstanbul, Yapı Endüstri Merkezi Yayınları, p. 1413.

Topbasan, V. (2013) *Digital illustration and character design in computer games.* Master's thesis. Mustafa Kemal University, Institute of Social Sciences.

Turani, A. (1975) *Dictionary of art terms.* 9th ed. İstanbul, Remzi Kitabevi.

Ultimaker (2022) *Ultimaker TPU 95A Technical Data Sheet.* Available from: https://um-support-files.ultimaker.com/materials/2.85mm/tds/TPU-95A/Ultimaker-TPU95A-TDS-v5.00.pdf [Accessed 30th November 2025].

Yıldırım, G., Yıldırım, S. & Çelik, E. (2018) Yeni Bir Bakış- 3 Boyutlu Yazıcılar ve Öğretimsel Kullanımı: Bir İçerik Analizi. *Bayburt Eğitim Fakültesi Dergisi.* 13 (25), 163–184.

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Design of thermoformed plastic container using mould from three-dimensional printing for pear protective performance

ABSTRACT

Thermoforming is a widely used plastic packaging method due to its affordability, high protective performance, and ability to prevent mechanical damage to fruits during transportation. This study aimed to investigate the factors influencing the thermoforming packaging moulding process, evaluate the structural strength of thermoformed packaging, and assess the effectiveness of various shaped thermoformed containers in protecting pears. The prototype design was based on different geometric shapes and dimensions, divided into four relief geometries: cylindrical (M1), semi-circular (M2), geodesic dome (M3), square (M4), and commercial dome shapes. According to the mould thermoforming process, the mockups of each pattern were modelled using SolidWorks software and formed using a 3D printer. Polyvinyl chloride (PVC) plastic sheets were formed in a container mould with a thermoformed machine under the same parameter conditions of time, temperature, and pressure. The compression resistance of the thermoformed containers was tested. According to these findings, the compression force was higher in inferior thermoformed containers than in superior thermoformed containers. This is due to the relief size, geometry, and dimensions of the thermoformed containers. Then, thermoformed containers were employed to perform the dart drop impact test, with the pears dropped from heights of 20, 40, and 60 cm. The thermoformed container sample with a square shape (M4) had the lowest proportion of bruises (8.33%) on fruit. For container sample M4, the bruised area (BA) was assessed at drop heights of 20, 40, and 60 cm at 97.12, 140.75, and 206.02 square millimeters, respectively. Based on this finding, the bruise volume increased as the impact height increased. Additionally, a drop test was performed at a height of 90 cm using a thermoformed container with pears in a double-wall corrugated board for the BC flute. A higher total area of bruises on pears without thermoformed containers was observed in the evaluation of bruised damage. Therefore, this study concludes that the shape, size, and relief position of thermoformed containers reduce the damage caused by the compression strength and dropping height during transportation.

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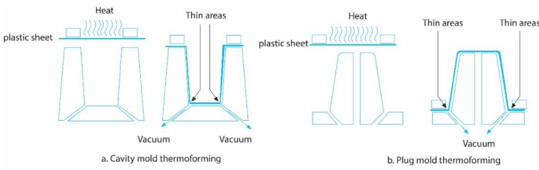
Introduction

The current retail packaging design for fruit containers in the postharvest industries involves thermoforming packaging. The plastic thermoforming technology is highly popular in the packaging industry due to its cost- effectiveness, ease of production, and rapid processing capabilities. It's particularly advantageous for retailing fresh fruits, as it helps protect the product during transit and preserves long-term quality. Fresh fruits, both domestically produced and imported, especially those with delicate textures, are susceptible to damage during transportation. Soft fruits can easily develop bruises, making them more prone to microbial degradation. In addition, the aforementioned characteristics of plastic thermoforming packaging is available options for protecting the quality of delicate fruits. In previous research, soft fruits such as kiwi, peach, and cantaloupe were been used for experimentation of packaging protection for transport (Xia et al., 2020; Lin et al., 2020; Günther et al., 2021; Azam, Saad & Amer, 2022).

Apart from the protective role of packaging, the types of packaging material are crucial in preventing fruit damage. PVC and PET are mostly chosen to create the thermoforming packaging in industry because their properties can form easily, durable structure of preventing impact and clear surface. Three-dimension mould in this study not only did the researchers utilize thermoforming technology, but they also explored the design of containers for fresh produce. They analyzed the dimensions of the containers using SolidWorks software and three-dimensional printing systems. The design factors, such as curved shapes, triangular shapes, and the creation of ribs, contributed to the efficiency of protecting the packaged fruits. Additionally, the study included testing the structural strength of the thermoformed plastic container and its effectiveness in reducing damage during transportation in comparison to foam boxes, plastic crates, and paper pulp boxes when fruits were stacked.

Selke & Culter (2016) described the procedures of forming thermoformed packaging using plastic sheet. The thermoforming process has three basic steps: heating the sheet, forming the sheet, and trimming the part. There are many methods for moulding the sheet of plastic, once it has been softened by heat. The simplest are drape forming, vacuum forming, and pressure forming. The normal procedure is to make a prototype mould to determine the process parameter of product geometry. Prototype molds can be made by various techniques. Robertson (2013) presented the description of a plastic sheet (generally 72-250 mm thick) of thermoplastic material is heated to its softening temperature, usually by means of an infrared radiant panel heater. By either pneumatic or mechanical means, the sheet is forced against the mould contours and, after cooling, is removed and trimmed.

Typical thermoplastics used for thermoforming include HIPS, PVC, PP and PA. Soroka (2009) revealed the thermoforming methods is the simplest thermoforming method. The core part of the die simply pushes the softened plastic into the matching cavity half. Most thermoplastic materials can be thermoformed, including single-polymer materials, co-extrusion and laminated sheets. Pliable plastic sheet can be formed by mechanical means, with vacuums, with pressure or by combinations of these. In Figure 1 exhibits vacuum holds are required in the cavity' s lowest point. The most common application of thermoforms is for various forms of blister or clamshell display packaging (Soroka, 2009).



» **Figure 1:** *Simple vacuum forming over cavity (a) and plug mould (b) the material is pulled to the mould shape when a vacuum is applied between the mould and sheet interfaces*

According to research in the area of 3D modeling, Chantarapanich et al. (2020) designed plastic tray models using computer-aided design (CAD) and three-dimensional printing. The 3D models were then evaluated for the compression strength of the tray geometry using finite element (FE) method analysis. They found that the bottom corners of the tray exhibited a high-stress magnitude. Based on the FE results, the edges, shape, and plastic sheet thickness provided sufficient strength to withstand the vertical stacking compression of the thermoformed tray design.

Nilmanee (2023) designed packaging assistant opener tools to improve consumer access to contents by creating models with SolidWorks software and prototyping them using a 3D printer. The FSUDE system was employed to evaluate the function, safety, usability, design, and engineering of all prototypes.

Based on the results of this study, form, dimensions, surface texture, friction, and grip posture were factors affecting torque force exertion, slitting and cutting force, and the openability for consumers.

Ibrahim & Fahmy (2021) developed an attractive, eco-friendly packaging item using polylactic acid (PLA) filament and considered health impacts through the structural design of a 3D-printed bottle prototype. Their study aimed to apply ergonomic principles to design a comfortable packaging bottle that is easy to drink from and handle. Tuhin et al. (2021) studied the features of an opioid smart packaging system that includes a dual-wall medical bottle for anti-tampering performance testing.

The inner and outer containers were designed using SolidWorks and 3D-printed with corresponding materials: the inner container was made from polylactic acid (PLA) filament, while the outer container was made from acrylonitrile butadiene styrene (ABS) filament. They varied in wall thickness, the gap distance between the walls of the inner and outer containers, and channel widths.

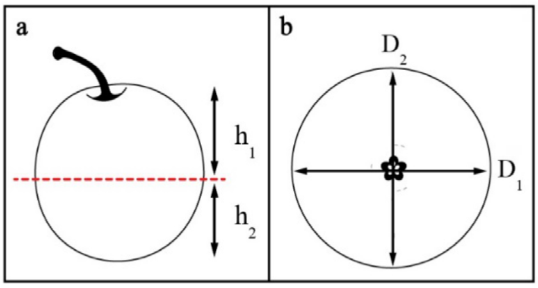
In this research, celery was chosen as the focus due to its delicate nature, susceptibility to bruising, relatively high market value, and the need for a packaging material with a strong structure capable of providing protection against external impacts. The study used three-dimensional design software to enhance the efficiency of the packaging in protecting celery quality. The research also examined the damage incurred during mechanical testing, including how shape characteristics influenced the structural strength and the packaging's ability to reduce impact forces. The shape, size, and relief position of thermoformed containers play a significant role in reducing damage from compression and drop height during transportation. Therefore, the objectives of this study were to investigate the factors affecting the plastic thermoforming packaging process for pears and to evaluate the structural strength of the thermoformed packaging. Additionally, the effectiveness of thermoformed packaging in various shapes for protecting pears was assessed.

Materials and Methods

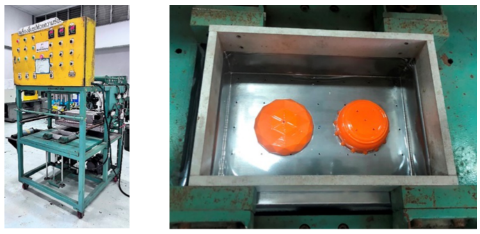
Thermoforming design process

The first process was designed for the mockup samples of thermoforming container molds using SolidWorks software Version 2021. According to the mold design, the average pear dimension was measured by collecting fresh pears in supermarkets in Thailand. Figure 2 presents the technique of measuring the ratio dimension within two parts: the superior mold (h_1 and h_2) and inferior mold (D_1 and D_2) (Rodríguez-Parada, Mayuet & Gamez, 2019a). The mold for the pear was created using four different conceptual forms, including a control mold based on the commercial type. Next, the mockup files were converted from Standard Triangle Language (STL) format to G-Code format using ideaMaker software. Each mockups pattern was modeled and formed using a 3D printer (Pro 2Plus, Ruise 3D printer, United States) with 1.75 mm diameters ABS filament (Acrylonitrile Butadiene Styrene) set at a printing temperature of 245- 265 °C. For the thermoforming process, the printed mold samples were placed in the box of the thermoforming machine, as shown in Figure 3.

Based on the plastic sheet formation, a polyvinyl chloride (PVC) plastic sheet was selected to form the samples of the thermoforming process with the machine. The melting temperature (Tm) of the PVC sheet was measured using DCS (differential scanning calorimetry (DSC, Mettler DSC 30, USA) in accordance with ASTM 3418-08. PCV samples of approximately 3-5 mg were weighed and sealed in aluminum pans, using an empty sample pan as a reference. The heating scan was performed from 35 °C to 270 °C. The heating rate was increased at a rate of 10 °C/min. A thermal analysis technique for the heat flow into or out of a sample can be measured as a function of temperature and time control in the thermoforming process. PVC sheets were clamped in the thermoforming machine and heated to 210 °C for 40 s under a pressure of 4-5 bar and vacuum of 30 inHg. Five configurations of the top and bottom molds were formed using a thermoforming machine, and all tests were conducted under the same conditions.



» **Figure 2:** *Model of result measurement of pear samples (a) the superior and interior heights (b) the diameter of the pear*



(a) (b)

» **Figure 3:** *Thermoforming design process (a) Thermoforming machine (b) model features after forming*

Process of compression testing the thermoforming samples

The compression resistance force of the thermoforming plastic sheets for each model was measured using a universal testing machine (H10KS, Tinius Olsen, Taiwan) on the upper and lower parts of each model. Five different mold geometries were tested with five repetitions for each model. During the compression force test, the thermoformed samples were placed securely on the grips of the machine. The load cell was set to 50kN, and the compression speed was set to 10 mm/min (Rodíguez-Parada, Mayuet & Gamez, 2019b). The samples were compressed from above, as shown in Figure 4.

» **Figure 4:** *Compression test with Universal testing machine*

Bruise size measurement of pear fruits using dart drop impact and drop testing

After molding the thermoforming samples of various calibres, they were tested with a dart drop using a Dart drop impact tester (Model DDI, ATLAS, United States). Pear fruits were individually packed in thermoforming containers of different forms and subjected to drop tests, as described by Pathare & Al-Dairi (2021). Each pear-containing container was evaluated for its protective performance by testing drop heights of 20, 40, and 60 cm, with three pears tested at each height using a 260-gram pendulum (Figure 5). After the drop tests, the pears were stored at room temperature for two days, after which the bruise size of each pear was measured. Follows (Equation 1): where mb is the mass of dropped ball 260 g, g is the gravitational constant (9.81 m s-2), and h is the drop height in meter. (Pathare & Al-Dairi, 2021). Table 1 lists the impact energy generated from the various drop impacts.

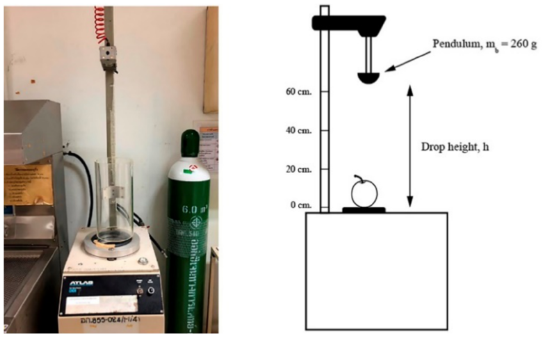
$$E_i = m_b \times g \times h \text{ (J)} \tag{1}$$

Each shape of the samples was 3 tested repetitions. The pears were plated at room temperature for 2 days. On the second day, the tested pears were peeled and measured the bruising diameter (W1 and W2) and the depth as shown in Figure 6. The weight loss percentage (% weight loss) was calculated using Equation (2) while bruise area and internal bruise index percentage were calculated using Equation (3) and Equation (4), respectively. The physical characteristics of the thermoformed container were observed and recorded the results.

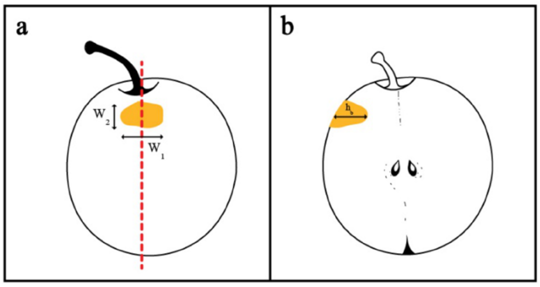
$$\text{Weight loss} = (M_0 - M_n) / M_0 \times 100\% \tag{2}$$

$$\text{Bruise area (BA)} = (\pi/4) \times W_1W_2 \text{ (mm}^2\text{)} \tag{3}$$

$$\text{Bruise index (BI)} = \frac{\Sigma(\text{bruise scale} \times \text{number of fruits corresponding the scale})}{\text{total fruit number} \times \text{highest number of bruise scale}} \times 100\% \tag{4}$$



» **Figure 5:** *Experimental set up of Dart Drop Impact Tester*



» **Figure 6:** *Bruise measurements (a) bruise diameter and (b) bruise depth (Pathare & Al-Dairi, 2021)*

Table 1
Drop height and impact energy produced in the experiment

Drop height (cm)	Impact energy (J)
20	0.510
40	1.020
60	1.530

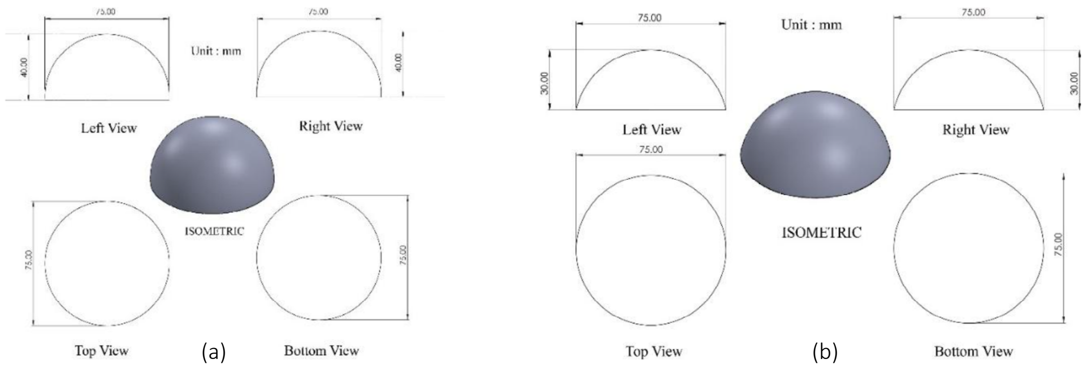
Furthermore, this study also tested the protective efficiency of fresh pears contained in thermoforming samples using drop testing. The pears were packed in thermoformed plastic containers of five different geometries and then fixedly placed in the corrugated boxes commonly used in commercial transportation as regular slotted containers (RSC) by the private logistics company (Figure 7). The dimensions of the box were 27 × 37 × 14 cm. Pears were observed and recorded after the test. Drop resistance testing was performed using a drop test machine model GT-7003, and the drop height was set at 0.90 meters (Xia et al., 2020). The pears were kept at ambient temperature for two days. On the second day, the pears were peeled, and bruising of the pears was inspected.

» **Figure 7:** *Drop testing machine GT-7003, GOTECH, Taiwan*

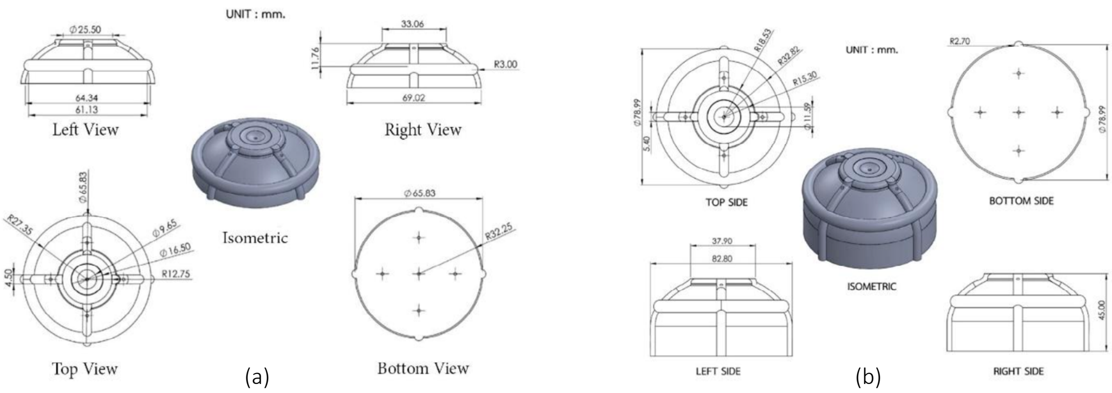
Results and Discussion

Conceptual design of thermoforming mould

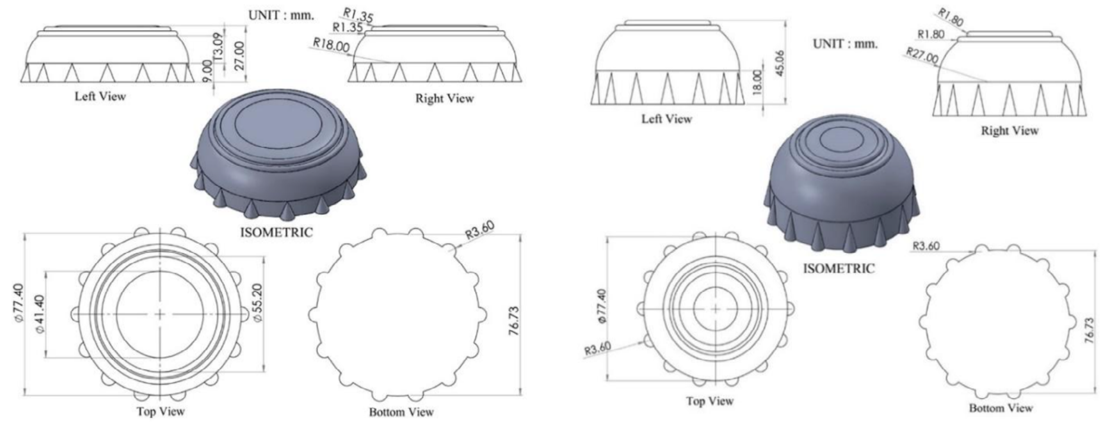
The concept of thermoforming mould design was started with measuring the shapes and dimension of fresh pears from the supermarkets. According to the mould mockup design, the mold's geometry of was divided into 2 parts in different sizes: a superior and an inferior component. The superior mould part was taller than inferior part because both parts had distinct roles in protecting the fresh pears. The inferior based mould was responsible for supporting and reducing impact forces. On the other hand, the superior component of the mould was designed to assist pressure occurrent from stacking the pears in packaging during transportation. It was also facilitated easy opening and ensured proper interaction between the supporting base and the cover lid. Furthermore, the design concept also considered the efficiency in pressure resistance. This study involved defining the dimensions for both small and large relief shapes including rectangular and triangular forms. The orientation of these shapes is also examined in both vertical and horizontal directions to enhance structural integrity, ensuring the can withstand pressure and absorb impacts effectively. The mould mockup samples were created five geometries using SolidWorks in drawing, as shown in Figures 8 to 12.



» **Figure 8:** *Drawing of the mould dimension used for thermoformed commercial type (a) superior mould (b) inferior mould*

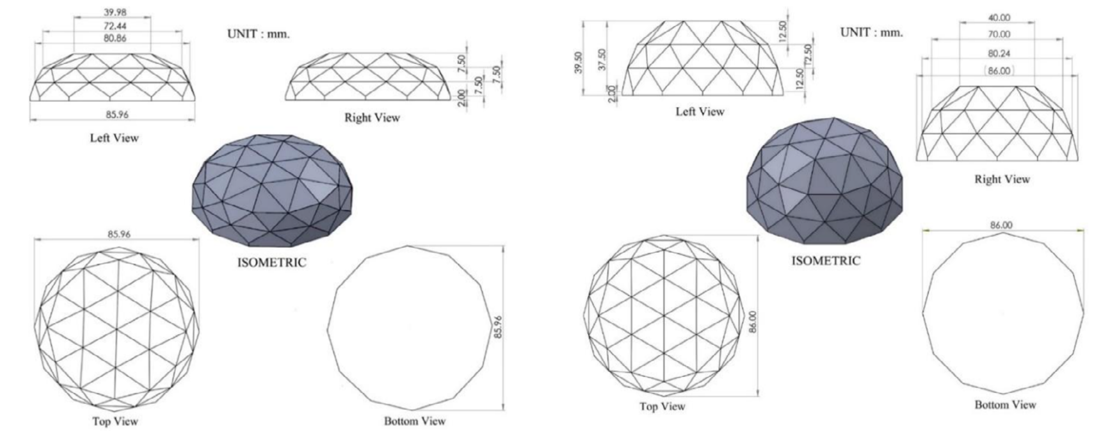


» **Figure 8:** *Drawing of the mould dimension used for thermoformed container type M1 (a) superior mould (b) inferior mould*



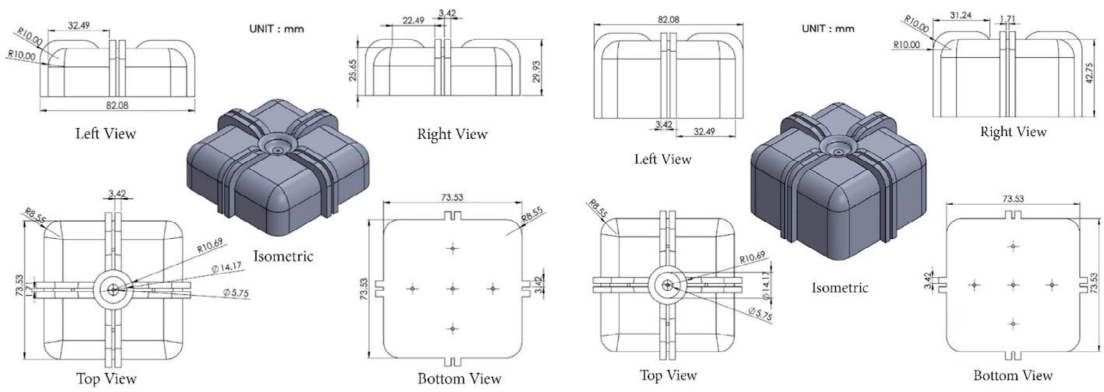
(a) (b)

» **Figure 10:** *Drawing of the mould dimension used for thermoformed container type M2 (a) superior mould (b) inferior mould*



(a) (b)

» **Figure 11:** *Drawing of the mould dimension used for thermoformed container type M3 (a) superior mould (b) inferior mould*



(a) (b)

» **Figure 12:** *Drawing of the mould dimensions used for thermoformed container type M4 (a) superior mould, (b) inferior mould*

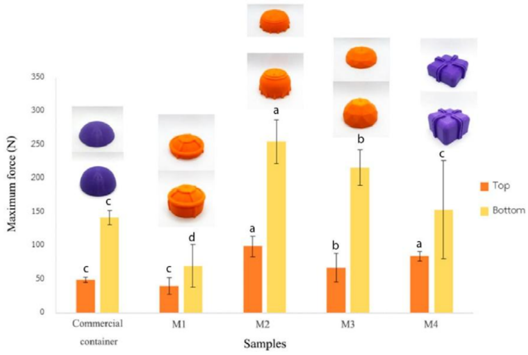
Strength elevation of thermoformed mould structure

Figure 13 depicts the compressive resistance force of thermoformed plastic containers using five structural geometries. The container sample Model 2 (M2) showed a greater compressive resistance force than the other samples. The superior mold section had a higher compressive force than the inferior mold part, with values of 254.67 Newtons and 99.40 Newtons respectively. In contrast, the sample M1 in cylindrical shape was the lowest compressive strength to compare with different geometries under 40.47 Newtons for superior parts and 70.37 Newtons for inferior parts. This finding was consistent with previous study by Rodríguez-Parada, Mayuet & Gamez (2019b) which confirmed that their experiment consistently showed higher compressive resistance in the inferior mould part compared to the base across all moulds, attributed to the smaller size of the mold resulting in reduced compressive strength. The findings of Afshariantorghabeh, Kırki, & Leminen (2022) indicated that the geometric shapes, thickness, and low mold depths of thermoforming affected the distribution behaviour and mechanical properties. In addition, when comparison of geometry M2 with the other geometries had lower compressive strength due to enhancement of force distribution and resistance for curved side shape mould. However, the force distribution capability of mould design for thermoforming process in this study was depended on mould dimension, geometry, thickness, relief features, and relief position.

Table 2 illustrates deformation of the computer simulation and the actual testing of the molded prototypes with different geometries using compression force 50 Newtons. The results found that the thermoforming mould samples had the same deformation as the actual samples and computer simulation testing. According the results of resistant force and color appearance on the samples during both tests, the red areas are indicated region of maximum damage and deformation configuration under applied force, while the blue areas are indicated the strongest or without deformation boundary. Furthermore, the results of both tests were consistently related with each other as visual simulation and laboratory evaluation.

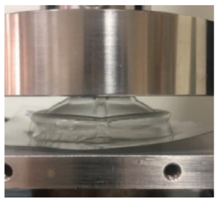
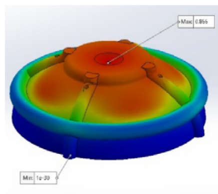
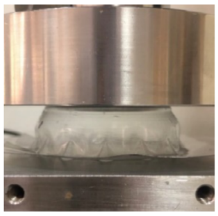
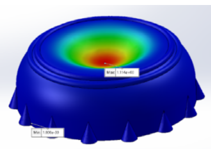
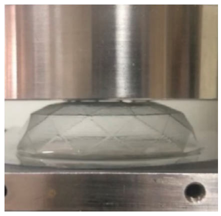
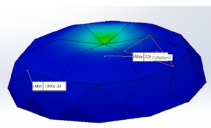
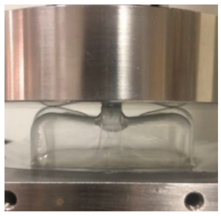
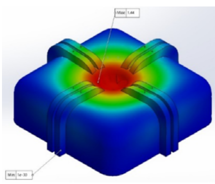
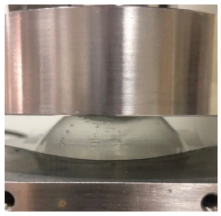
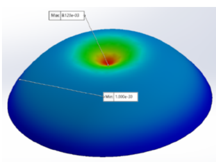
Effect of thermoformed containers on bruise area and bruise index in protecting pears

The result of bruising area with fresh pear by conducting the dart dropping impact test, as shown in Figure 14. A 260-gram pendulum was dropped in heights of 20, 40, and 60 centimeters on the pears. All the pears were packed inside each thermoformed sample of different geometries. It found that the trend of bruising area was increased with higher drop heights.



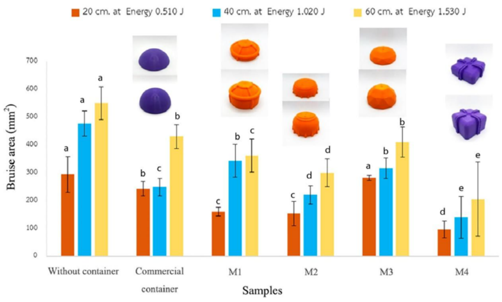
» **Figure 13:** *Maximum compression force of thermoformed plastic samples with varying geometries, mean value followed by different superscript indicates the significant different ($p < 0.05$)*

Table 2
Comparative analysis of compression resistance and compression testing simulation

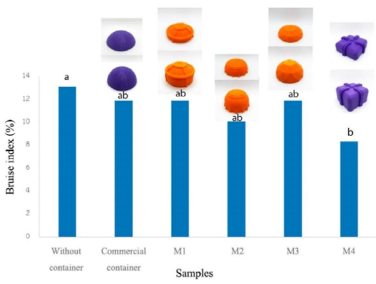
Samples	Compression testing in the experiment	Simulation of compression test
M1		
M2		
M3		
M4		
Control		

The rectangular-shaped container (M4) was the most effective in protecting the pear, with a bruising area of 97.12, 140.75, and 206.02 square millimeters for drop heights of 20, 40, and 60 centimeters, respectively. Additionally, comparing the pear bruise area of a thermoformed sample without a container, and a commercial container shape was obviously higher than the other container geometries. According to the similarity of the studies by Pathare & Al-Dairi (2021) with pears and Azam, Saad & Amer (2022) with cantaloup, they confirmed that the results found a similar trend of increased bruising area with higher drop heights testing. According to study of Lin et al. (2020), they investigated the effect of cushioning materials on quality damage of peaches in the vibration test. The bruise area of peaches was reduced to involve with types of cushioning material for protective performance.

Accordance with the experimental results of the bruising index for packed pears in thermoformed containers, the rectangular-shaped sample (M4) had the lowest bruising index of all the container sample forms at 8.33%. On the other hand, pears packaged in commercial dome-shaped containers had the highest bruise index (11.9%). The indication of the rectangular-shaped container (M4) had a lower bruising for pears was due to its different sizes and shapes of relief. The cause also provided a larger surface area to absorb force compared to other shapes, as shown in Figure 15.



» **Figure 14:** *Bruise area of pears under dart drop testing using different thermoformed shapes, mean value followed by different superscript indicates the significant different ($p < 0.05$)*

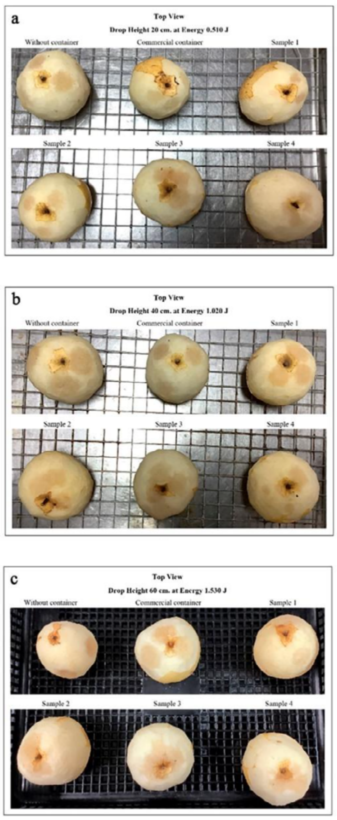


» **Figure 15:** *Bruise index of pears under dart drop testing using different thermoformed shapes, mean value followed by different superscript indicates the significant different ($p < 0.05$)*

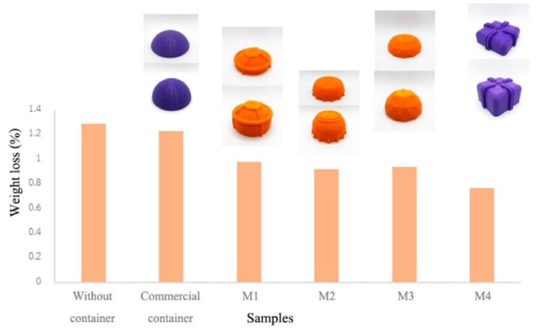
Evaluation of pear damage external appearance and weight loss

In Figure 16 illustrates the external characteristics of fresh pears during containing thermoformed containers to place on the corrugated box after drop tests at heights of 20, 40, and 60 centimeters for 2 days of storage at room temperature. High damage patterns on pear surfaces were observed in pears contained in dome-shaped container (commercial shaped sample) and without any container. Conversely, the bruise areas on pears stored in rectangular-shaped containers (M4) and small semi-circular-shaped sample containers were less noticeable compared to other container shapes. In terms of drop heights, the surface areas of the pears were highly damaged at a drop height of 60 centimeters. After drop tests, in Figure 17 presents the weight loss percentage of pears. It was found that pears were packed in commercial container had the highest weight loss percentage at 1.23% when compared to the other thermoformed container samples. Among these, the rectangular container (M4) had the lowest weight loss percentage at 0.77%.

The study of Xia et al. (2020) investigated the impact of three packaging materials (EPS box, wooden box, and HDPE box) on the lowest loss in kiwifruit during free drop test. The results indicated the potential of EPS box as softening and high young' modulus material to reduce bruise damage and the lowest weight loss of kiwifruit.



» **Figure 16:** *External appearance of pears surface containing in thermoformed samples by drop testing*



» **Figure 17:** *Percent weight loss of pear storge*

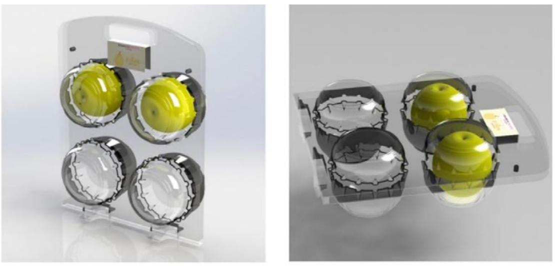
The development of thermoformed container prototypes for commercial applications

After developing the sample shapes of a thermoformed plastic container, they were evaluated based on tests for their ability to withstand compression, impact resistance, drop impact resistance, and the visibility of pear fruit during containment.

The researchers proceeded to the next phase of the study. They were modeled containers aimed at enhancing value and usability. Additionally, they designed labels to be attached to the mockup. The thermoformed plastic container sample utilized two shapes: a cylindrical shape with small relief (M2) as shown in Figure 18, and a rectangular shape (M4) as shown in Figure 19.

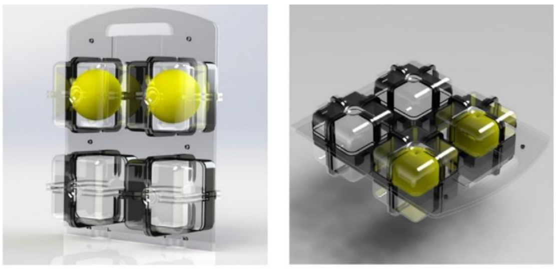
The design concept focused on creating packaging capable of accommodating all four pear fruits. The package mockup can be placed both vertically and horizontally in a stable orientation.

The interlock mechanism of the mockup was incorporated to ensure secure closure upon assembly, and convenient rectangular holes were included for easy handling.



(a) (b)

» **Figure 18:** *The mockup of thermoformed plastic container using SolidWorks with Semi-circular geometry (M2) in design display on the vertical (a) and horizontal (b) directions*



(a) (b)

» **Figure 19:** *The mockup of thermoformed plastic container using SolidWorks with Square geometry (M4) in the design display on the vertical (a) and horizontal (b) directions*

Conclusion

In designing molds, 3D printing is one of the choices for designers to improve primary mould prototypes. Innovative materials like ABS filament, with model forming, are useful for higher temperatures in thermoforming packaging. This study evaluated the structural integrity of various thermoformed container shapes and assessed their effectiveness in protecting pear fruits. Several key findings follow the effect of thermoforming design on success. Containers with superior mould parts exhibit greater resistance to compression than those with inferior mould parts. This is because the larger bottom sections can better withstand external forces. Impact tests conducted on plastic containers at varying heights revealed that, as the height increased, the incidence of bruising on pear fruit also increased significantly. Performance tests of thermoformed plastic containers showed that character container mould 4 (M4), with its rounded edges and rectangular shape, was the most effective in reducing bruise indices and bruised areas on pear fruit. Transport protection tests indicated that pear fruits packaged in thermoformed containers experienced significantly less bruising than those transported without packaging. In conclusion, this study emphasizes that the shape, dimension, and location of the relief of heat-formed plastic containers play a crucial role in minimizing the damage from compression and impact tests.

Ethical approval

This article dosed not contain any studies with human participants or animal performed by any of the authors.

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References

Afshariantorghabeh, S., Kırki, T. & Leminen, V. (2022) Three-dimension forming of plastic-coated fibre-based materials using a thermoforming process. *Packaging Technology and Science.* 35 (7), 543–555. Available from: doi: 10.1002/pts.2650

Azam, M. M., Saad, A. & Amer, B. M. A. (2022) Assessment of the quality losses of cantaloupe fruit during transportation. *Processes.* 10 (6), 1187. Available from: doi: 10.3390/pr10061187

Chantarapanich, N., Vakeeprakhon, T., Wanchat, S. & Veerasakul, M. S. (2020) Design of plastic medical tray: a case study of orthopaedic implant packaging. *Suan Sunandha Science and Technology Journal.* 7 (2), 49–53. Available from: doi: 10.14456/ssstj.2020.15

Günther, D., Erhard, P., Schwab, S. & Taha, I. (2021) 3D printed sand tools for thermoforming application of carbon fiber reinforced composites – a perspective. *Materials.* 14 (16), 4639. Available from: doi: 10.3390/ma14164639

Ibrahim, S. & Fahmy, H. (2021) The structural design of 3D printed bottle prototype using a PLA-based eco-friendly polymer packaging material. *International Design Journal.* 11 (4), 321–331. Available from: doi: 10.21608/idj.2021.180941

Lin, M., Chen, J. F. K., Zhu, C., Wu, D. & Wang, J. (2020) Effects of cushioning materials and temperature on quality damage of ripe peaches according to the vibration test. *Food Packaging and Shelf Life.* 25, 100518. Available from: doi: 10.1016/j.fpsl.2020.100518

Nilmanee, S. (2023) Developing prototypes of the assistant opener of packaging for consumer accessibility. *Journal of Graphic Engineering and Design.* 14 (3), 27–36. Available from: doi: 10.24867/JGED-2023-3-027

Pathare, P. B. & Al-Dairi, M. (2021) Bruise susceptibility and impact on quality parameters of pears during storage. *Frontiers in Sustainable Food Systems.* 5, 1–13. Available from: doi: 10.3389/fsufs.2021.658132

Robertson, G. L. (2013) *Food Packaging: Principles and Practice.* Boca Raton, CRC Press.

Rodríguez-Parada, L., Mayuet, P. F. & Gamez, A. J. (2019a) Custom design of packaging through advanced technologies: a case study applied to apples. *Materials.* 12 (3), 467. Available from: doi: 10.3390/ma12030467

Rodríguez-Parada, L., Mayuet, P. F. & Gamez, A. J. (2019b) Evaluation of reliefs' properties on design of thermoformed packaging using fused deposition modelling moulds. *Materials.* 12 (3), 478. Available from: doi: 10.3390/ma12030478

Selke, S. E. M. & Culter, J. D. (2016) *Plastics Packaging: Properties, Processing, Application, and Regulation.* 3rd ed. Munich, Hanser Publishers.

Soroka, W. (2009) *Fundamentals of Packaging Technology.* 4th ed. Illinois, Institute of Packaging Professionals.

Tuhin, M. O., Cheng, K., Naveed, M., Aliakbarian, B. & Babnawaz, M. (2021) A dual-wall 3D-printed anti-tampering medical bottle. *Journal of Packaging Technology and Research.* 5, 89–95. Available from: doi: 10.1007/s41783-021-00113-4

Xia, M., Zhao, X., Wei, X. X., Guan, W., Xu, C. & Mao, L. (2020) Impact of packaging materials on bruise damage in kiwifruit during free-drop test. *Acta Physiologiae Plantarum.* 42, 119. Available from: doi: 10.1007/s11738-020-03081-5

Original scientific paper http://doi.org/10.24867/JGED-2026-1-053

Customized helmet design using computational and physical prototyping design principles

ABSTRACT

Bicycle helmets are designed to protect the user in case of a fall or collision. The effectiveness of a helmet depends on many factors, one of which is its correct fit on the user's head. The presented paper aims to develop an application that can generate personalized helmet designs based on user-provided data. After receiving the user's data, the design process is automatically carried out via a computer-based algorithm. The data provided includes two photos, capturing both the front and side views of the user's head. Using these images, the algorithm analyzes the curvature, proportions, and size of the head to create curves that closely align with the user's head shape. This information is then used to design a helmet comprising of two main components: the outer shell and the inner lining. The outcomes of this study were effectively assessed through two methods. The initial evaluation involved digital analysis using 3D scanning technology to compare the head curvatures between the algorithm and the scanned model. The second evaluation utilized 3D printing technology. Using appropriate materials, the helmet was fabricated while its geometry was applied evenly to the user's head.

KEY WORDS
helmet design, safety design, computational design, product design, wearable devices, algorithmic design, visual programming, 3D printing

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Introduction

The process of helmet design focuses on creating a product that prioritizes user safety, as well as comfort and aesthetics. Helmets are designed to be lightweight, durable, and visually appealing. More specifically, end-users seek out the perfect helmet for themselves based on these features, turning the chosen product into a personal accessory. The most conventional materials used to make a helmet are expanded polystyrene (EPS) foam. This material can greatly and effectively reduce an impact. In recent years, the design of helmets has also included inspiration elements from nature according to biomimicking principles. Using novel technologies, helmet geometries with complex structures and composite materials are now being designed and produced (Leng, Ruan & Tse, 2022). Computational design is a design methodology based on Computer Aided Design (CAD) system programming.

Based on computational design, 2D (two-dimensional) and 3D (three-dimensional) geometries can be modelled using textual or visual programming interfaces. It involves the use of algorithms to process input data and generate a result, such as geometry. A key aspect of computational design is the diverse range of complex outcomes that can be achieved (Manavis, Kakoulis & Kyratsis, 2023).

CAD systems' programming is utilized in various industries. Design automation is one of the most important factors as design time is significantly reduced by creating and using various algorithms (Minaoglou et al., 2023; Kyratsis, Manavis & Davim, 2023).

Wearable products are one of the areas where computational design comes to solve a series of problems. A wearable product should schematically maintain a basic form but should be able to be customized to suit its user (Efkolidis et al., 2020).

The primary use of a helmet is to protect the user in the event of a fall or collision with another vehicle. A significant focus of helmet design research involves analyzing digital and physical crash data. Finite element analysis (FEA) is a digital method in which a collision can be simulated in order to collect the appropriate data. In the case of helmet design, the goal is to optimize its performance in a real crash. Optimizations can be made both in the morphology of the design and in the materials to be used (Mills & Gilchrist, 2006).

Each helmet consists of its inner and outer part. Both sections are equally important during helmet impact. By using a different morphology in the inner part of the helmet the shock absorption capacity is increased. The definition of the final shape can be obtained through a series of optimizations. In some research studies, the inner part of the helmet is made using two different materials. Finite element can analyze actual helmet impact tests which are in the final design stage (Teng, Liang & Nguyen, 2014; Deck et al., 2019; Oikawa et al., 2017; Mills & Gilchrist, 2008). The correct fit of a helmet on a user's head is a crucial factor in determining its impact effectiveness. To address this issue, a methodology was developed utilizing 3D anthropometry, reverse engineering techniques, and computational analysis with an aim to establish a helmet fit index. This specific indicator can be used in several phases of helmet design in order to improve it (Perret-Ellena et al., 2014; Zhu et al., 2024).

A series of studies were conducted on both injured and uninjured cyclists. Anthropometric measurements of the cyclists' heads were taken, and questionnaires were developed to assess proper helmet usage. The findings revealed that differences in head shape or improper helmet fit can significantly increase the risk of injury in the event of a collision (Thai, McIntosh & Pang, 2015; Rivara et al., 1999; Pang et al., 2018). Mass customization is a process of creating industrial grade custom products. By dividing a group of users into smaller subgroups of similar anthropometric data (i.e. use of 3D scanning) products can fit the users' bodies with great accuracy. 3D scanning is a method of digitizing a real object and transferring its geometry to the computer in 3D format (Lužanin & Puškarević, 2015).

The implementation of this process can be based on some fixed and some variable dimensions of a product. In this way, a product can be easily manufactured at an industrial level (Ellena et al., 2018; Skals et al., 2016; Mustafa et al., 2015). An issue frequently encountered in designing wearable products is the lack of precise anthropometric measurements for heads. To address this, a portable 3D scanner was developed to accurately capture the dimensions of a variety of head shapes. This high level of accuracy provided by a 3D scanner system can benefit future research in the design of products intended for use on or around the head (Perret-Ellena et al., 2015).

3D printing is a manufacturing method which in recent years has also been used in the field of helmet design. Several studies have dealt with the creation of new complex structures for the inner part of the helmet, which in order to be manufactured require 3D printing due to their complexity. In many cases, a cellular structure is used which, through various controls, shows better impact results compared to traditional materials. Furthermore, the use of flexible materials can offer the reuse of the helmet even after a fall. The most common 3D printing technologies used in the construction of the inner part of the helmet are Laser Sintering technology and Fused Filament Fabrication (FFF) (Soe et al., 2015; King et al., 2024; King et al., 2022; Decker & Kedziora, 2024).

The process of computational design involves using CAD-based programming to create 3D models, particularly in situations where the model has intricate geometry or requires parameters for both its dimensions and shape (Manavis et al., 2022). The use of mathematics is one of the key elements of computational design as by creating equations, complex geometries and structures can be designed (Jha & Biswal, 2020). In several studies, Grasshopper™ as part of Rhinoceros™ is used to create products that are worn on the head and in general on the human body. In these cases, the algorithm created uses specific input data and can provide as output the final personalized product, that is focused on a specific user (Bai et al., 2021; Man, Tian & Yue, 2022).

The current paper presents an application for the automated design of bicycle helmets. The application uses an algorithm to generate a 3D CAD model of a helmet by collecting data from the user. Two images of the head from different angles serve as the input data for the algorithm. The application results are verified in the study using a second algorithm based on a 3D scanning technique. The application developed is based on Grasshopper™ and automates the customized geometry generation. A specially developed algorithm was implemented with an aim to increase the accuracy of the lines that built the 3D CAD models. Several different geometrical types and shapes are proposed with an aim to further satisfy the customized requirements. At the conclusion of the research, a model bicycle helmet is created using 3D printing technology.

The proposed methodology

Workflow description

Bicycle helmets are designed to protect cyclists, and the main design challenge is ensuring that they fit different head sizes and shapes. The problem is solved by introducing standardized sizes and shapes, such as Small (S), Medium (M), Large (L), and Extra Large (XL). Nevertheless, some users still struggle to find the right size, shape, or both for smooth usage.

The main aim of the proposed research was to create an application (based on computational design principles), which would be able to automate the design of the helmet using 2D images from the user's head. More specifically, using two 2D images, the intricate details of the head were incorporated into a customized helmet design. The core concept of the algorithm focused on generating and analyzing the outer curves of the head. In addition to the initial 2D images-based algorithm, a separate algorithm was developed using 3D data from reverse engineering techniques (e.g. 3D scanning). The second algorithm aimed at verifying the proper functioning of the application. Figure 1 illustrates the workflow of the proposed methodology. More specifically, the discussion focuses on the product category related to bicycle helmet design and manufacturing. The tools utilized include computational design, 3D scanning, photogrammetry, and 3D printing. Computational design was carried out with the assistance of the Grasshopper™ visual programming language within the Rhinoceros3D™ platform.

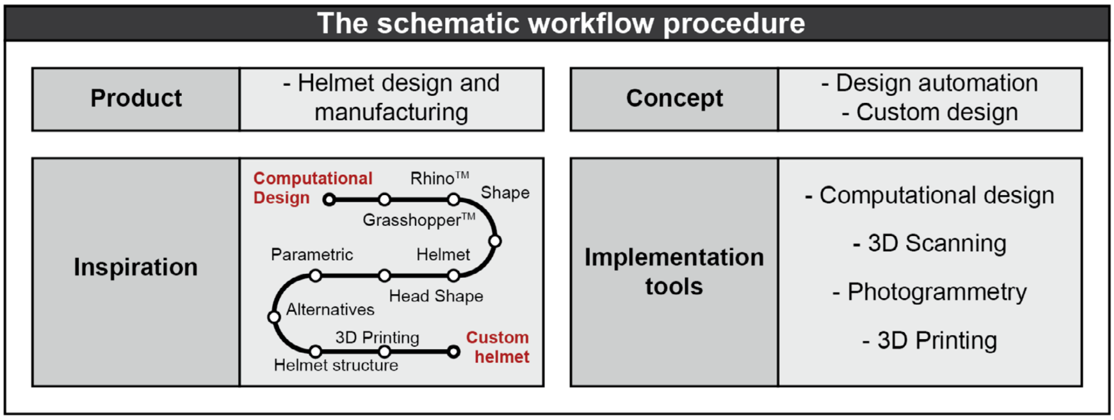
Computational design procedure

The produced algorithm consists of two sub-algorithms named as Code_A and Code_B. Each sub-algorithm varies in both the input data it receives and the way it processes that data. The Code_A starts by inserting and placing the two 2D images from the users' head, followed by their processing to generate the helmet basic outline curves.

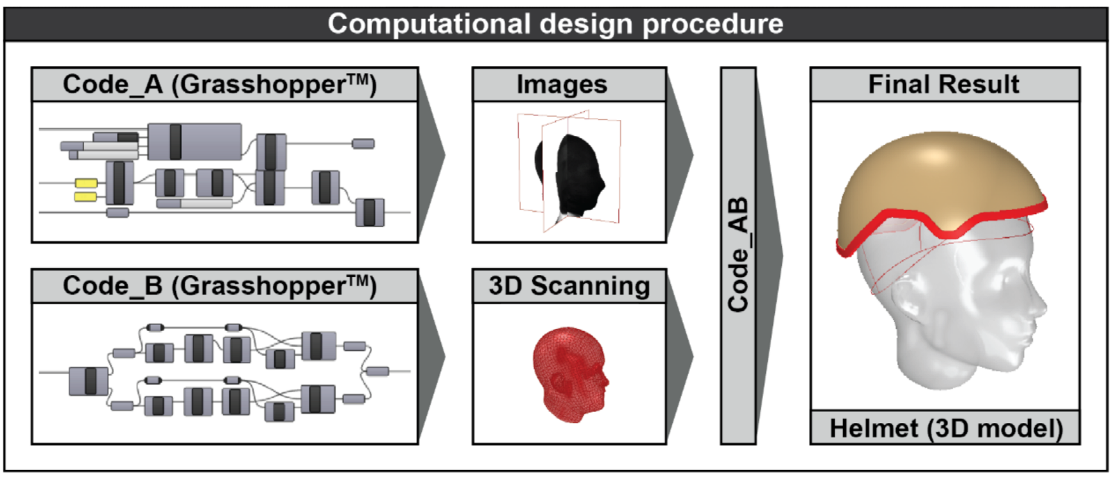
On the other hand, the Code_B begins by inserting and positioning the 3D scan model, then proceeds to process it in order to generate the appropriate guidelines/curves. In the next step, the two sub-algorithms were combined with each other. The final helmet was generated from the output data of both sub-algorithms, but the overall algorithm could still function with just one of them. The Figure 2 shows schematically the procedures of the two sub-algorithms as well as the way they are combined for the final result of Code_AB.

Head shape digitalization

Prior to taking photos of the head, it is crucial to use a stretchy, thin fabric to reduce the volume of the hair, resulting in a more distinct head silhouette.



» **Figure 1:** *Schematic workflow for helmet design and manufacturing*



» **Figure 2:** *The combined sub-algorithms that produced the final result*

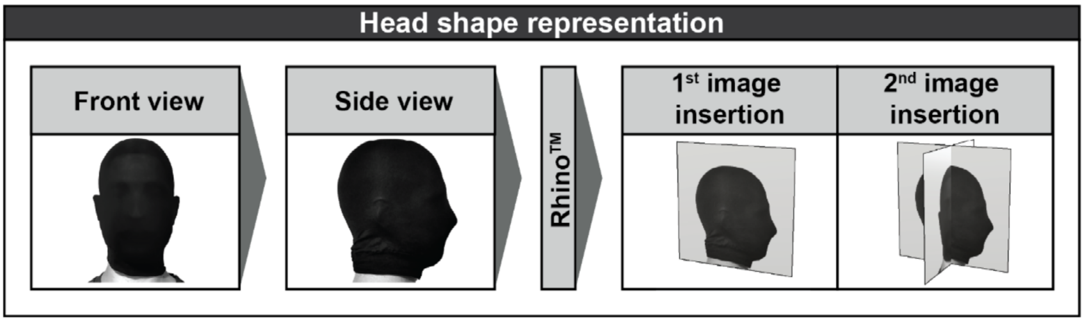
Following this, two 2D images were taken from different angles to provide the algorithm with the necessary data on the head's shape, using a minimal number of viewpoints for user convenience.

Furthermore, in order to determine the size of the images accurately, the user must provide the diameter of the head from the forehead to the back of the head (above the neck) along with the two photos. This dimension will be inserted into the algorithm following the creation of the curves to ensure proper sizing. Figure 3 demonstrates that the fabric is black against a white background, which aids the algorithm in a later phase. The two 2D images are condensed into a 1000x1000-pixel frame, loaded into the algorithm, and arranged at right angles to each other. Subtle adjustments are then made to the images to align their edges.

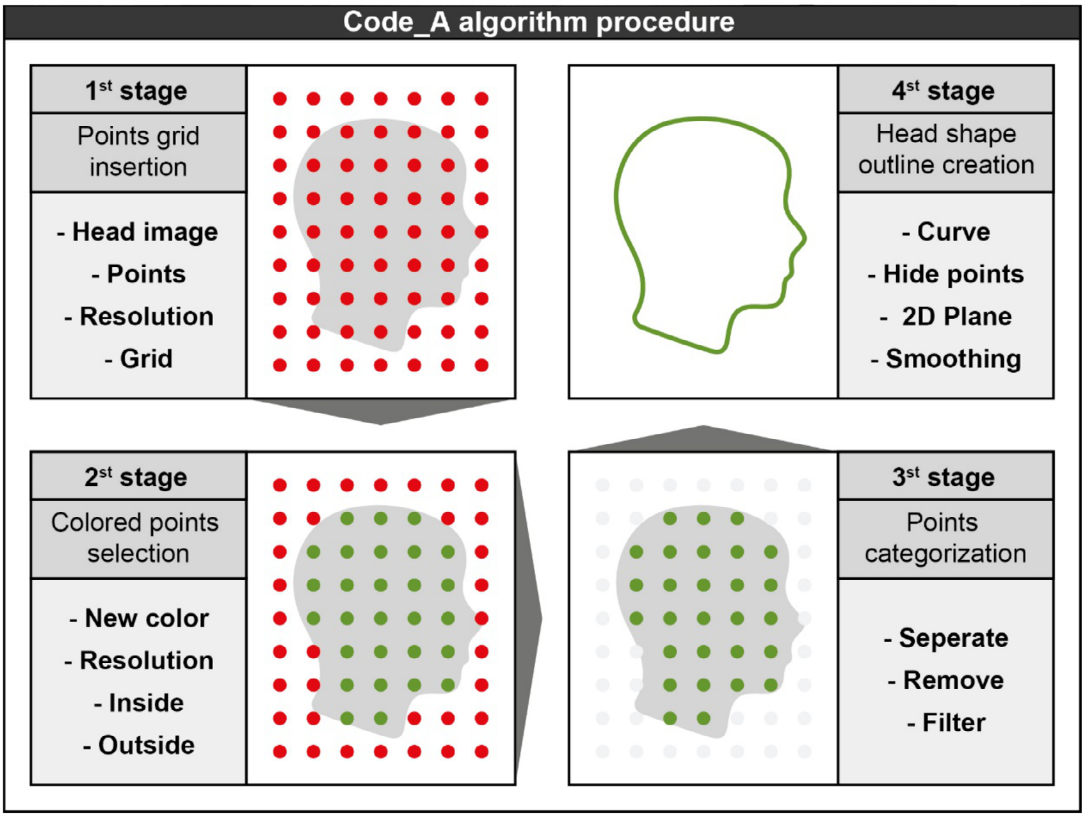
Head shape representation via Code_A algorithm

The main goal of the Code_A algorithm is to create curves that follow the actual shape of the user's head. Code_A consists of four generation stages, which are shown schematically in Figure 4.

The first stage involves creating a grid of points that is bounded by the image, with the number of points determining the initial curve quality. In the second stage, points are categorized based on the color of their corresponding image area. The third stage involves collecting and filtering points from dark areas of the image. Finally, in the fourth stage, a curve is generated by tracing the outline of the points. These four stages are then repeated for the second image.



» **Figure 3:** *Head shape digitalization via image processing*



» **Figure 4:** *Stages of head shape representation*

In the initial phase of Code_A, a grid of 10,000 points is generated for each image, equating to a ratio of 1:100 points per pixel from a total of 1,000,000 pixels. This number of points ensures the algorithm operates effectively within a 10-second computing time constraint. It is important to highlight that utilizing a 1:1 ratio would significantly lengthen the computation time needed by 100 times. After the first stage is completed, it is recommended to use proportions close to a 1:1 point/pixel ratio for optimal curve accuracy.

The RGB color code is then utilized to categorize points in bright and dark areas of the image. Each color in the RGB coding can range from 0 to 255, with 0 representing the absence of color and 255 representing the full presence of color.

By multiplying the color values together, a number is generated for each point, indicating the amount of color present in that area. Points in bright areas will have lower numbers approaching 0, while points in dark areas will have higher numbers approaching 16,581,375 (255^3). This difference in number size divides the points into two main categories (inside and outside of the head shape).

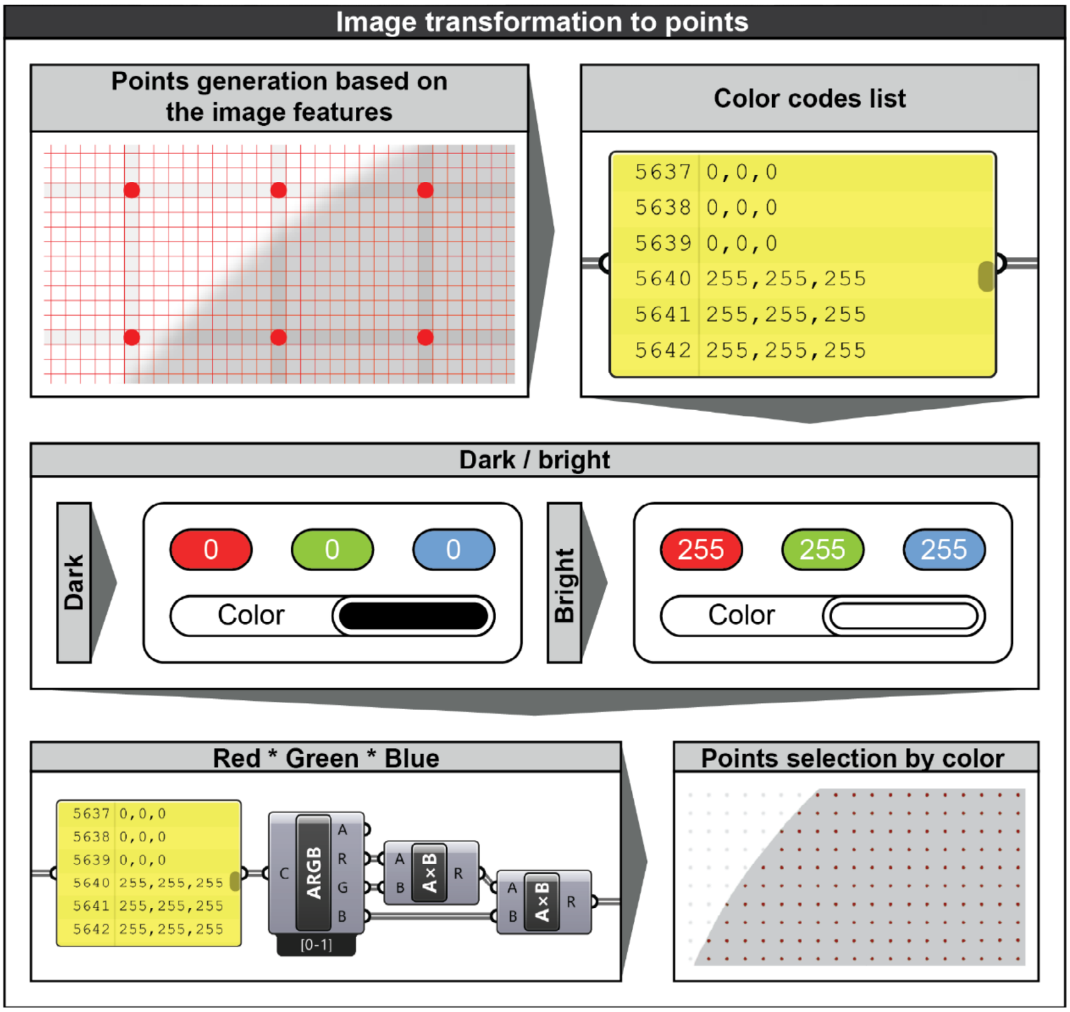
Keeping the points of the dark areas, we have in our possession the points which are located in the area of the head. Corresponding algorithms for pixel management can be found in the bibliography (Chahdi et al., 2021; Laraqui, Laraqui & Saaidi, 2023).

Figure 5 depicts the above-described stages of Code_A.

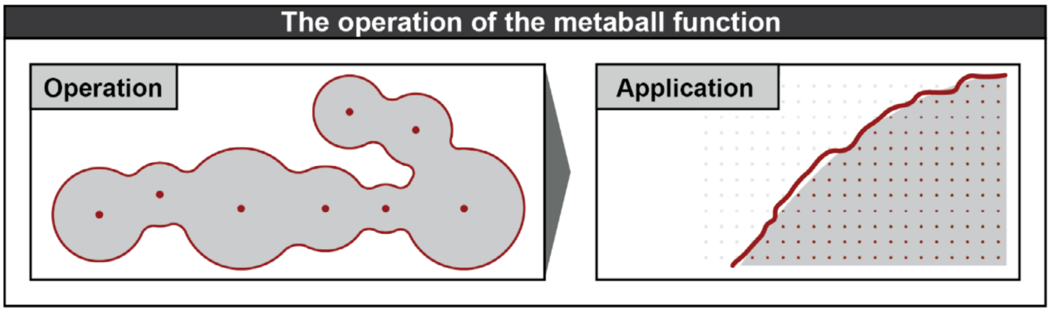
Head shape outline smoothness

The head's shape is determined by a collection of points situated both within it and along its perimeter. The metaball function is a technique that generates closed shapes centered around the specified points. Along with the points, the metaball function utilizes an additional variable to generate circles around each point.

The circles' sizes are designed to eliminate any gaps in the grid by covering the distance between the points. More specifically the size of the circles declared in the metaball function was: R = (PtD / 2) + (0.8 * PtD), where (R) the radius of circles and where (PtD) the distance of the points. The metaball function was applied to the selected points and the result is shown in Figure 6.



» **Figure 5:** *Points generation and selection based on the image colors features*



» **Figure 6:** *Metaball function application to the selected points*

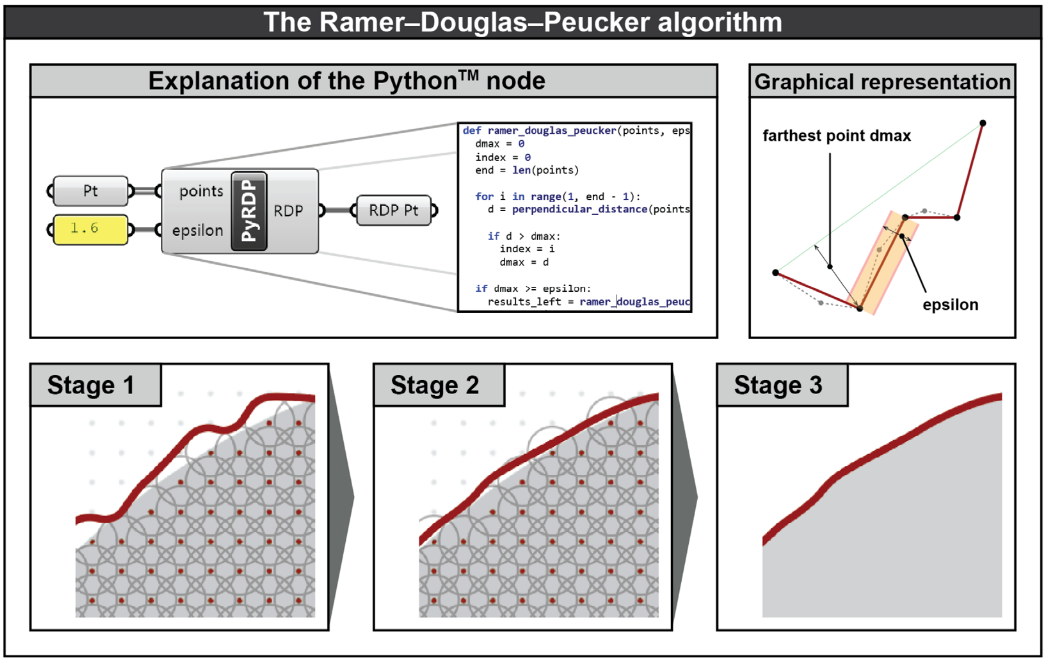
The Ramer-Douglas-Peucker (RDP) algorithm is a curve smoothing procedure (Ramer, 1972). The goal of this specific algorithm is to simplify a polygon by reducing the number of its vertices, i.e. producing a similar polygon with fewer points.

The main features of the algorithm are: a) the iterative method for checking and generating polygons, b) the use of the epsilon variable as a fitting criterion, and c) the output which is a subset of the points determined at the beginning of the algorithm. In this particular study, the algorithm was designed using the Python™ programming language and stored in a GhPython Script™ component named PyRDP. The input data is defined through the variables points and epsilon, while the result of the algorithm is exported through the variable RDP.

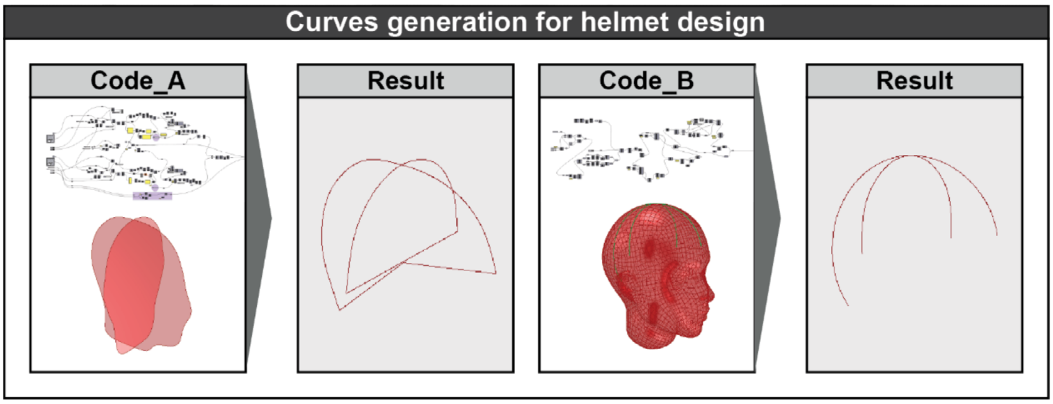
Figure 7 illustrates three stages of implementing PyRDP in the research algorithm. The first stage shows the circles of the metaball function along with its outer polygon outline. In the second stage, the outcome of applying PyRDP to the polygon is shown. Lastly, the third stage presents the new polygon in relation to the curve of the head.

3D scanning integration

In the last part of Code_A, the two polygons representing the front and side views were transformed into curves. Using the dimensions of these curves and considering the user's circumference, a third curve was created, which corresponds to the top view of the head. The measurement of head circumference is affected by factors such as the user's age, height, and gender (Bushby et al., 1992). Additionally, the contour shape can be crafted by combining two 2D shapes: a circle and an ellipse (Ball et al., 2010). With the upper bounds obtained from the other two curves, the combined shape to the endpoints of these curves were aligned. This process results in a three-dimensional wireframe model that takes on the form of a head. Details pertaining to the face, ears, and neck are eliminated by systematically erasing the front and side curves. Simultaneously, while developing Code_A, we also work on the design of Code_B. Specifically, this involves integrating the 3D scanned head into the algorithm. By utilizing three planes along with the 3D geometry, the algorithm calculates the intersection curves between the geometries.



» **Figure 7:** *Curve smoothing utilizing an algorithm in the Python™*



» **Figure 8:** *The high accuracy outcomes of the Code_A and Code_B procedures*

This process results in the generation of a new wireframe that outlines the shape of the head. At this stage, a comparison is conducted between Code_A and Code_B to verify the proper functioning of Code_A. Figure 8 displays both Code_A and Code_B, along with their outcomes in 3D space and their high accuracy.

Helmet 3D CAD modeling

Curves were generated by utilizing the control points of each polygon. The endpoints of these curves on all three sides were assessed based on their spatial positions.

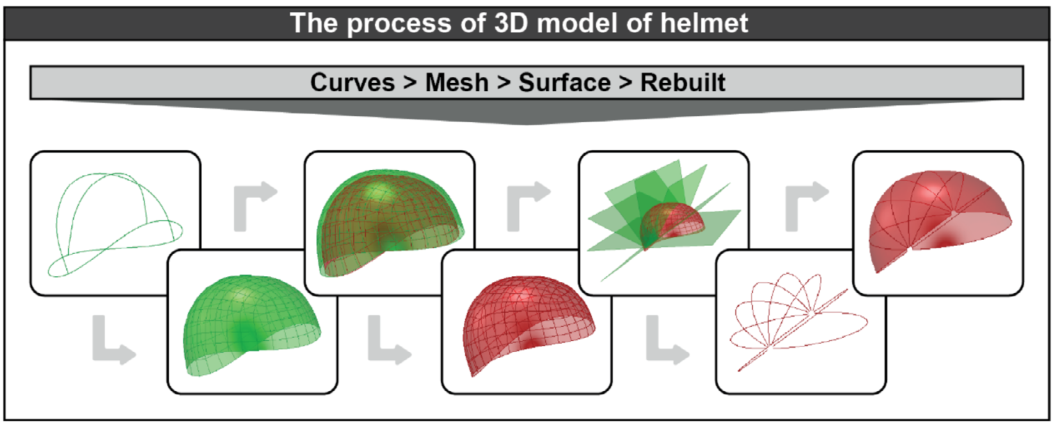
This step is crucial for accurately drawing a surface that conforms to the wireframe. Simultaneously, symmetry was established between the right and left sides of the wireframe. This symmetry was achieved through the development of an average curve, calculated from the average absolute coordinate values. By curving the polygons, connecting the endpoints, and ensuring symmetry within the wireframe, it was made ready for conversion into a mesh. The mesh is constructed from 318 surface squares, which are further divided into smaller squares using the subdivision command. Next, the surface is shifted parallel using an offset to create a gap that defines the internal geometry of the helmet. Subsequently, the mesh is segmented with surfaces to generate new curves.

These new curves are then used to create a surface with an updated topology. This new topology will be beneficial in the later stages of the design process for adding additional features. Figure 9 illustrates the various stages of the helmet modeling process.

Every helmet consists of two main parts which are the outer part and the inner part. The role of the inner part is to absorb shock in the event of a fall. Materials are usually chosen based on their properties and can absorb external loads to protect the head. The role of the outer part is to contain and protect the inner part.

The algorithm generates these two components based on the dimensions of the surface. Additional features and details were incorporated into the helmet's design, such as holes on the sides and a retaining strap. Figure 10 illustrates these features in various colors, with the outer section depicted in red and the inner section in yellow.

In the continuation of the algorithm, the goal was to parameterize the shape of the helmet around the perimeter. More specifically, four sidecut geometries Shape_1, Shape_2, Shape_3 and Shape_4 were created. All geometries consist of curves, which keep their ends at the same points. The differentiation of the geometries is carried out inside each shape.



» **Figure 9:** *Bicycle helmet design step by step*

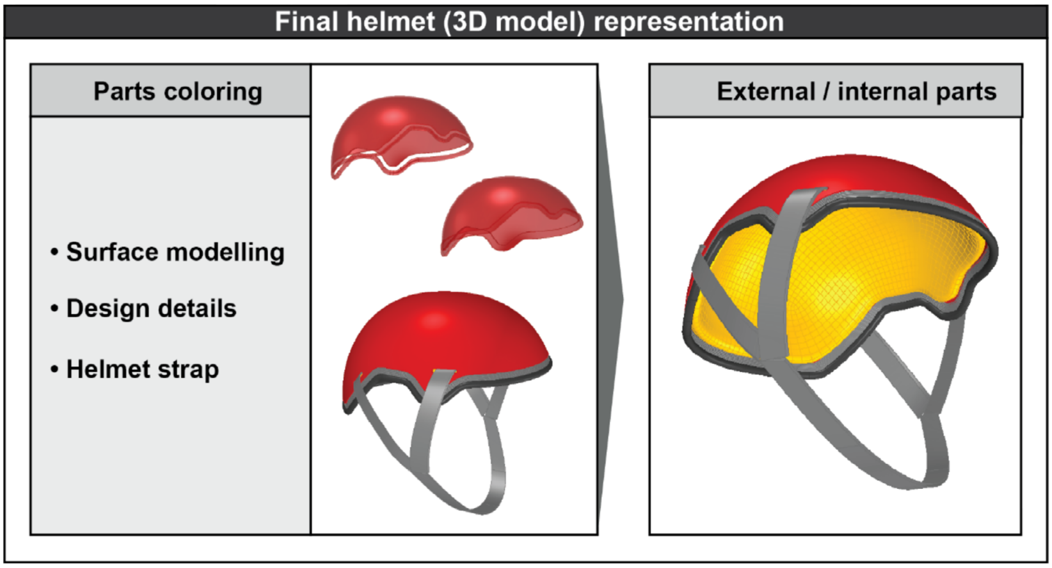
Figure 11 shows the geometries from Shape_1, Shape_2, Shape_3 and Shape_4 in 2D view. Furthermore, the results from applying the geometries to the final helmet are presented in a 3D view.

Using the same methodology, the upper section of the helmet is parameterized. Specifically, six different geometries are created for this part, labeled Type_1, Type_2, Type_3, Type_4, Type_5, and Type_6. These geometries are then used to modify the helmet, leading to the formation of internal holes. Figure 12 illustrates the 2D representations of Type_1 through Type_6. Additionally, the outcomes of applying these geometries to the final helmet are displayed in a 3D perspective.

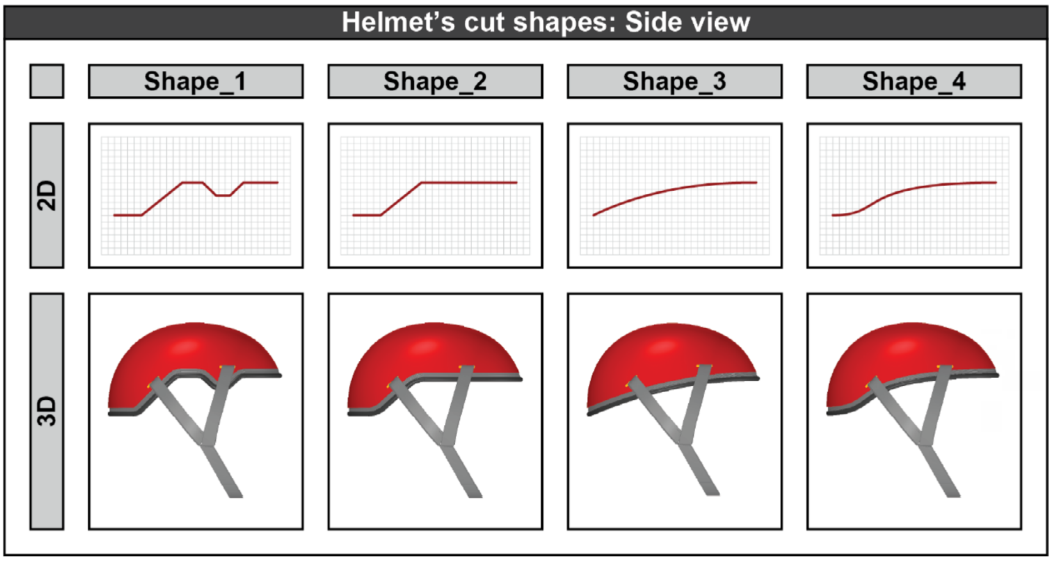
Using the same methodology, the upper section of the helmet is parameterized. Specifically, six different geometries are created for this part, labeled Type_1, Type_2, Type_3, Type_4, Type_5, and Type_6. These geometries are then used to modify the helmet, leading to the formation of internal holes. Figure 12 illustrates the 2D representations of Type_1 through Type_6. Additionally, the outcomes of applying these geometries to the final helmet are displayed in a 3D perspective.

At this stage, all examples of helmet creation using the combinations of Type_1-6 and Shapes_1-4 have been presented. As illustrated in Figure 13, the parameterizations for the helmet shape were consistently applied across all combinations. The algorithm was designed to ensure that the geometries of the shapes do not interfere with one another.

One technique employed to prevent discrepancies is adjusting the shape proportions relative to the helmet's overall size.



» **Figure 10:** *Helmet's design architecture*



» **Figure 11:** *Representation of helmet's cutting shapes: Side view*

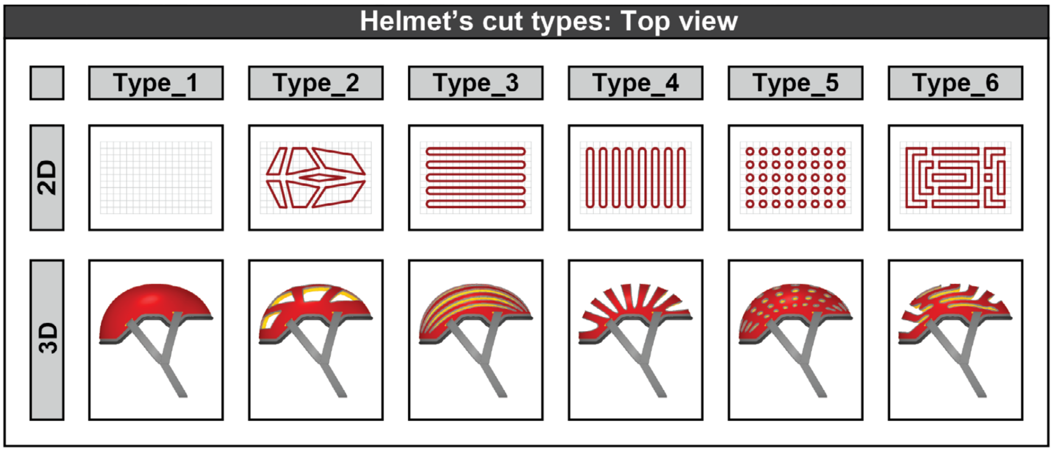
Essentially, if the head dimensions are below average, the Type_1-6 and Shapes_1-4 will adapt to fit the new size.

3D printing

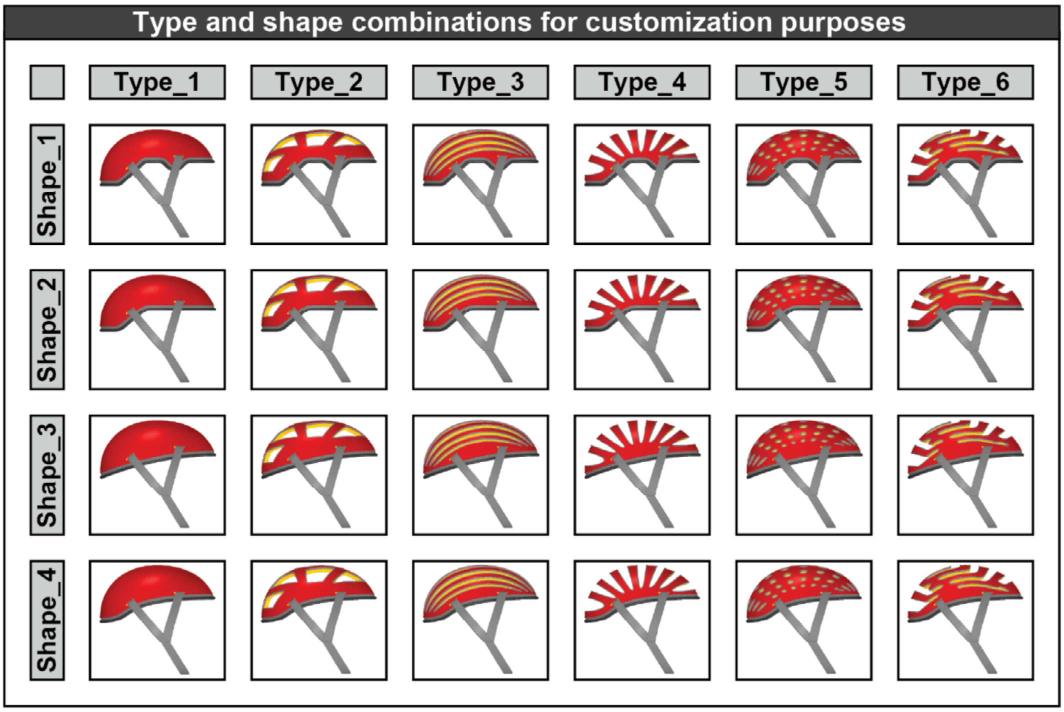
A helmet prototype was created using the 3D printing method. The materials used are s CARBON: PLUS (NEEMA3D™, Athens, Greece) and CR-TPU (Shenzhen Creality 3D Technology Co., Shenzhen, China). CARBON: PLUS is a PET-G based material reinforced with 20% carbon fiber. The carbon fibers give the material a very high resistance to stiffness, impact and heat. And they also affect its specific gravity, which is 1.19 g/cc.

The printing settings for the CARBON: PLUS material are: Layer = 0.1 mm, Wall = 2.4 mm, Flow = 115%, Nozzle Temperature = 245ºC, Infill = 100% and Printing Speed = 40 mm/s. These values optimize the strength measured in tension which reaches σ = 98.48 MPa.

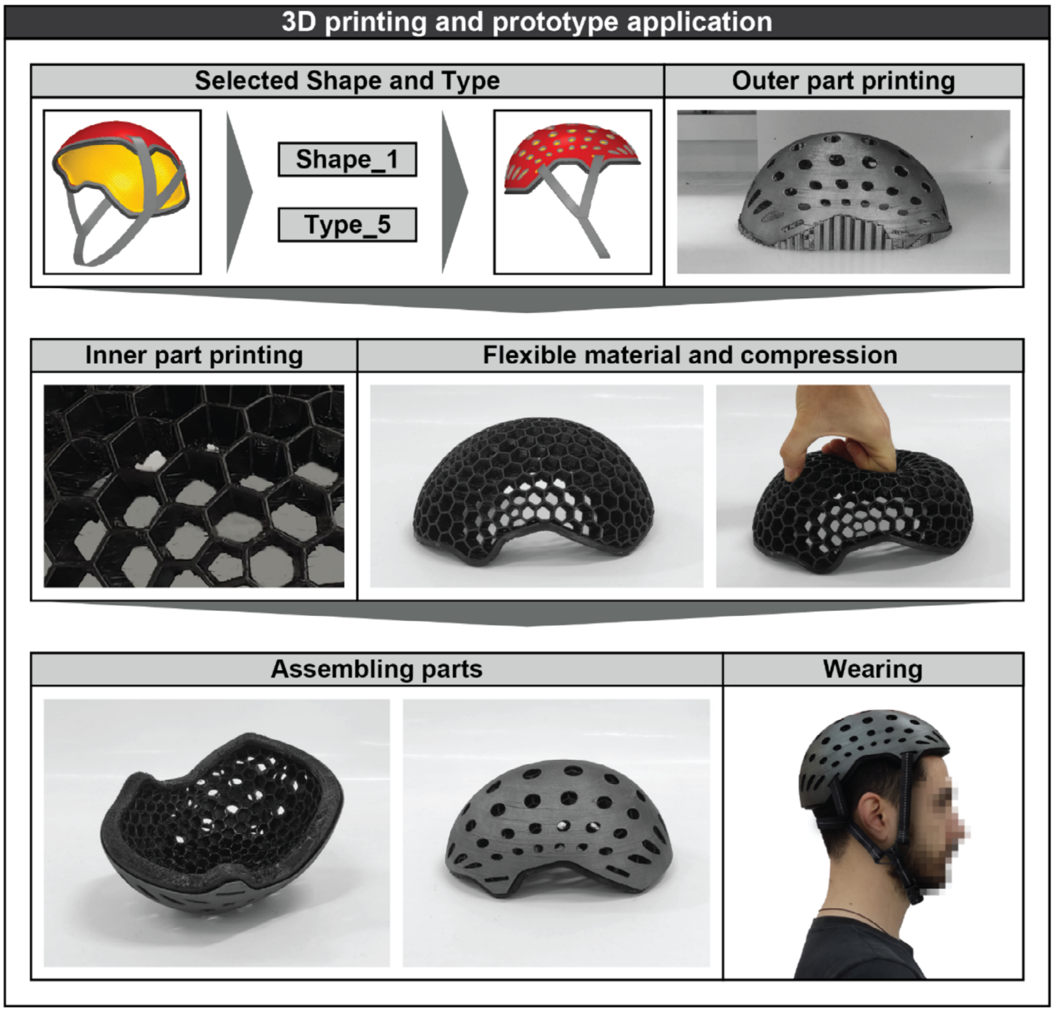
The optimization of the settings was found based on the RSM (Response Surface Methodology) research published (Minaoglou et al., 2024). CR-TPU is a flexible material which, depending on its internal structure, can absorb different shocks. This material can be stretched up to 500% before breaking and its specific gravity is 1.16 g/cc. CARBON: PLUS will be used for the outer part of the helmet and CR-TPU for the inner part. The printer used for this particular prototype print was the CreatBot™ D600 Pro (Henan Creatbot Technology Limited, Zhengzhou, China) which belongs to the FFF (Fused Filament Fabrication) 3D printer category (Figure 14).



» **Figure 12:** *Representation of helmet's cutting types: Top view*



» **Figure 13:** *Helmet combinations for customization purposes*



» **Figure 14:** *Helmet prototyping procedure and application*

Conclusions

Computational design is a tool that helps automating various processes. In this study, the computational design algorithm comes to automate the CAD-based design process of a custom cyclist helmet. The algorithm is using two photographs of a user's head and as a result it can design the helmet, which will be able to fully match the morphological characteristics and dimensions of the user. The algorithm used was divided into two sub-algorithms. The two algorithms use different procedures with an aim to arrive at the same result. More specifically, the first algorithm designs the helmet frame through the use of two photos, while the second one through a 3D scanned model of the head. 3D scanning is a tool that is not readily available for every use. The purpose of the first algorithm is to replace 3D scanning using two photos.

The first algorithm is the basic process of the application, while the second comes to checking the correct operation of the first. Based on the results of using the application on real users, there was no significant deviation between the results from the two sub-algorithms.

By controlling some parameters of the algorithm, the deviation between the results can be greatly reduced. In the context of the study, the application was designed with the aim of being able to parameterize the shape of the helmet, giving the user some predefined external appearance and shape options. The specific shape parameterizations did not create any problem neither in their combined application nor in their application to helmets with very large or small dimensions. At each size change the parameterizations were adjusted to the new data.

At the end of the study, 3D printing was performed using two NEEMA3D™ CARBON materials: PLUS and CREALITY CR-TPU. The printed helmet was tested by its user without any difficulty. The dimensions and curvature of the inner part of the helmet presented a uniform fit on the head.

This particular application could be expanded with more functions and automations in the future. For example, searching for the location of eyes and ears using photos could evolve the app. Also, Artificial Intelligence AI is a tool that could improve how the algorithm works.

Finally, Computer-aided design (CAD) has become a fundamental aspect of product design and manufacturing in today's industry. The incorporation of advanced technologies plays a crucial role in developing unique products tailored to meet user needs. Future research in this study could focus on determining the optimal internal geometric structure of a helmet and Computer-Aided Engineering (CAE) evaluation of different structural designs to maximize safety for cyclists.

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References

Bai, X., Huerta, O., Unver, E., Allen, J. & Clayton, J. E. (2021) A Parametric Product Design Framework for the Development of Mass Customized Head/Face (Eyewear) Products. *Applied Sciences*. 11 (12), 5382. Available from: doi: 10.3390/app11125382

Ball, R., Shu, C., Xi, P., Rioux, M., Luximon, Y. & Molenbroek, J. (2010) A comparison between Chinese and Caucasian head shapes. *Applied Ergonomics*. 41 (6), 832–839. Available from: doi: 10.1016/j.apergo.2010.02.002

Bushby, K. M., Cole, T., Matthews, J. N. & Goodship, J. A. (1992) Centiles for adult head circumference. *Archives of Disease in Childhood.* 67 (10), 1286–1287. Available from: doi: 10.1136/adc.67.10.1286

Chahdi, A. O., Ragragui, A., Halli, A. & Satori, K. (2021) Per-pixel displacement mapping using cone tracing with correct silhouette. *Journal of Graphic Engineering and Design*. 12 (4), 39–61. Available from: doi: 10.24867/JGED-2021-4-039

Deck, C., Bourdet, N., Meyer, F. & Willinger, R. (2019) Protection performance of bicycle helmets. *Journal of Safety Research.* 71, 67–77. Available from: doi: 10.1016/j.jsr.2019.09.003

Decker, T. & Kedziora, S. (2024) Optimizing the thickness of functionally graded lattice structures for high-performance energy absorption: a case study based on a bicycle helmet. *Applied Sciences.* 14 (7), 2788. Available from: doi: 10.3390/app14072788

Efkolidis, N., Minaoglou, P., Aidinli, K. & Kyratsis, P. (2020) Computational design used for jewelry. In: *Proceedings - 10th International Symposium on Graphic Engineering and Design, GRID 2020, 12–14 November 2020, Novi Sad, Serbia.* Novi Sad, University of Novi Sad, Faculty of Technical Sciences, Department of Graphic Engineering and Design. pp. 531–536. Available from: doi: 10.24867/GRID-2020-p60

Ellena, T., Mustafa, H., Subic, A. & Pang, T. Y. (2018) A design framework for the mass customization of custom-fit bicycle helmet models. *International Journal of Industrial Ergonomics.* 64, 122–133. Available from: doi: 10.1016/j.ergon.2018.01.005

Jha, P. & Biswal, B. B. (2020) A mathematical approach for creative graphics design. *Journal of Graphic Engineering and Design.* 11 (1), 37–43. Available from: doi: 10.24867/JGED-2020-1-037

King, A. R. A., Rovt, J., Petel, O. E., Yu, B. & Quenneville, C. E. (2024) Evaluation of an elastomeric honeycomb bicycle helmet design to mitigate head kinematics in oblique impacts. *Journal of Biomechanical Engineering.* 146 (3), 1–10. Available from: doi: 10.1115/1.4064475

King, A. R. A., Tyedmers, A., Gonder, S., Yu, B. & Quenneville, C. E. (2022) Design of a nature-inspired honeycomb bicycle helmet for prevention of traumatic brain injury. In: *The 17th Annual Injury Biomechanics Symposium, 18–19 May 2022, Columbus, Ohio*, Columbus, The Ohio State University Injury Biomechanics Research Center.

Kyratsis, P., Manavis, A. & Davim, J. P. (2023) *Computational design and digital manufacturing.* Cham, Springer Nature. Available from: doi: 10.1007/978-3-031-21167-6

Laraqui, A., Laraqui, M. & Saaidi, A. (2023) Fast mosaicing method based on image resizing pre-processing. *Journal of Graphic Engineering and Design.* 14 (1), 37–47. Available from: doi: 10.24867/JGED-2023-1-037

Leng, B., Ruan, D. & Tse, K. M. (2022) Recent bicycle helmet designs and directions for future research: a comprehensive review from material and structural mechanics aspects. *International Journal of Impact Engineering.* 168, 104317. Available from: doi: 10.1016/j.ijimpeng.2022.104317

Lužanin, O. & Puškarević, I. (2015) Investigation of the accuracy of close-range photogrammetry—a 3D printing case study. *Journal of Graphic Engineering and Design.* 6 (2), 13–18. Available from: doi: 10.24867/JGED-2015-2-013

Man, K., Tian, W. & Yue, F. (2022) A design method of sports protective gear based on periodic discrete parameterization. In: *24th International Conference on Human–Computer Interaction, HCII 2022, 26 June – 1 July 2022.* Cham, Springer. pp. 77–89. Available from: doi: 10.1007/978-3-031-05890-5_6

Manavis, A., Firtikiadis, L., Spahiu, T., Efkolidis, N. & Kyratsis, P. (2022) Parametric architectural design using shapes and structures. *Journal of Graphic Engineering and Design.* 13 (4), 13–20. Available from: doi: 10.24867/JGED-2022-4-013

Manavis, A., Kakoulis, K. & Kyratsis, P. (2023) A brief review of computational product design: a brand identity approach. *Machines.* 11 (2), 232. Available from: doi: 10.3390/machines11020232

Mills, N. J. & Gilchrist, A. (2006) Bicycle helmet design. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications.* 220 (4), 167–180. Available from: doi: 10.1243/14644207JMDA100

Mills, N. J. & Gilchrist, A. (2008) Finite-element analysis of bicycle helmet oblique impacts. *International Journal of Impact Engineering.* 35 (9), 1087–1101. Available from: doi: 10.1016/j.ijimpeng.2007.05.006

Minaoglou, P., Kakoulis, K., Manavis, A. & Kyratsis, P. (2023) Computational wearables design: shoe sole modeling and prototyping. *International Journal of Modern Manufacturing Technologies.* 15 (2), 143–151. Available from: doi: 10.54684/ijmmt.2023.15.2.143

Minaoglou, P., Tzotzis, A., Efkolidis, N. & Kyratsis, P. (2024) Influence of the 3D printing fabrication parameters on the tensile properties of carbon-based composite filament. *Applied Mechanics.* 5 (4), 745–761. Available from: doi: 10.3390/applmech5040041

Mustafa, H., Pang, T. Y., Perret-Ellena, T. & Subic, A. (2015) Impact attenuation of customized user-centered bicycle helmet design. In: *7th Asia-Pacific Congress on Sports Technology, APCST 2015, Procedia Engineering 112, 23–25 September 2015, Barcelona, Spain.* Amsterdam, Elsevier. pp. 77–84. Available from: doi: 10.1016/j.proeng.2015.07.179

Oikawa, S., Nakadate, H., Zhang, Y., Ueno, T., Aomura, S. & Matsui, Y. (2017) Finite element analysis of the effectiveness of bicycle helmets in head impacts against roads. *Journal of Biomechanical Science and Engineering.* 12 (4), 17–00175. Available from: doi: 10.1299/jbse.17-00175

Pang, T. Y., Lo, T. S. T., Ellena, T., Mustafa, H., Babalija, J. & Subic, A. (2018) Fit, stability and comfort assessment of custom-fitted bicycle helmet inner liner designs, based on 3D anthropometric data. *Applied Ergonomics.* 68, 240–248. Available from: doi: 10.1016/j.apergo.2017.12.002

Perret-Ellena, T., Skals, S. L., Subic, A., Mustafa, H. & Pang, T. Y. (2015) 3D anthropometric investigation of head and face characteristics of Australian cyclists. In: *7th Asia-Pacific Congress on Sports Technology, APCST 2015, Procedia Engineering 112, 23–25 September 2015, Barcelona, Spain.* Amsterdam, Elsevier. pp. 98–103. Available from: doi: 10.1016/j.proeng.2015.07.182

Perret-Ellena, T., Subic, A., Pang, T. Y. & Mustafa, H. (2014) The helmet fit index: a method for the computational analysis of fit between human head shapes and bicycle helmets. In: *Proceedings of the 2nd International Congress on Sport Sciences Research and Technology Support, icSPORTS, 24–26 October 2014, Rome, Italy.* Setúbal, SciTePress. pp. 145–153. Available from: doi: 10.5220/0005084101450153

Ramer, U. (1972) An iterative procedure for the polygonal approximation of plane curves. *Computer Graphics and Image Processing.* 1 (3), 244–256. Available from: doi: 10.1016/S0146-664X(72)80017-0

Rivara, F. P., Astley, S. J., Clarren, S. K., Thompson, D. C. & Thompson, R. S. (1999) Fit of bicycle safety helmets and risk of head injuries in children. *Injury Prevention.* 5 (3), 194–197. Available from: doi: 10.1136/ip.5.3.194

Skals, S., Ellena, T., Subic, A., Mustafa, H. & Pang, T. Y. (2016) Improving fit of bicycle helmet liners using 3D anthropometric data. *International Journal of Industrial Ergonomics.* 55, 86–95. Available from: doi: 10.1016/j.ergon.2016.08.009

Soe, S. P., Martin, P., Jones, M., Robinson, M. & Theobald, P. (2015) Feasibility of optimizing bicycle helmet design safety through the use of additive manufactured TPE cellular structures. *International Journal of Advanced Manufacturing Technology.* 79, 1975–1982. Available from: doi: 10.1007/s00170-015-6972-y

Teng, T. L., Liang, C. C. & Nguyen, V. H. (2014) Innovative design of bicycle helmet liners. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications.* 228 (4), 341–351. Available from: doi: 10.1177/1464420713493590

Thai, K. T., McIntosh, A. S. & Pang, T. Y. (2015) Bicycle helmet size, adjustment, and stability. *Traffic Injury Prevention.* 16 (3), 268–275. Available from: doi: 10.1080/15389588.2014.931948

Zhu, Z., Huang, Y., Ji, W., Zhu, J. & Wang, W. (2024) A parametric design framework for the mass customization of bicycle helmet. *Heliyon.* 10 (5), e27409. Available from: doi: 10.1016/j.heliyon.2024.e27409