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Research article

Case study of potential design perceptions for 3D printed accessories made of used face masks

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Abstract: This study aimed to explore consumer perceptions and acceptance of potential 3D-printed accessories made from used face masks. Based on the principles of the circular economy, a proposed conceptual framework was developed to determine the role of experiential value in the relationship between product design perception and perceived purchase intention. Data were collected through a web-based survey questionnaire, employing a nationwide convenience sample of consumers via crowdsourcing marketplaces. Among the 899 respondents, 470 were female, and 429 were male, with an average age of 38. A structural equation model was used to test the hypotheses in the proposed conceptual framework. The findings indicated that consumer experience plays a crucial role in significantly enhancing purchase intentions for 3D-printed accessories made from used face masks. Participants identified jewelry, electronic cases, and home decor items (e.g., picture frames) as the top three preferred product categories for 3D printing. Usability, social value, and environmental concerns emerged as the most influential components of consumer experience in driving purchase intentions for 3D-printed accessories. Additionally, the study confirmed the mediating role of consumer experience between design perception and purchase intention. These findings provide opportunities to rethink, redesign, and reimagine environmentally responsible, socially inclusive, and economically viable practices. The development of new 3D printing filaments using recycled plastic-based materials further aligned with 3D-printed accessories. Finally, this study offers a critical bridge between academia and industry, paving the way for a sustainable future through innovation in design and manufacturing.

Keywords: 3D printing technology; circular economy; recycling materials; plastic; 3D filaments; accessories

1. Introduction

The application of 3D printing technology leverages various industries, including construction, healthcare, industrial design, automotive, and higher education curricula [1]. The global 3D printing market is projected to reach over $117.78 billion by 2033 [2]. For example, well-known fashion companies (i.e., Nike, Patagonia, and Adidas) have utilized 3D printing technologies to create sustainable apparel, such as clothing and footwear, using recycled materials (e.g., water bottles, fishing nets, etc.) [3–5]. This contributes to sustainability initiatives (e.g., cradle-to-cradle, circular economy, etc.) by reducing the reliance on natural resources and diverting waste from landfills. Consequently, 3D printing technology emerges as a powerful tool for advancing sustainability efforts across diverse industries and academia. Furthermore, 3D printing filaments commonly utilize polylactic acid (PLA), thermoplastic elastomer (TPE), and acrylonitrile butadiene styrene (ABS) with properties in Table 1 [6]. The material's physical properties and unique characteristics contribute to the diverse range of potential engineering plastics and recycling materials used for the future 3D printing industries. Understanding the physical properties, features, and performance parameters of the 3D printing filaments is crucial for selecting appropriate materials for specific applications. Therefore, 3D printing technology is considered a core method for future consumption and additive manufacturing systems [7]. It enables rapid production of various products or components in hours or minutes, enabling individuals to create their designs, parts, and a wide spectrum of items/objects using computer-aided design. This versatile technology finds applications in both academia and industries.

Table 1. Seven 3D printer filament types and physical properties.

Types	Printability	Color selection	Heat resistance	Tensile Strength	Toughness	UV resistance	Moisture resistance	Creep resistance
PLA	Excellent	Excellent	Poor	Excellent	Poor	Excellent	Excellent	Poor
PETG	Good	Good	Average	Good	Good	Excellent	Poor	Good
TPE	Average	Average	Average	Average	Excellent	Good	Poor	Good
ABS	Average	Average	Good	Good	Good	Average	Good	Excellent
ASA	Good	Average	Good	Good	Good	Excellent	Good	Excellent
PA	Poor	Poor	Good	Good	Excellent	Average	Poor	Average
PC	Poor	Poor	Excellent	Excellent	Excellent	Excellent	Poor	Excellent

Note: PLA = Polylactic Acid; PETG = Polyethylene Terephthalate Glycol; TPE = Thermoplastic Elastomer; ABS = Acrylonitrile Butadiene Styrene; ASA = Acrylonitrile Styrene Acrylate; PA = Polyamide or Nylon; PC = Polycarbonate.

Plastics have many valuable uses in our lives and various industries. Consumers have used single-use plastic products (e.g., 50 billion plastic bottles of water and five trillion plastic bags per year) with severe environmental, social, economic, and health consequences [7,8]. By 2020, researchers estimated that at least 14 million metric tons (15.4 million short tons) of microplastic particles enter the oceans yearly [8]. For example, in 2022, global manufacturers produced a staggering 53 billion disposable face masks, with about 1.6 billion of them ending up in the oceans [5]. The used face masks have been disposed of in landfills, contributing to air pollution through incineration and negatively impacting water and land quality due to their extremely slow biodegradation period, which can last up to 450 years [9,10]. These waste-related challenges have triggered a global environmental crisis, encompassing issues such as climate change and water pollution, emphasizing the urgent need for sustainable solutions [10].

It is important to investigate plastic-based 3D printing filament further as a potential new recycling material and assess its performance, durability, and other characteristics that are relevant to 3D printed accessories [11]. Using plastic-based materials can help reduce the variety of industries' dependence on recycling sources and solve environmental problems associated with plastic production and consumption [7,8,11]. It is important to explore consumer evaluation and acceptance of products made of recycled materials (e.g., face masks, water bottles, etc.). Research has shown that consumers are progressively aware and concerned about the global environmental and social sustainability problems regarding plastic recycling in a circular economy [12–14]. The circular economy (CE) concept is "a response to environmental and social problems, being a replacement for the previously used liner concept based on the take-make-dispose model" [14]. In general, despite growing environmental awareness, consumer satisfaction with and expectations for recycled or upcycled products remain low, largely due to limited popularization, negative perceptions, and a lack of acceptance of 3D-printed accessories. Therefore, this study aimed to explore consumer perceptions and acceptance of potential 3D-printed accessories made from used face masks. Two objectives were: (1) to identify consumer preferences and their willingness to purchase 3D-printed accessories made from recycled materials used in face masks and (2) to explore how experiential values (including usability, social value, and pleasure in use) mediate the relationship between product design perception and perceived purchase intention for 3D-printed accessories made from used face masks.

2. Literature review

2.1. Theoretical framework

Universities, industries, organizations, and nations have launched sustainability initiatives aligned with the United Nations Sustainable Development Goals to guide their efforts toward a greener future [15]. Sustainability initiatives enhance their reputation, comply with regulations, innovate, meet stakeholder expectations, adopt a holistic approach, and effectively measure and report their progress. In the fashion industry (including clothing, footwear, accessories, etc.), the many stages of production, from raw materials to finished products, are often handled as separate processes and include disconnected operations with little consideration for the total product waste [7,12,13]. Additionally, additive manufacturing or 3D printing technology, along with production leverage, has given little attention to post-consumer product disposal. Rajabi-Kafshgar et al. studied significant steps toward establishing a circular supply chain that combines the strength of 3D printing technology and the repurposing of plastic bottle waste [7]. 3D printing technology holds significant promise for application across diverse industries, including automobile [16,17], military [18,19], healthcare [20,21], education [22–24], and fashion products including clothing, footwear, and accessories [11, 25–29]. Due to the layer-by-layer assembly system, materials and products with excellent physical and mechanical properties have been explored intensively [30].

The circular economy (CE) not only proposes that materials for products should be incorporated into a continuous cycle of reuse or regeneration but also holds promise for reducing waste, enhancing sustainability, and fostering economic and social well-being. As shown in Figure 1, the CE is a design framework that incorporates several ideas to help with sustainable product design, allowing for the reduction of natural resources, waste, and environmental pollution minimization, as well as for the recovery of materials and energy based on the principles of the 6Rs: reduce, reuse, recycle, recover, redesign, and remanufacture [12,13]. The circular economy (CE) emphasizes the realization of closed-loop material flows with the goal of enhancing environmental and economic sustainability [29]. However, the use of plastic-based recycled materials in upcycled composites for 3D printing presents significant CE challenges, particularly in addressing physical, chemical, and mechanical properties during the process [31,32]. Additionally, manufacturers must consider energy-efficient manufacturing processes, production time, and the incorporation of clean practices to meet market demands and optimize the use of available resources [33]. Ghabezi et al. [31] found that combining plastic-based recycled materials (e.g., polypropylene) with short carbon fibers offers a promising approach for advancing 3D printing technology. However, optimizing printing parameters—such as layer thickness, printing speed, and infill density—that influence the composite's interfacial properties, including adhesion strength and interlayer bonding, remains a challenge. Kechagias et al. [34] explored the feasibility of 3D printing on fashion products such as cotton T-shirts and tulles to extend product life cycles. They examined decorative geometries 3D printed on textile fabrics, focusing on the effects of different materials with varying fluidity and thermal properties. Special attention was given to the impact of various fabric weaves on the adhesion mechanism between TPU materials and textiles. Tabary and Fayazfar [32] addressed enhancing the processability of recycled polyethylene terephthalate (PET), whose properties deteriorate during recycling. By incorporating 75% proprietary additives, they improved the suitability of recycled PET for 3D printing, expanding its potential applications in additive manufacturing and contributing to sustainable plastic waste management within the CE. Consequently, the overall process of this study regarding the development of 3D printing filaments made from single-use facemasks as a potential plastic-based material for 3D printed accessories is associated with the CE. Using plastic-based recycled materials to make new products is a key strategy for promoting sustainability, reducing waste, and conserving resources in a world with finite natural resources and growing environmental challenges. Therefore, the CE concept emphasizes designing products with recyclability in mind from the outset. It aims to optimize the ease and efficiency of recycling by considering various factors during the product design phase.

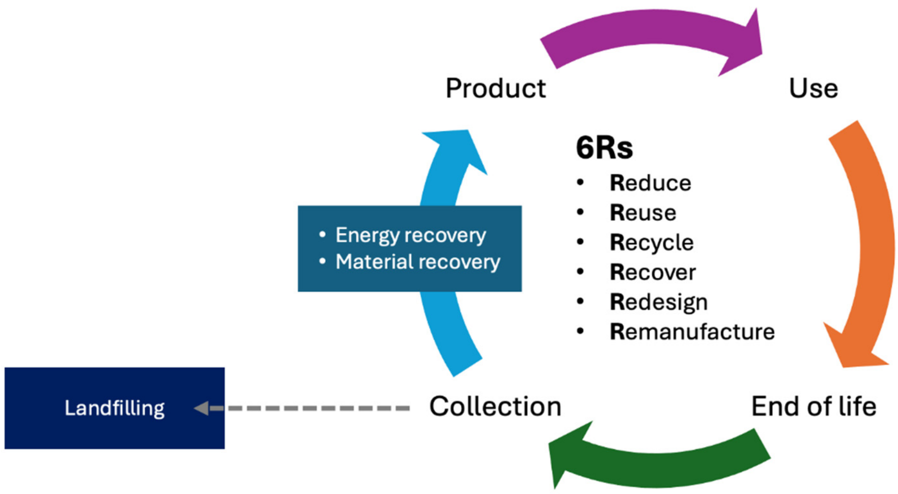


Figure 1. The concept of circular economy.

2.2. Consumer perception and acceptance of 3D printed accessories

Research has identified several barriers that prevent consumer perception and acceptance of sustainable products and 3D-printed goods, including a lack of experience with the effects of sustainable goods on the environment in industries [1,9]. For example, most college students have limited practical experience in understanding and developing recycling materials into sustainable products using 3D printing technology. This deficiency includes a lack of expertise regarding the environmental impacts of sustainable products, difficulties in understanding the processes of recycling and utilizing materials, and challenges in creating sustainable products using 3D printing technology. The gap emphasizes a pressing need to integrate sustainable practices and innovative recycling methods, contributing to sustainability efforts by reducing material waste, improving energy efficiency, and promoting the use of recycled materials in academia. Nam et al. conducted the development of new recycling 3D printing filaments (3DFs) using single-used face masks and 3D printing waste and compared them with commercial PLA filaments [35,36]. However, few researchers explore consumer acceptance of recycling 3DFs used in 3D printing waste and single-use facemasks. In addition, despite longstanding interest in sustainability initiatives within universities, among educators and students [37], there remains a deficiency in the perceptions and acceptance of 3D-printed goods using recycling 3DFs. It is essential to assess consumers' acceptance and evaluation of sustainable products in the product design and development stages to ensure that consumer preferences and needs are being considered to bring products to market successfully.

2.3. Proposed hypotheses and model

A modified conceptual framework integrating a consumer-based brand equity model with an additional environment concern model regarding green products based on the circular economy concept was used [14,38–40]. The proposed model in this study also incorporated an additional construct (perceived purchase intention), followed by Yadav and Pathak [41]. The major concepts from these frameworks were used to develop a proposed research model, which was used to explore the influence of design perceptions along with visual, functional, and kinesthetic values on consumers' intention of 3D printed accessories made of used face masks (see Figure 5). Based on the aforementioned rationale, the variables of the proposed framework were to be selected for consumers' design perceptions, experiential values, environmental concerns, and purchase intentions.

2.4. Dimensions of product design perception

Product design is recognized as the first impression of a product for consumers because the strength of the first impression of the product design for the environment affects their purchase decision [42,43]. Product design plays a crucial role in a successful brand strategy, as the combined efforts of all related activities in the production process create the main point of interaction for consumers to purchase and use the product and a vital driver for the success of both the product and the company [42–44].

Some researchers have proposed and empirically investigated the design perception dimensions (e.g., visual, functional, kinesthetic, and symbolism) of accessories [11], digital devices [38], and green products [40], which were proposed and have been extensively applied in the literature. Consumers also assess design value while using the product after purchasing it [38]. Several research studies have presented product design as a complete summary of multiple activities in the production phases (e.g., color, material, and finish) and as fundamental reasons for buying and using a product [25,45,46]. Product design is an influential strategic tool not only for brand development but also for its sustainability [40]. Kermavnar et al. highlighted that ergonomic product development using 3D printing provides valuable information to support users in developing initial impressions of a product [47]. Consequently, three major design dimensions (visual, functional, and kinesthetic) of design perception that are operational in consumer cognition were proposed.

2.4.1. Visual design dimension

Visualization in design perception is key to communication and shared perception of designs, making it essential for meaningful design development and collaboration [48]. In this study, visualization in design perception includes appearance, aesthetics, looks, and initial impressions, defined as the pleasure of seeing the product [38,49]. Product appearance enables consumer-product engagement to be a critical component of the overall product-brand strategy and is one of the major determinants of consumers' decision-making [45].

Cui et al. conceptualized visual design as a characteristic representing a product's appearance reflected in its materials, textures, colors, shapes, sizes, and reflectivity [45]. Moreover, the visual aspect of the product acts as an important brand utility, providing the product with a deeper symbolic meaning. This, in turn, enhances consumers' brand knowledge, rendering visual design a crucial product design consideration [11,38]. Bakhshian and Lee found that aesthetic attributes positively influence consumers' intentions [49] and perceived product value [50]. The design of a product can provide valuable information to support consumers in developing their initial impression of the product. However, Meng and Bari identified that the visual design perception of 3D-printed smartphone accessories did not significantly enhance consumer-based brand equity [11]. Post-experience, however, consumers realized the importance of visuality. In other words, once consumers obtain experience and feedback from peers, families, and others on social media and websites, the visuality of the product becomes very important.

2.4.2. Functional design dimension

Functional value refers to the "perceived utility acquired from an alternative's capacity for functional, utilitarian, or physical performance and is thought to be generated by a product's salient attribute" [51]. The functional value of green products is influenced by their physical performance, determined by factors such as reliability, durability, and price, which combine to generate functional consumer benefits [40]. Additionally, the price of green products significantly impacts consumers' perceived value of a product and their buying intentions [52].

Consumers consider both price and quality when deciding whether to purchase green products. Functional design features include the latest essential basic functions, superior features compared to competitors, durability, long lifespan, multiple capabilities, smooth usability, and low failure rates [11]. Mishra et al. found that complex functional designs can overwhelm consumers' cognitive abilities, reducing usability and causing negative emotional responses [38]. Conversely, enhanced functional features contribute positively to the overall consumer experience. Furthermore, Meng and Bari further addressed that consumers value the design function and kinesthetic aspects of 3D-printed accessories more than their visual design [11]. This indicates that while aesthetic appeal is important, a product's practical and tactile functionalities play a crucial role in consumer satisfaction. Integrating the functional design dimension, it becomes evident that product designers must balance complexity and usability to enhance functional value. Products that achieve this balance can effectively meet consumer expectations, leading to higher satisfaction and increased purchase intentions. Therefore, understanding the interplay between functional attributes and consumer perceptions is essential for developing successful products, particularly in the growing green and technologically advanced products market using 3D printing technology.

Consumer perception of product form and its effectiveness in reducing human effort during usage is crucial. Kinesthetic design properties include the perception of shape (large vs. small), weight and size (easy to hold in one hand or carry in a pocket), and ergonomics (ease of typing on a keypad) [11]. These three dimensions of product design apply to all general products. Consequently, this study has focused on the design perception of 3D-printed accessories made from used face masks as independent variables in the proposed framework.

2.5. Consumer experiences and intention

The three dimensions of product design perception outlined above establish a solid foundation for the premise that product design and its perception can yield positive outcomes, which is contingent upon factors such as usability, social value, and the overall consumption experience. Mishra et al. proposed that product attributes and benefits derived from meaningful experiences serve as antecedents to both products or brand images and associations, key components influencing consumer experience and environmental concern [38,40]. Furthermore, research indicates an insignificant correlation between experience, the adoption of green products, and consumer choice behaviors [53,54]. Nevertheless, a significant correlation exists between sustainable consumption and the purchase of green products, with peer opinion and social recognition emerging as primary influencers of sustainable consumption behavior [55]. Therefore, this study suggested using experience variables, grounded in two values (experiential and environmental), as mediators between consumer perceptions of design and purchase intention concerning 3D-printed accessories.

2.5.1. Experiential value

Experiential value is diminished when consumers' observations rely on interactions through direct use or indirect appreciation of goods and services [38]. Consumer experiential values encompass social value, usability, and pleasure in use [38]. Social value refers to how a reference group perceives the social and symbolic benefits of owning and using a product [56], and it assesses the perceived advantages of being associated with certain social groups [55]. Social responsibility influences consumer environmental concerns and behavior [55]. Products are well-known platforms that foster social interpretation and impressions [57]. According to Mishra’s study, a product must be enjoyable to use, which is linked to a final condition of experience that positive emotions from product usability led to customer satisfaction [56]. Usability and pleasure in use encompass utilitarian values (e.g., effectiveness and efficiency in task completion) and hedonic values (e.g., memorability, satisfaction, learnability, and ease of use) [56,58]. Mishra identified a strong correlation between design perceptions [56] and consumer experiences for smartphone samples and 3D-printed accessories [11]. Consequently, consumer experience is crucial as it bridges high-design attribute products and purchase intentions [50]. Experience value also measures the effect of consumer emotions in their purchase of green products to express environmental concern.

2.5.2. Environmental value

In this study, environmental concerns and issues such as resource limitations, climate change, and pollution were considered. The influence of consumer perceptions of functional, social, conditional, and knowledge values on their purchase of green products to express environmental concern was examined [55]. Additionally, the role of environmental concern in influencing consumer knowledge and experience has been highlighted, further emphasizing its impact on consumer attitudes and behaviors [55,59]. The relationship between environmental concern and purchase intentions has been studied extensively. For example, studies have demonstrated that environmental concern positively influences purchase intentions for sustainable apparel, indicating a strong link between environmental attitudes and purchasing behavior [60,61].

Furthermore, the influences of environmental concern on specific product consumption behaviors, such as apparel buying and disposal behavior, have been highlighted, underscoring the broad impact of environmental concern on consumer behaviors [62–64]. Biswas and Roy stated that individuals support attempts to solve environmental issues or are willing to contribute [64]. There is a positive association between environmental concern and environmentally friendly behavior [59]. It is much more likely that people who are highly aware of environmental issues will purchase products for their environmental values rather than for their other attributes. The increasing number of consumers showing environmental concern might be reflected by the growing tendency to purchase green products [40]. Consumers who purchase green products help preserve the environment themselves and motivate others to do the same, as others wish to follow their families' and friends' behaviors [56].

Although the emergence of 3D printing technology brings new possibilities to accessory design, there is a lack of research on 3D-printed accessories made of recyclable and reusable materials that will be more widely used in the 3D printing industry in the future [65]. Recycled 3D printing filaments have caught the attention of designers in developing 3D-printed textiles and sustainable products made of recycled materials [36,63,66,67]. Incorporating 3D printing technology can boost designers' creative freedom and production efficiency while reducing the time and cost of creating product prototypes or intricate accessories [26,68,69].

Therefore, the following hypotheses were formulated:

H1: Visual design perception positively impacts (a) usability, (b) social value, and (c) environmental concerns.

H2: Functional design perception positively impacts (a) usability, (b) social value, and (c) environmental concerns.

H3: Usability positively impacts perceived purchase intention.

H4: Social value positively impacts perceived purchase intention.

H5: Environmental value positively impacts perceived purchase intention.

3. Methodology

A quantitative research approach was employed to examine the relationships among variables (visual, functional, experiential, usability, social value, environmental value, and perceived purchase intention) within the proposed conceptual framework. Data were collected through crowdsourcing marketplaces, and descriptive statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS 29). Confirmatory factor analysis (CFA) was performed with Analysis of Moment Structures (AMOS) to validate the psychometric properties of the measured variables. Structural equation modeling (SEM) was also employed to test the proposed hypotheses.

3.1. Sampling and data collection

A web-based survey questionnaire was employed in this study. An online questionnaire using Qualtrics was created. The online survey collected a nationwide convenience sample of consumers in the United States through crowdsourcing marketplaces (i.e., Amazon Mechanical Turk and Prolific). The data were collected in June 2024. It was set to include only people in the United States. To have more representative data, participants were limited to those with a 95% successful completion rate for HITs and were over 18 years old. All participants were informed of the purpose of the study, and a consent form was provided before starting the questionnaire. The institutional review board (IRB) at the primary investigator's institution approved the study. A total of 950 surveys were initially obtained from the crowdsourcing marketplaces. After deleting incomplete and inappropriate questionnaires (e.g., multivariate outliers), 899 valid questionnaires were used for data analysis with a response rate of 94.6%.

3.2. Instrument

The survey questionnaire consists of three sections: (1) Open-ended questions, (2) the constructs with multiple-item measurements, and (3) demographics.

First, open-ended questions (i.e., preference of 3D printed accessories, types of recycling materials, preferred cost, key points of purchasing accessories) were measured. Additionally, the overall process of creating 3D printing filaments from used face masks was described, as illustrated in Figure 3 of the survey. Second, the multiple-item measurements were adapted and modified from previous research [11,40,41,70,71]. To test the hypothesized paths in the proposed conceptual framework, four main variables were assessed: (1) Design perceptions—visual (three items) and functional (four items), (2) experiential values—usability (four items) and social value (four items), (3) environmental value (three items), and (4) perceived purchase intention (four items). These variables were rated on a 7-point Likert scale (1 = strongly disagree; 7 = strongly agree). Last, the demographic section included questions regarding participants' birth year, ethnicity, gender, education, occupation, and annual income.

4. Results and discussion

This study will offer opportunities to rethink, redesign, and reimagine a future that is environmentally responsible, socially inclusive, and economically viable and to develop new 3DFs using potential plastic-based materials. The findings of this study will highlight the potential effectiveness of using plastic-based materials (e.g., disposable face masks, waste materials, etc.) as a PLA filament alternative for 3D printing, contributing to the design and production of sustainable products in the 3D printing industry. By focusing on the right combination of features and performance, companies can ensure that their products attract initial interest and foster long-term loyalty and positive emotional experiences among consumers. This comprehensive approach to product design is crucial in today's competitive market, where consumers have high expectations and numerous alternatives.

4.1. Sample profile

Of the 899 respondents, 470 were females, and 429 were males, with an average age of 38. The majority of respondents were Caucasian (74.1%), followed by Asian (9.7%), Hispanic American/Latino (5.9%), and African American (3.8%). Most participants were full-time employees (71.9%), while 13.8% were part-time employees. Additionally, 78.1% of participants had a college degree or higher. Over half of the participants (53.5%) reported annual incomes between $25,000 and $74,999.

4.2. Understanding 3D-printed accessories

Based on the open-ended questions, participants preferred to make the following top three products using a 3D printer: jewelry (i.e., necklaces, hairpins, earrings, etc.; 45%), electronic cases (i.e., phone, laptop, headset, etc.; 35%), home decor and products (e.g., picture frames, garbage/laundry baskets, etc.; 15%), and others (5%). Additionally, participants identified water bottles (35.8%), wood/fabric (32.2%), and food cans or containers (22%) as the top three potential materials for making 3D printing filaments, as shown in Figure 2.

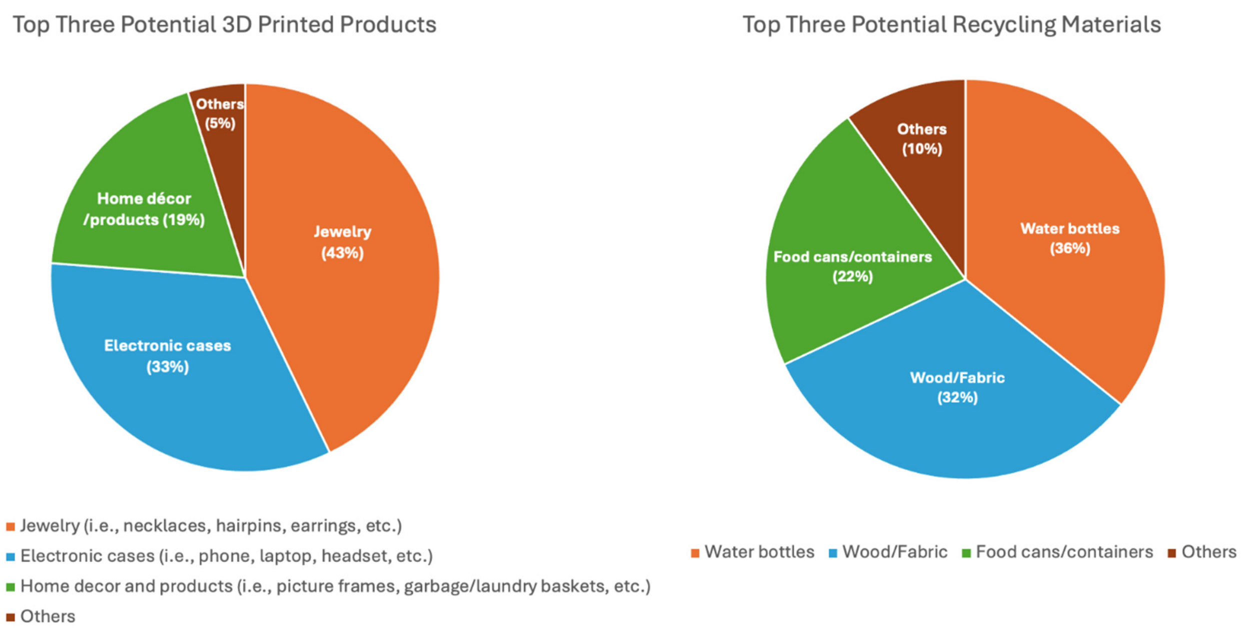


Figure 2. The potential products and recycling material.

After being informed about the recycling filament process using face masks, as shown in Figure 3 of the survey questionnaire, participants identified the following potential 3D-printed accessories: Face-covering frames (30.8%), eyeglass frames (28.9%), phone/laptop cases (17.2%), golf tees (8.8%), footwear (6.5%), keyholders (5.1%), and others (2.7%). Future 3D-printed products should include the use of recycled materials.

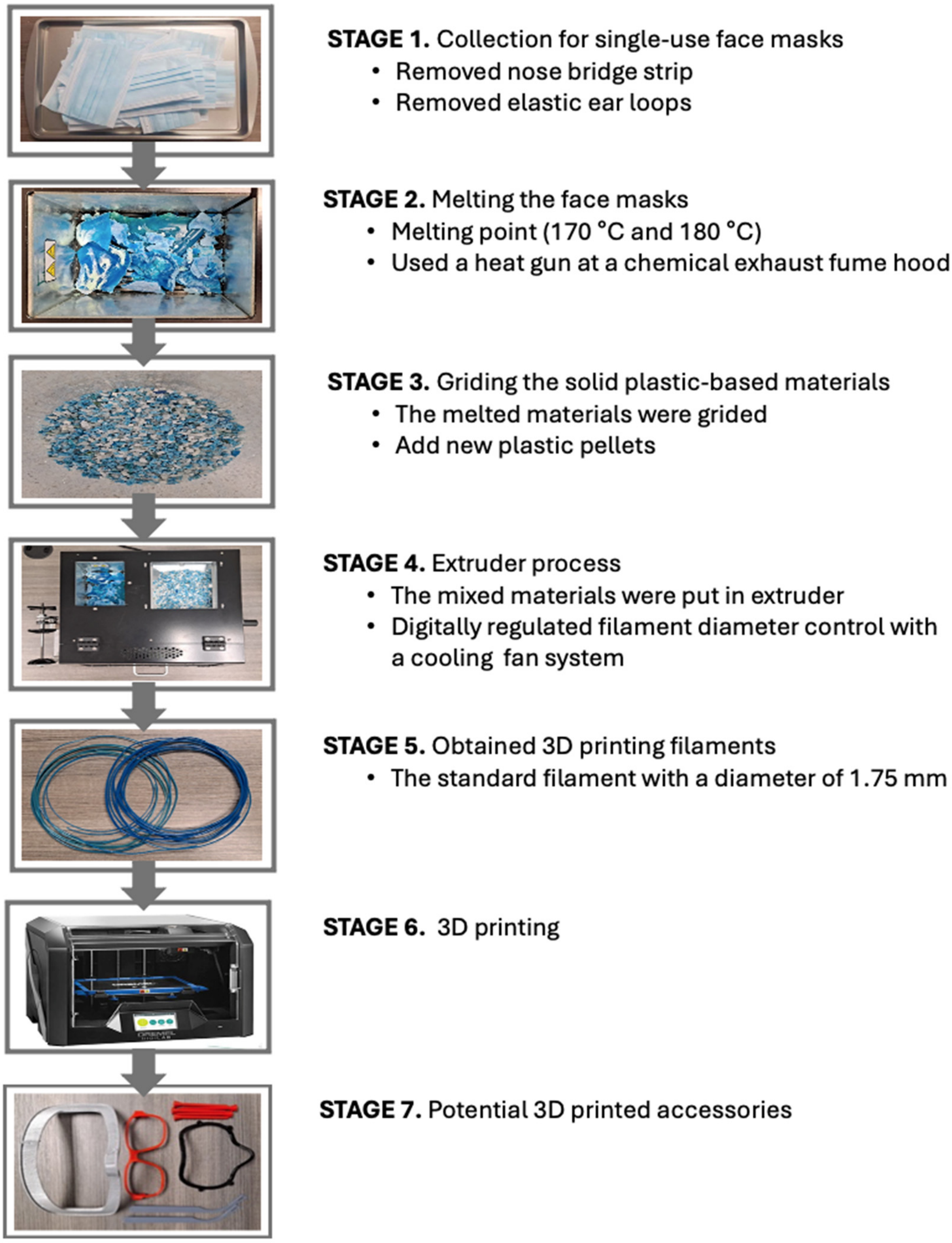


Figure 3. The process of recycling used facemasks.

Most participants (75.8%) expressed a willingness to purchase 3D-printed accessories made from used face masks. However, 24.2% were hesitant due to concerns about low quality (65%), limited product availability (25%), and lack of product information (15%). Participants also indicated that they would pay no more than 25% extra for accessories made from recycled materials using a 3D printer. The most important factors influencing their purchasing decisions were functionality (33.8%), followed by price (24.6%), design (23.7%), material (15.6%), and color (2.3%), as shown in Figure 4. Therefore, future 3D-printed products made from plastic-based recycled materials should prioritize these factors to align with consumer preferences.

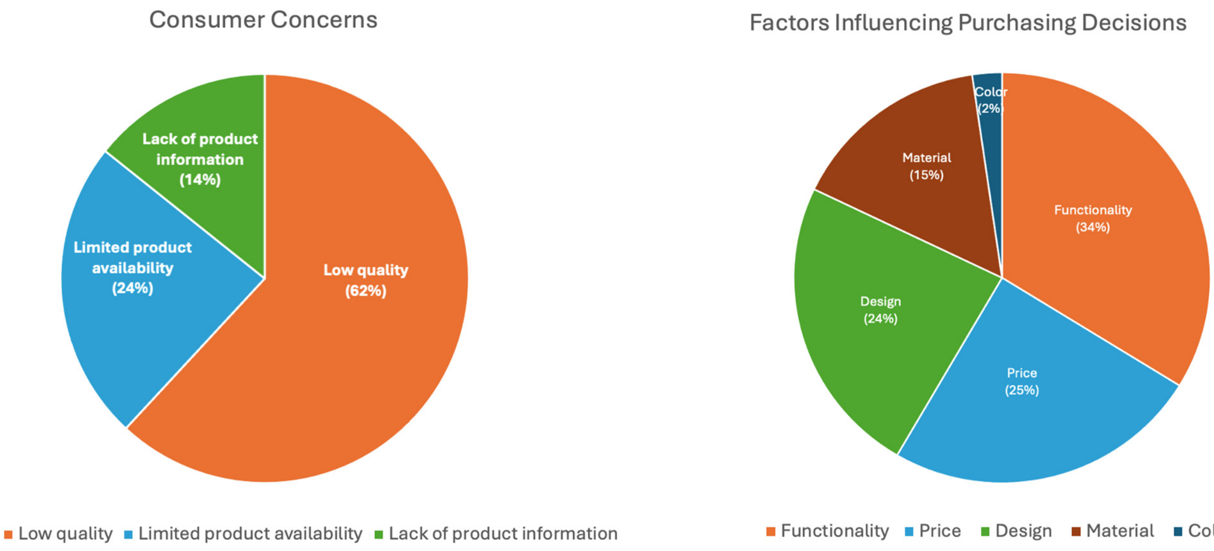


Figure 4. Consumer concerns and purchasing decisions.

4.3. Confirmatory factor analysis

Prior to assessing the underlying structure of the relationship among visual perception, functional perception, experiential values (usability and social value), environmental value, and perceived intention to purchase 3D printed accessories made of used face masks, the reliability and validity of the measures were assessed. As shown in Table 2, The factor loadings for the indicators were higher than 0.70, higher than the required value of 0.50 [72]. The average variance extracted (AVE) values ranged from 0.56 to 0.68, exceeding the minimum cut-off value of 0.50 for the constructs, establishing convergent validity [73]. The composite reliability (CR) value exceeded the minimum requirement of 0.80 [74] and ranged from 0.83 to 0.89. The Cronbach alpha (CA) values were greater than 0.7 for all the constructs [75]. The CR and CA scores indicate internal consistency reliability [75,76]. Therefore, the constructs were suitable for testing the proposed model. The measurement model showed an acceptable fit of the data ($\chi^2 = 759.23$, $df = 215$, $\chi^2/df = 3.53$, CFI = 0.95, RMSEA = 0.05, SRMR = 0.04).

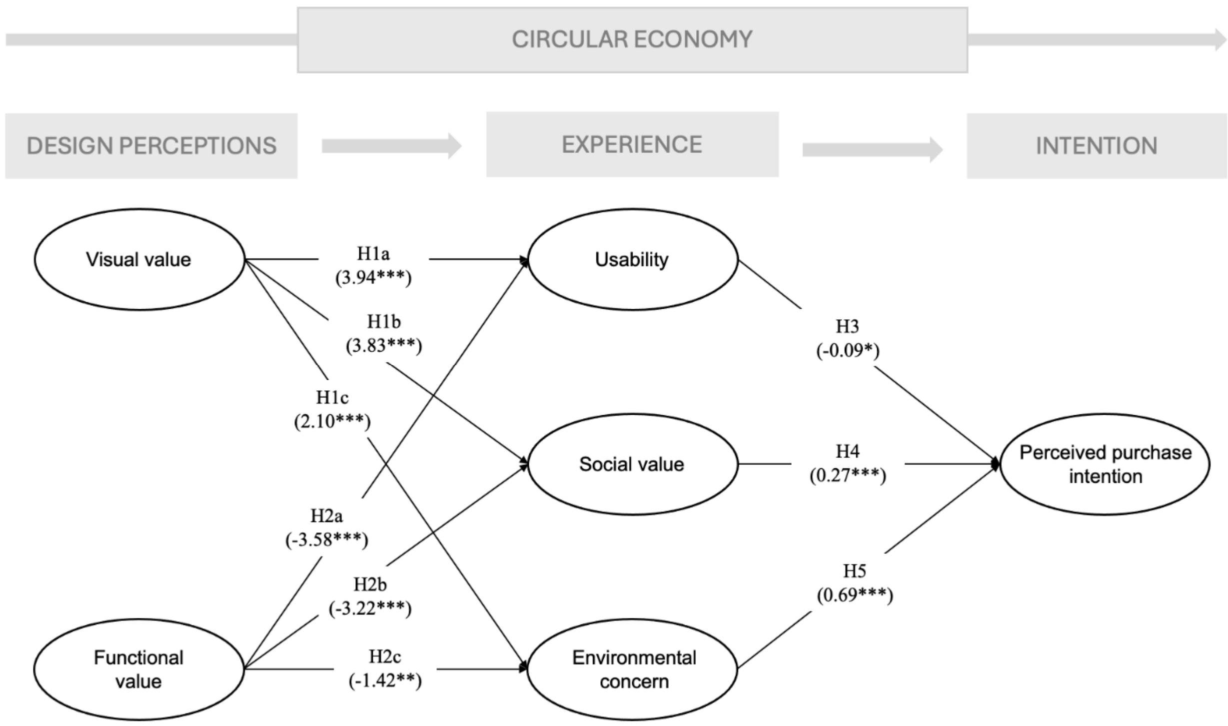
Table 2. The result of the measurement model.

Construct & Item	Factor loading	CA	CR	AVE
Visual perception		0.76	0.84	0.63
The appearance of accessories is eye-catching	0.82			
Various elements of accessories go well together	0.85			
Accessories exhibits proper contrast through color combination	0.81			
Functional perception		0.84	0.88	0.64
The accessories are well made	0.86			
The accessories have an acceptable standard of quality	0.85			
The accessories would perform consistently	0.81			
The accessories are a good product for the price	0.78			
Experiential value (Usability)		0.88	0.88	0.65
I frequently need the help of an expert to use these accessories completely	0.85			
I feel there is too much inconsistency in the accessories' functions	0.85			
I find these accessories awkward to use	0.88			
I needed to learn lots of things before starting using use these accessories	0.84			
Experiential value (Social value)		0.93	0.89	0.68
Buying the accessories would help me to feel acceptable	0.89			
Buying the accessories would improve the way that I am perceived	0.92			
Buying the accessories would make a good impression on others.	0.90			
Buying the accessories would give its owner social approval	0.91			
Environmental concern		0.71	0.83	0.62
I purchase the one less harmful to other people and the environment	0.80			
I have avoided buying plastic accessories due to potentially harmful environmental efforts.	0.80			
I have read newsletters, magazines or other publications written by environmental groups.	0.79			
Perceived purchase intention		0.87	0.86	0.56
I am ready to purchase 3D-printed accessories when shopping	0.70			
It makes sense to choose these accessories of this brand	0.84			
I will prefer to choose the accessories with the same features	0.87			
I will prefer to choose the accessories as good as similar brands	0.84			
I will prefer to choose the accessories as not different brands	0.81			

Note: CA = Cronbach alpha; CR = Composite Reliability; AVE = average variance extracted.

4.4. Structural model

After confirming the measurement model, a structural equation model (SEM) was explored for the hypotheses testing in the study. The SEM demonstrated acceptable fit of the data ($\chi^2 = 939.81$, $df = 220$, $\chi^2/df = 4.27$, CFI = 0.94, RMSEA = 0.06, SRMR = 0.05). For the proposed model, as shown in Figure 3, the visual value had a positive effect on usability (H1a; $\beta = 3.94$, $p = 0.001$), social value (H1b; $\beta = 0.665$, $p = 0.001$), environmental concern (H1c; $\beta = 2.10$, $p = 0.001$). However, functional value had a negative effect on usability (H2a; $\beta = -3.58$, $p = 0.001$), social value (H2b; $\beta = -3.22$, $p = 0.001$), environmental concern (H2c; $\beta = -1.42$, $p = 0.01$). Usability had a negative effect on perceived purchase intention toward 3D-printed accessories made of used face masks (H3; $\beta = -0.09$, $p = 0.05$). Also, social value positively affected perceived purchase intention toward 3D-printed accessories made of used face masks (H4; $\beta = 0.27$, $p = 0.001$). Finally, environmental concern positively affected perceived purchase intention toward 3D-printed accessories made of used face masks (H5; $\beta = 0.69$, $p = 0.001$).



Note: H = hypothesis, p < 0.05, p < 0.01**, p < 0.001****

Figure 5. Hypotheses testing in the theoretical conceptual framework.

The findings of this study offered valuable insights into theoretical advancements in SEM, supported by statistical indicators showing acceptable values. H1a, H1b, and H1c were positively supported, indicating that the visual value of 3D-printed accessories made of used face masks had possibly positive experiences regarding usability, social value, and environmental concern. In other words, attractive 3D-printed accessories were shown as more socially useful and desirable, increasing environmental concerns. However, H2a, H2b, and H2c were negatively supported, indicating that highly functional products might be perceived as low quality and price to use for 3D-printed accessories made of used face masks. Also, it seems the 3D-printed accessories might be very practical products and less socially desirable. Functional value negatively affects environmental concern, meaning practical products might be perceived as less environmentally friendly. H3 was supported; usability negatively impacts the intention to buy 3D-printed accessories from used face masks. This suggested that ease of use alone might encourage purchase because 3D-printed accessories from used face masks lack information, and the actual products have not been seen. H4 was supported; social value positively affected perceived purchase intention toward 3D-printed accessories made of used face masks. Social value positively influences the intention to buy these accessories. If consumers think the products are socially desirable, they are more likely to want to buy the 3D-printed accessories. Finally, H5 was supported; environmental concern positively affected perceived purchase intention toward 3D-printed accessories made of used face masks. Environmental concerns strongly and positively affected the intention to buy the accessories. Therefore, consumers who believe the product is good for the environment are much more likely to purchase it.

5. Conclusion and implication

Consumer perceptions and acceptance of potential 3D-printed accessories made from used face masks within the circular economy (CE), emphasizing the fashion and product development industries were explored. The visibility of these 3D-printed accessories significantly enhanced their usability, social value, and environmental impact on the consumer experience. Although functionality was important, it may have negatively influenced perceptions of usability, social value, and environmental concerns. Thus, the overall consumer experience was crucial and could significantly increase purchase intentions for 3D-printed accessories made from used face masks.

These findings supported the hypotheses in the proposed conceptual framework, which integrated the CE and consumer-based brand equity model with a consumer environmental concern model regarding green 3D-printed accessories. The results of this study demonstrated the positive impact of visual values and the negative impact of functional values on consumer experience, respectively. Notably, consumer experience—including usability, social value, and environmental concerns—emerged as the most influential predictor of purchase intention for green 3D-printed accessories. The study confirmed the mediating role of consumer experience between design perceptions and the intention to use. In other words, usability, social value, and environmental concerns served as crucial mediators within the main elements of the proposed theoretical framework. This suggested that consumer experience was key to shaping purchase intentions for 3D-printed accessories made from used face masks. Therefore, the proposed theoretical framework, which integrated a consumer-based brand equity model with an environmental concern model within the CE for 3D-printed accessories, could be invaluable for the 3D printing and sustainable product industries.

Companies specializing in 3D-printed accessories could enhance the functionality and usability of products made from used face masks and recycled materials, thereby improving the consumer experience and positively influencing purchase intentions. Strategies could include emphasizing features that enhance the functionality and usability of these 3D-printed accessories while addressing concerns related to the use of various recycled materials. For example, potential 3D-printed accessories such as glasses, face-covering frames, golf tees, phone cases, and key holders could be made from used face masks.

Researchers should explore additional variables (e.g., kinesthetic dimensions, sensory engagement, or consumer attitudes) and potential moderators to enhance the model's predictive efficacy and provide more comprehensive insights into consumer intentions regarding 3D-printed accessories made from recycled materials. Additionally, while purchase intentions through the web-based survey using convenience sampling were focused, it did not explore actual 3D-printed accessories. Therefore, future studies should entail not only material testing under various conditions and solutions to achieve high performance and quality of 3DFs as part of an experimental approach but also qualitative research methods (e.g., focus group interviews and wearable testing) to better understand consumers' perceptions and acceptance of 3D-printed accessories. This would help identify the specific reasons underlying the relationships among variables concerning 3D-printed accessories. Despite its limitations, the proposed conceptual framework for 3D-printed accessories within the advanced 3D printing discipline was introduced. As a result, this study provided a unique opportunity for students to reconsider sustainability practices in their classrooms, laboratories, and future businesses [77,78]. This study contributed to a more circular and sustainable approach to material testing and usage by exploring innovative recycling methods. Therefore, it served as a crucial bridge between academia and industry, paving the way for a sustainable future.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

No potential conflicts of interest was reported by the author.

References

1. Yu DG, Li Q, Song W, et al. (2023) Advanced technique-based combination of innovation education and safety education in higher education. *J Chem Edu* 100: 507–516. https://doi.org/10.1021/acs.jchemed.2c00568
2. Zoting S (2024) 3D printing market size, share, and trends 2024 to 2023. *Preced Res.* Available from: https://www.precedenceresearch.com/3d-printing-market.
3. Schwaar C (2023) 3D Printing meets the billion-dollar footwear industry. *Forbes*. Available from: https://www.forbes.com/sites/carolynschwaar/2023/07/19/3d-printing-meets-the-billion-dollar-footwear-industry/.
4. Listek V (2024) 10 Stunning pieces of 3D printed fashion defining the 21st century. *3D print.com*. Available from: https://3dprint.com/307467/10-stunning-pieces-of-3d-printed-fashion-defining-the-21st-century/.
5. Malloy V, Johnson AD (2024) How Brazil recycling co-ops are helping turn plastic waste into shoes. Time. Available from: https://time.com/7198461/brazil-recycling-co-ops-helping-turn-plastic-waste-into-shoes-veja/.
6. Filament properties table. Simplify 3D®. Available from: https://www.simplify3d.com/resources/materials-guide/properties-table/.
7. Rajabi-Kafshgar A, Seyedi I, Tirkolaee EB (2024) Circular closed-loop supply chain network design considering 3D printing and PET bottle waste. *Environ Dev Sustainability*, 1–37. https://doi.org/10.1007/s10668-024-04767-3

8. Moore C (2025) Plastic pollution. *Britannica*. Available from: https://www.britannica.com/science/plastic-pollution.
9. Lu M (2021) 1.6 billion disposable masks entered our oceans in 2020. Available from: https://www.visualcapitalist.com/1-6-billion-disposable-masks-entered-our-oceans-in-2020/.
10. Trafton A (2021) The environmental toll of disposable masks. Available from: https://news.mit.edu/2021/covid-masks-environment-0720.
11. Meng Y, Bari MW (2019) Design perceptions for 3D printed accessories of digital devices and consumer-based brand equity. *Front Psychol* 10: 1–12. https://doi.org/10.3389/fpsyg.2019.02800
12. Jawahir IS, Bradley R (2016) Technological elements of circular economy and the principles of 6R-based closed-loop material flow in sustainable manufacturing. *Proc CIRP* 40: 103–108. https://doi.org/10.1016/j.procir.2016.01.067
13. Kaur G, Uisan K, Ong KL, et al. (2018) Recent trends in green and sustainable chemistry & waste valorisation: Rethinking plastics in a circular economy. *Curr Opin Gre Sustainable Chem* 9: 30–39. https://doi.org/10.1016/j.cogsc.2017.11.003
14. Mikula K, Skrzypczak D, Izydorczyk G, et al. (2021) 3D printing filament as a second life of waste plastics—A review. *Environ Sci Pollut Res* 28: 12321–12333. https://doi.org/10.1007/s11356-020-10657-8
15. United Nations (2015) Department of economic and social Affairs: Sustainable development. Available from: https://sdgs.un.org/goals.
16. Jhinkwan A, Kalsi S, Pankaj P (2023) An overview on 3D metal printing technology in automobile industry. In: *AIP Conference Proc,* 2558. https://doi.org/10.1063/5.0120028
17. Prabhu L, Krishnamoorthi S, Joseph J, et al. (2023) Development of advanced 3D printing technology in automotive industry. In: *AIP Confer Proc,* 2523. https://doi.org/10.1063/5.0110513
18. Hossain KR, Shishir MMA, Rashid S, et al. (2023) Application of 3D printing technology in the military. *J Chemistry Letters* 4: 103–116. https://doi.org/10.22034/jchemlett.2023.395069.1113
19. Marciniak M (2023) The 3D printing in military applications: FDM technology, materials, and implications. *Adv Military Technol* 18: 241–257. https://orcid.org/0000-0003-3921-9205
20. Datta S, Barua R (2024) 3D printing in modern healthcare: an overview of materials, methods, applications, and challenges. *Emerging Technol Health Literacy Medical Practice,* 132–152. https://doi.org/10.4018/979-8-3693-1214-8.ch007
21. Tasneem I, Ariz A, Bharti D, et al. (2023) 3D printing technology and its significant applications in the context of healthcare education. *J Industrial Integration Manage* 8: 113–130. https://doi.org/10.1142/S2424862221500159
22. Özeren Ö, Özeren EB, Top SM, et al. (2023) Learning-by-Doing using 3D printers: Digital fabrication studio experience in architectural education. *J Eng Res* 11: 1–6. https://doi.org/10.1016/j.jer.2023.100135
23. Sun Z, Wong YH, Yeong CH (2023) Patient-specific 3D-printed low-cost models in medical education and clinical practice. *Micromachines* 14: 1–32. https://doi.org/10.3390/mi14020464
24. To TT, Al Mahmud A, Ranscombe C (2023) Teaching sustainability using 3D printing in engineering education: An observational study. *Sustainability* 15: 1–27. https://doi.org/10.3390/su15097470
25. Lyu J, Hahn K, Lee HJ (2023) Potential determinants of consumers' intention to purchase 3D printed fashion products. *Inter J Retail Distribution Manage* 51: 1027–1044. https://doi.org/10.1108/IJRDM-09-2021-0437

26. Ma T, Ma W, Liu W (2024) The application of carving technique based on 3D printing digitalization technology in jewelry design. *Int J Interactive Design Manufacturing*, 1–11. https://doi.org/10.1007/s12008-023-01730-w
27. Tufan Tolmaç N, İşmal ÖE (2023) A new era: 3D printing as an aesthetic language and creative tool in fashion and textile design. *Res J Textile Apparel* 28: 656–670. https://doi.org/10.1108/RJTA-05-2022-0058
28. Yang L, Meng J, Xue T, et al. (2024) Application of 3D printing cellulose fabrics based on cotton fibers in the textile and fashion industry. *Additive Manuf,* 81. https://doi.org/10.1016/j.addma.2024.104000
29. Zhao J, Yang Y, Kobir M, et al. (2024) Driving additive manufacturing towards circular economy: State-of-the-art and future research directions. *J Manuf Proc* 124: 621–637. https://doi.org/10.1016/j.jmapro.2024.06.018
30. Kechagias JD (2022) Materials for additive manufacturing. *AIMS Mater Sci* 9: 785–790. https://doi.org/10.3934/matersci.2022048
31. Ghabezi P, Sam-Daliri O, Flanagan T, et al. (2024) Circular economy innovation: A deep investigation on 3D printing of industrial waste polypropylene and carbon fibre composites. *Res Conserv Recycl* 206: 1–13. https://doi.org/10.1016/j.resconrec.2024.107667
32. Tabary SAAB, Fayazfar HR (2024) Circular economy solutions for plastic waste: Improving rheological properties of recycled polyethylene terephthalate (r-PET) for direct 3D printing. *Progress Additive Manuf,* 1–10. https://doi.org/10.1007/s40964-024-00784-w
33. Saxena P, Stavropoulos P, Kechagias J, et al. (2020) Sustainability assessment for manufacturing operations. *Energies* 13: 1–19. https://doi.org/10.3390/en13112730
34. Kechagias JD, Chaidas D, Spahiu T (2024) Decorative 3D printing on textiles using elastomer TPU filament under different printing conditions. *Rapid Prototyping J* 30: 2033–2042. https://doi.org/10.1108/RPJ-03-2024-0106
35. Nam C, Chung H, Ridgway JL (2022) New filaments from used face masks as PLA filament alternative for 3D printing: Part I. *Int Textile Apparel Association Annual Conference Proceedings* 79: 1–3. https://doi.org/10.31274/itaa.15878
36. Nam C, Chung H, Ridgway JL (2023) Evaluation of new filaments from used disposable face masks in the 3D Printing industry: Part II. *Int Textile Apparel Association Annual Conference Proceedings* 80: 1–3. https://doi.org/10.31274/itaa.17074
37. Amaral AR, Rodrigues E, Gaspar AR, et al. (2020) A review of empirical data of sustainability initiatives in university campus operations. *J Cleaner Product* 250: 119558. https://doi.org/10.1016/j.jclepro.2023.137270
38. Mishra A, Dash S, Malhotra NK (2015) An integrated framework for design perception and brand equity. *AMS Rev* 5: 28–44. https://doi.org/10.1007/s13162-015-0063-y
39. Sheng ML, Teo TS (2012) Product attributes and brand equity in the mobile domain: The mediating role of customer experience. *Int J Inf Manage* 32: 139–146. https://doi.org/10.1016/j.ijinfomgt.2011.11.017
40. Suki NM (2016) Consumer environmental concern and green product purchase in Malaysia: Structural effects of consumption values. *J Cleaner Product* 132: 204–214. https://doi.org/10.1016/j.jclepro.2015.09.087

41. Yadav R, Pathak GS (2017) Determinants of consumers' green purchase behavior in a developing nation: Applying and extending the theory of planned behavior. *Ecol Econ* 134: 114–122. https://doi.org/10.1016/j.ecolecon.2016.12.019
42. Bloch PH (1995) Seeking the ideal form: Product design and consumer response. *J Mark* 59: 16–29. https://doi.org/10.1177/002224299505900302
43. Fiksel JR (2009) Design for environment: A guide to sustainable product development. New York: McGraw-Hill.
44. Brunner RJ, Emery S, Hall R (2008) Do you matter? How great design will make people love your company. New Jersey: FT Press.
45. Cui T, Chattaraman V, Sun L (2022) Examining consumers' perceptions of a 3D printing integrated apparel: A functional, expressive and aesthetic (FEA) perspective. *J Fash Mar Man* 26: 266–288. https://doi.org/10.1108/JFMM-02-2021-0036
46. Nawar SH, Etawy MS, Nassar GE, et al. (2024) The impact of CMF design on product design. *J Textiles, Colorat Polymer Sci* 21: 259–272. https://doi.org/10.21608/JTCPS.2024.258196.1250
47. Kermavnar T, Shannon A, O'Sullivan LW (2021) The application of additive manufacturing/3D printing in ergonomic aspects of product design: A systematic review. *Appl Ergonomics* 97: 1–19. https://doi.org/10.1016/j.apergo.2021.103528
48. Dunston P, Wang X, Billinghurst M, et al. (2003) Mixed reality benefits for design perception. *Nist Special Publication SP*, 191–196. https://doi.org/10.22260/ISARC2002/ 0030
49. Bakhshian S, Lee YA (2022) Social acceptability and product attributes of smart apparel: Their effects on consumers’ attitude and use intention. *J Textile Institute* 113: 671–680. https://doi.org/10.1080/00405000.2021.1898138
50. Shi A, Huo F, Hou G (2021) Effects of design aesthetics on the perceived value of a product. *Front Psychol* 12: 1–17. https://doi.org/10.3389/fpsyg.2021.670800
51. Sheth JN, Newman BI, Gross BL (1991) Why we buy what we buy: A theory of consumption values. *J Business Res* 22: 159–170. https://doi.org/10.1016/0148-2963(91)90050-8
52. Cătoiu I, Vrânceanu DM, Filip A (2010) Setting fair prices—Fundamental principle of sustainable marketing. *Amfiteatru Eco J* 12: 115–128. Available from: https://hdl.handle.net/10419/168690.
53. Diaz A, Schöggl JP, Reyes T, et al. (2021) Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management. *Sustainable Prod Cons* 26: 1031–1045. https://doi.org/10.1016/j.spc.2020.12.044
54. Wijekoon R, Sabri MF (2021) Determinants that influence green product purchase intention and behavior: A literature review and guiding framework. *Sustainability* 13: 6219. https://doi.org/10.3390/su13116219
55. Biswas A, Roy M (2015) Green products: an exploratory study on the consumer behaviour in emerging economies of the East. *J Cleaner Product* 87: 463–468. https://doi.org/10.1016/j.jclepro.2014.09.075
56. Mishra A (2016) Attribute-based design perceptions and consumer-brand relationship: Role of user expertise. *J Business Rese* 69: 5983–5992. https://doi.org/10.1016/j.jbusres.2016.05.012
57. McDonagh D, Bruseberg A, Haslam C (2002) Visual product evaluation: Exploring users’ emotional relationships with products. *Appl Ergo* 33: 231–240. https://doi.org/10.1016/S0003-6870(02)00008-X
58. Nielsen J (1994) Usability engineering. Burlington, MA: Morgan Kaufmann.

59. Stojanov J, Malobabic M, Stanojevic G, et al. (2021) Quality of sleep and health-related quality of life among health care professionals treating patients with coronavirus disease-19. *Inter J Soc Psych* 67: 175–181. https://doi.org/10.1177/0020764020942800
60. Cowan K, Kinley T (2014) Green spirit: Consumer empathies for green apparel. *Int J Consumer Studies* 38: 493–499. https://doi.org/10.1111/ijcs.12125
61. Hwang JA, Park Y, Kim Y (2016) Why do consumers respond to eco-labels? The case of Korea. *SpringerPlus* 5: 1–13. https://doi.org/10.1186/s40064-016-3550-1
62. Cachero-Martínez S (2020) Consumer behaviour towards organic products: The moderating role of environmental concern. *J Risk Fina Manage* 13: 1–13. https://doi.org/10.3390/jrfm13120330
63. He B, Li F, Cao X, et al. (2020) Product sustainable design: A review from the environmental, economic, and social aspects. *J Comp Inf Sci Eng* 20: 1–16. https://doi.org/10.1115/1.4045408
64. Rausch TM, Kopplin CS (2021) Bridge the gap: Consumers' purchase intention and behavior regarding sustainable clothing. *J Cleaner Product* 278: 1–5. https://doi.org/10.1016/j.jclepro.2020.123882
65. Colorado HA, Velásquez EIG, Monteiro SN (2020) Sustainability of additive manufacturing: The circular economy of materials and environmental perspectives. *J Materials Res Technol* 9: 8221–8234. https://doi.org/10.1016/j.jmrt.2020.04.062
66. Lekeckas K, Stirbe J, Ancutiene K, et al. (2023) Testing of 3D printing on textile fabrics for garments application within circular design. *Int J Clothing Sci Technol* 35: 627–647. https://doi.org/10.1108/IJCST-06-2022-0080
67. Spahiu T, Canaj E, Shehi E (2020) 3D printing for clothing production. *J Eng Fibers Fabrics* 15: 1–8. https://doi.org/10.1177/1558925020948216
68. Mavri M, Fronimaki E, Kadrefi A (2023) Survey analysis for the adoption of 3D printing technology: Consumers' perspective. *J Sci Tech Policy Man* 14: 353–385. https://doi.org/10.1108/JSTPM-02-2020-0023
69. Rossi E, Di Nicolantonio M, Barcarolo P, et al. (2020) Sustainable 3D printing: Design opportunities and research perspectives. In: Di Nicolantonio, M., Rossi, E., Alexander, T. (eds), *Proceedings of the AHFE 2019 International Conference on Additive Manufacturing, Modeling Systems and 3D Prototyping* 975: 3–15. https://doi.org/10.1007/978-3-030-20216-3_1
70. Brooke J (1996) SUS: A quick and dirty usability scale. *Usability Evaluation in Industry*, 1–7.
71. Sweeney JC, Soutar GN (2001) Consumer perceived value: The development of a multiple item scale. *J Retailing* 77: 203–220. https://doi.org/10.1016/S0022-4359(01)00041-0
72. Gefen D, Straub D, Boudreau MC (2000) Structural equation modeling and regression: Guidelines for research practice. *Com Assoc Inf Syst* 4: 1–79. https://doi.org/10.17705/1CAIS.00407
73. Fornell C, Larcker DF (1981) Evaluating structural equation models with unobservable variables and measurement error. *J Mark Res* 18: 39–50. https://doi.org/10.1177/002224378101800104
74. Lance CE, Butts MM, Michels LC (2006) The sources of four commonly reported cutoff criteria: What did they really say? *Organizational Res Meth* 9: 202–220. https://doi.org/10.1177/1094428105284919
75. Taber KS (2018) The use of Cronbach's alpha when developing and reporting research instruments in science education. *Res in Scie Educa* 48: 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

76. Hair JF, Sarstedt M, Ringle CM, et al. (2012) An assessment of the use of partial least squares structural equation modeling in marketing research. *J Academy Marketing Sci* 40: 414–433. https://doi.org/10.1007/s11747-011-0261-6
77. Huysman S, Debaveye S, Schaubroeck T, et al. (2015) The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders. *Resour Cons Recyc* 101: 53–60. https://doi.org/10.1016/j.resconrec.2015.05.014
78. Payne A (2015) Open-and closed-loop recycling of textile and apparel products. In: *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*, United Kingdom: Woodhead Publishing Series in Textiles, 103–123. https://doi.org/10.1016/B978-0-08-100169-1.00006-X

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