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Customer Perceived Value for Self-designed Personalised Products Made Using Additive Manufacturing

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Abstract

As end-users become more involved in personalising designs, Additive Manufacturing (AM also known as 3D printing) has become an enabler to deliver this service through the manipulation of three-dimensional designs using easy-to-use design toolkits. Consequently, end-users are able to fabricate their personalised designs through various types of AM systems. This study employs an experimental method to investigate end-users' reflections on the value of 3D Printed personalised product designs based on Product Value and Experiential Value. The results suggest that end-users gave higher value to all measurements for the 3D printed personalised products. This indicates that 3D printed personalised products have increased perceived value when compared to standard mass-production counterparts.

Key words: *Additive Manufacturing, End-users' Involvement, Perceived Value, Product Personalisation*

1. INTRODUCTION

The advancement of Additive Manufacturing (AM), also known as 3D printing, in the design and manufacturing sectors has created much attention and increasingly gained acceptance, particularly from non-expert users [1], [2]. Within the consumer product market (e.g. consumer electronics and household goods), AM is most advantageous in the environments characterised by demand for customisation and personalisation, flexibility and design complexity [3]. This movement has paved the way for 'do-it-yourself' production among individuals. They can personally design their own products using AM-enabled mass customisation toolkits and fabricate them using personal desktop 3D printers or through existing 3D printing service bureaus.

Such emerging technologies present an opportunity for a new paradigm of product realisation. End-users are able to participate in the process of designing their own product through product personalisation and are able to tailor the design of the product according to their own needs and preferences [4]. There is a wide range of consumer personalised products implemented using AM, including gadgets, home and personal accessories, jewellery, toys and artistic sculptures. According to recent research [5], [6], many hobbyists are making use of AM with 17% of those doing so using it for consumer goods. A majority of them considered themselves beginners and most of them were making products using AM due to their passion and strong interest in AM technology.

Through AM, many personalised product design shapes can be fabricated at the same time and this makes it economical to create unique products that meet the needs of personalisation [7]. Whether it is a personalised smartphone case with a biomimicry pattern, a microcellular structure on a bracelet or a self-designed drone, product personalisation can be matched to the needs and preferences of end-users. Several studies have revealed that product personalisation can create greater benefits and increased value for end-users because it delivers a closer preference fit when compared to mass-manufactured standard products [8], [9].

However, there appears to be little analysis of end-users' reflections on the value of 3D printed personalised products, particularly to explain the benefits and values that end-users acquire when they design and own those products. Therefore, it was necessary to conduct a study to discover how AM is likely to increase the value of personalised consumer product designs. A value taxonomy for product personalisation was developed to be used in this study.

2. PRODUCT PERSONALISATION AND END-USER ADOPTION OF AM

Product personalisation has drawn increased attention from both academia and industry in various fields such as economics, marketing, information systems, manufacturing as well as in design and product development. Generally, the purpose of product personalisation is to create products that fit particular needs and that have product attributes relevant for one user at one time. Through product personalisation, end-users can exercise control over the design of a product, which requires them to operate as co-designers of their own personalised designs [10]. Within the context of this study, product personalisation is refers to the process of taking a standard product design and tailoring it to the specific needs of an individual [11]. Mugge et al. [12] suggest that product personalisation is a promising strategy to offer end-users the opportunity to individualise their product with unlimited options. This will enable them to create products that match their identity and as a result, end-users will have more positive attitudes and higher purchase intentions due to a higher degree of design authority [13]. Nurkka [14] explains that the ability to personalise is a means of establishing a closer connection between users and products, as it enables them to determine relevant product attributes for themselves. Thus, product personalisation can provide users with superior product value. It can facilitate positive experiences, increase satisfaction with the product and meet both functional and hedonistic needs.

In the matter of realising a design idea, individuals may experience difficulty because they lack the skills to design and fabricate their personalised design [15]. End-users must be able to use accessible interfaces to control sophisticated design tools and fabrication processes and so personal fabrication requires significant personal investment to find appropriate tools and learn how to use them [16]. To enable end-users to create a unique and very personal product, recent research suggests that manufacturers should create easy-to-use software platforms with which non-expert end-users can easily model a 3D object in a virtual way [4], [17]. Shewbridge et al. [15] suggest that the adoption of fabrication tools such as 3D printers and easy-to-use design toolkits may lower the barriers to transforming physical representation from an idea to reality. This gap in technology has paved the way for researchers to investigate and develop computer-aided consumer design toolkits for product personalisation through AM technology [18]. These developments have combined to open up possibilities for AM applications in consumer product markets.

AM technology has the capability to offer unprecedented possibilities for shape complexity and customised geometry that makes it possible for a part or product series to have unlimited geometry variations at no extra manufacturing cost [19], [20]. AM can also improve a product's functionality and performance through the adoption of complex forms, user-fit requirements, producing consolidated parts and the ability to provide specific design features to increase the aesthetic value to the user [21]. The tool-less nature of AM lessens the manufacturing constraints and enables transition from mass-production to the need-oriented manufacturing requirements [22]. The most important aspect of AM is that it enables direct manufacturing from digital 3D models stored in a computer-aided design (CAD) file without the need for tools or moulds [23]. In this way, only a product's digital three-dimensional (3D) model is needed for fabrication and this helps product individualisation to be realised since no tooling or craft skills are needed [3].

Recent developments have seen a large number of companies begin to market entry-level 3D printers sold at affordable prices [24]. These machines have been priced so that they can be purchased by individuals and are capable of producing objects from a range of plastics. A personal 3D printer can produce reasonably complex shapes with minimal user intervention, making it possible for everyday users to produce physical objects at home [15]. Instead of owning a personal 3D printer, individuals may also turn to service bureaus or online retailers such as 3DHubs (www.3dhubs.com), i.materialise (i.materialise.com) and Shapeways (www.shapeways.com) that enable them to purchase 3D printed items and receive them by postal delivery. Others, such as MakerBot's Thingiverse (www.thingiverse.com), provide free web hosting for making and sharing 3D printable objects with online 3D printing communities.

Supported by AM-enabled design toolkits, end-users can readily design and manufacture their personalised products using suitable AM systems, such as personal desktop 3D printers. Additionally, with AM-enabled design toolkits, there will be fewer barriers for design complexity in the shape of the manufactured products, whereby, end-users could "play" and create very radical and complex patterns and shapes [25]. Existing free design toolkits such as 123D Design (www.123dapp.com/design), Tinkercad (www.tinkercad.com), CellCycle (n-e-r-v-o-u-s.com/cellCycle) and Project Shapeshifter (shapeshifter.io) offer easy-to-use design interfaces for non-expert users to produce their personalised designs with AM.

Reeves et al. [26] have stated that AM and 3D printing is much more important for design firms, manufacturers and consumers because the core driver of AM is to increase geometric freedom and this approach can be used to offer product personalisation to end-users. The demand for product personalisation is expected to grow in coming years. AM and 3D printing can provide high added value to consumer product markets by playing the role of a premium production process [27]. Hu [4] has stated that with the emergence of responsive manufacturing systems such as AM and the existence of design toolkits, there will be an opportunity for product personalisation to become a new paradigm for product realisation. End-users, however, need to realise the value of product personalisation in order for them to enjoy the benefits and take advantage of the advancement of AM.

3. THE VALUE OF PRODUCT PERSONALISATION USING AM

3.1 **Theoretical Background**

AM technology is well known to have great potential for customisation and personalisation of product designs. Although the authors recognise the capabilities of traditional manufacturing processes, AM has the unique capability of building complex geometries that cannot be fabricated by any other means and its possibility to create highly functional parts without the need for complex assemblies [28]. This has created public interest in using AM as a personal fabrication tool to produce personalised 3D parts. 3D printed personalised designs have become alternatives to standard designs that are produced through traditional mass-production processes. However, investigation into this area revealed a lack of knowledge about determining the value of 3D printed personalised products. This value is acquired by end-users when they are actively involved in the personalisation process, and when they possessed and consumed such products.

'Value' is one of the most widely and frequently used words in various disciplines to describe the worth or usefulness of something that a person desires to have. The concept of value varies among different disciplines and the idea has gone through many adaptations within the existing contextual environment [29], [30], [31], [32], [33], [34], [35], [36]. Previous empirical works have found that end-users' involvement in self-designing of products provides additional product value [37], [38], [39], [40]. Also, there is experiential value to end-users as they create designs that deliver a closer fit to their preferences [41], [42]. Past investigations show that value is related to the use of an object to satisfy needs and to provide benefits that end-users believe are important [43], [44]. The simple definition of value is what end-users get from the purchase and use of a product (i.e. benefits, quality, worth, utility) versus what they pay (i.e. price, costs, sacrifices), resulting in a positive or negative attitude towards the product [45]. The argument presented here is that an increase in the value of a consumer product is achieved when end-users are given a higher degree of direct and deliberate influence over the product's 3D form; from identification of a product's archetype and required characteristics to satisfy their needs, through to involvement in the design process by which an agreed solution to the design specification is arrived [46].

Through this approach, end-users have more freedom to define a product's form without the need for the designer's approval. Conversely, in a standard mass-produced product, the end-user has no possibility of direct involvement in shaping a product's form, at any development phase (except to do their own post-purchase personalisation). If end-users have difficulty in conveying their preferences or have low levels of involvement with the product design, they will not receive the benefits of co-creation [47].

From the end-user's perspective, the value of a product does not just lie within its attributes or technical features, but also in what benefits they get from consuming the product. Evidence shows that end-users' involvement in the design and fabrication of products can in itself provide value [38], [40], [48], [49], [50]. End-users will see added value if the personalised product provides a combination of additional attributes to the usual benefits, such as style, durability, quality, symbolism, ease-of-use, etc. However, these types of benefits will not be automatically perceived as valuable by end-users. This will happen only if they can see, appreciate and then use the product as anticipated in consumption activities to achieve their personal aims [30]. As mentioned by Smith and Colgate [45], the simplest equation to express the increase in an end-user's perceived value is by how much the additional benefits of the product exceed any additional costs to the user. Conversely, if the costs for the end-user to possess the product exceed the benefits, the market will not adopt product personalisation [51], [52].

Despite 3D printed personalised products creating benefits in the form of better preference matching and improved user experience, they also entail additional cost or investment to end-users [51]. This can be in the form of investment of money, time, attention and effort during personalisation activities [38], [51], [53], [54]. Therefore, in the context of this study, 3D printed personalised products are evaluated both in terms of added value for end-users in the form of benefits, and also any added cost to end-users.

3.2 **Value Taxonomy of Product Personalisation Through the Use of AM**

We acknowledge that there are several studies about value taxonomies related to self-designed product has been addressed by previous researchers [38], [40]. A recent study by Damm et al. [49] proposed key value drivers of self-designed product in relation with characteristics of products and the self-designed process. They suggest that the magnitude of key value drivers is jointly influenced by factors of the product and the self-designed process. They also addressed that not all products are equally suited to be individualised and not all individualisation approaches deliver identical value for end-users. They distinguished the perceived value of the self-designed product as perceived preference fit, perceived process enjoyment and effort, perceived product uniqueness and feelings of psychological ownership. Hunt et al. [50] further underscore the importance of functional fit and product uniqueness as drivers of self-designed value in relation to individual differences among the users.

Merle et al. [48] proposed the concept that the perceived value of a self-designed product could be classified into two components, product value and experiential value. The first value related to anticipated consumption experience and the second value is associated with the interaction between the consumer and the product during the co-design stage. Merle et al [41] further identified that under those classifications, there were five possible end-users' perceived benefits, of which three are related to product value and two others are related to experiential value. The product values are (1) utilitarian value, (2) unique value and

(3) self-expressiveness value. The experiential values consist of (4) hedonic value and (5) creative achievement value. We adopted this value taxonomy for self-designed products because it seems to be the most comprehensive and consistent with the phenomenon under investigation. However, several additional value components were required to accommodate the overall perspective associated with this study.

In this section, we proposed a value taxonomy of product personalisation through AM that was used to assess the value of such products if it is being personalised by non-expert users. The value taxonomy of product personalisation through AM consists of two first-level value types; (1) Experiential Value - derived from the interaction between the end-users and products during the personalisation process and (2) Product Value - derived from the anticipated consumption experience. Two second-level value components are identified under Experiential Value, namely (i) Co-design Value, (ii) Hedonic Value. Four second-level value components are identified under Product Value, namely (i) Functional Value, (ii) Unique Value, (iii) Sensory Value, and (iv) Personal-expressive Value. Two additional values (iv and v) have been added into the value taxonomy in order to capture the capability and complexity of AM technologies as well as the nature of the personalisation activities respectively.

3.2.1 *Value components*

Each of the two first-level value types has second-level value components. The definitions of the value components are listed in Table 1 below:

Table 1. Definitions of value components from the value taxonomy, adapted and adjusted from Merle et al. [42]

Value components	Value definitions
Experiential Value	
Co-design	Acquired from the interaction between the end-user or individual during their active role in the design of a product [41]
Hedonic Value	Acquired from the sensation by the enjoyment and pleasure that reflect entertainment aspect from end-user's experience or activities [42], [45], [55], [56].
Product Value	
Functional Value	Acquired from the increment in product utility derive from the 3D printed personalised product compared to the best standard product available [40].
Personal-expressive Value	Acquired from the opportunity to reflect image and personality of a person by establishing one's self-image [42], [57].
Sensory Value	Acquired from a product's capacity to present a sense of emotional response, reflection in the form of sensation, sense of beauty, sensory pleasure or delight to enhance personal expression [44], [58], [59].
Unique Value	Acquired from the creation of symbolic attributes that make an opportunity of attention, interest and personal to express peculiarity of self-expression of individual [34], [40], [42].

4. METHODOLOGY

The rationale of the study was to examine the relationships between the key value components of a personalised product using AM and the involvement of end-users in product personalisation. The ‘end-user’ in this study was defined as a layperson who was not professionally trained in industrial design, but who would be the ultimate beneficiary of the usage of the product and using it themselves [60]. The consumer products they designed were fabricated using AM systems. The study was expected to shed light on end-users’ perceived value of 3D printed personalised products. A quantitative method using experiments involving participants was chosen for this study since the relative importance of a social phenomenon was under investigation [61].

4.1 **Experimental setting and method**

This exploratory study recruited participants using purposive sampling, in which participants were chosen based on the judgement of particular characteristics being sought [62]. In this study, a specific and unique group of participants was required, i.e. participants who had shown interest in personalising a 3D object through the use of AM-enabled tools and 3D printing. Several other criteria were also used during selection, i.e. (i) participants who were representative of non-expert users who had little or no formal experience in designing or using 3D printing software and hardware, (ii) participants who were not professionally trained or practicing industrial/product design in their full time career and (iii) participants who are aged between 18 and 60 years old.

There were several limitations imposed on the experiment. The personalised 3D designs were to be printed through service bureaus and due to budget limitations, the cost of printing all of the final 3D printed products had to be within an overall allocated budget of £500. This, together with the use of purposive sampling yielded a sample size of ten participants.

Different types of existing easy-to-use, web-based product personalisation toolkits such as Project Shapeshifter, Tinkercad, CellCycle and 123D Design were used. Web-based toolkits were selected because they provided easy access for the participants through the internet. A Loughborough Design School-developed Lampshade Customisation Toolkit was also used in this study [25]. Three product categories in the consumer product market were selected – Household Goods, Jewellery and Gadget. The rational for choosing these product categories was that they constitute a large part of the personalised product market currently being addressed by the 3D printing community [63].

The criteria for choosing products to be tested were (i) the products must be able to be made using a 3D printing process; (ii) the 3D modelling designs must be able to be physically or parametrically modified by participants using existing AM-enabled design toolkits we used in the experiments; (iii) the cost of all 3D printing must be within budget limitation. Therefore, the products chosen had limitations on sizes and material types. Participants were invited through posters placed in strategic areas within Loughborough. Personal invitations were also sent through email to various groups and individuals from the authors' personal contacts and social media networks. Participants had to reply to the advert if they showed interest by making contact through the information given in the advertisement. Ten participants (n=10; 6 males, 4 females) who met the aforementioned criteria were selected. Participants attended two different sessions, (i) the product personalisation activity, and (ii) product assessment and evaluation. The participants were required to complete a questionnaire at the end of each session. A descriptive statistical analysis was conducted to analyse their responses.

In the first session, each participant was firstly thanked for his or her willingness to participate in the study. Participants were briefly informed about the flow of the experiment, the background of 3D printing, and the limitations of the study. They were then presented with the list of recommended products to choose from.

Each participant was asked to undertake a product personalisation activity using a designated easy-to-use web-based design toolkit as mentioned earlier. The selection of the toolkit was based on the type of product they wanted to personalise. Then, participants were briefly informed about the toolkit they had to use, regarding the interface and functional buttons that related to the toolkit.

Participants were given around 10 minutes to get used to the toolkit's user interface. Once they were ready, they were allowed to personalise the object until they were satisfied with the design. The first session took approximately 45 minutes to finish, although there were some participants who took more time to create their own design. Each participant produced one personalised design.

Every design was analysed by the authors using the Shapeways 3D Tool (for 3D printing manufacturability) and Autodesk Inventor CAD software (to analyse geometrical characteristics) to ensure its manufacturability with the chosen 3D printing method; in this case laser sintering (LS).

Participants were informed if a modification to their personalised design was needed. Any changes made to the 3D models were at a minimum level and did not affect the basic form of the personalised 3D model. The printing process and product delivery typically took between 10 and 15 working days. Participants were informed when the 3D printed personalised design was ready to be viewed. Table 2 shows the list of products personalised by participants.

In the second session, the 3D printed personalised products were presented to the participants. They were also provided with a comparable standard mass-produced design that had similarity in materials, design, patterns, surface finish, sizes and price. Participants were also told about the price of both standard designs and the 3D personalised design so that they could make a comparison between those two designs. The second session took approximately 15 minutes to complete. Figure 1 shows some examples of the final personalised products.

Table 2. List of products personalised by participants

		Category	**Personalised products**	**Software applications**
No. of participants	1	Household goods	Lampshade	Lampshade Customisation Toolkit
	2		Fruit plate	Project Shapeshifter
	3		Vase	
	4		Vase	
	5	Jewellery	Ring	CellCycle
	6		Bangle	
	7		Bracelet	
	8		Cuff bracelet	
	9	Gadget	Raspberry Pi case	123D Design
	10		Refuse Sack holder	

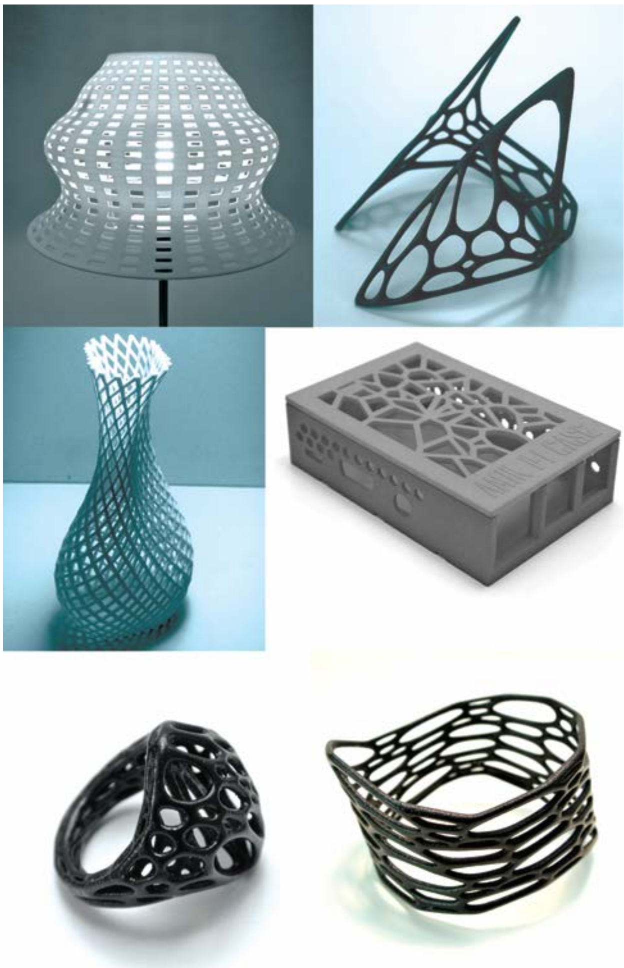

Figure 1. Examples of 3D printed personalised products designed by participants

5. RESULTS AND FINDINGS

5.1 **Experiential Value**

During the first session, the participants' opinions about their interaction with the personalisation process were evaluated. After finishing the personalisation process, the participants completed a questionnaire to provide feedback concerning their experience and reaction to the stimuli they received. Data was obtained about the participants' feedback on the types of design attributes and co-design activities they considered during the interaction process, as well as the type of hedonic experience they encountered during the process. Participants are allowed to select more than one answer from set choices to enable them to provide responses that related to their feelings and experience during the activities. Positive results were shown by high number of responses and negative results were shown by either low ranking or omissions from the choices.

5.1.1 *Design attributes*

Participants were asked about the types of design attributes they had considered during the personalisation process. In these questions, participants were able to select several answers that they thought were appropriate, based on their experience. The results are shown in Figure 2.

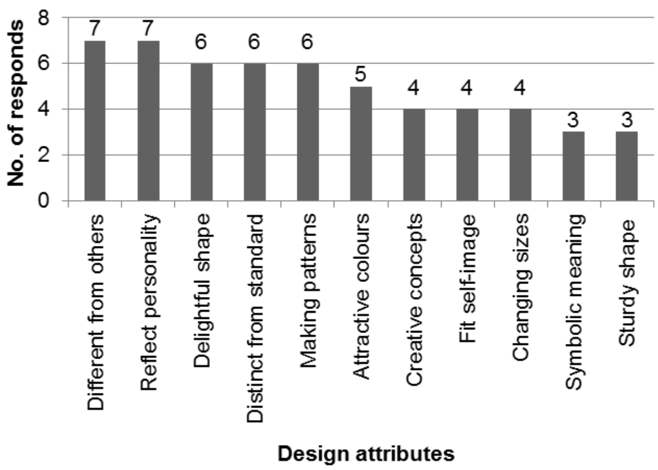

Figure 2. Design attributes considered during personalisation process

Figure 2 reveals that most design attributes were considered by several participants during the personalisation process. The two attributes that scored highest show that participants were looking for features that would differentiate the product from others. This response suggests that participants were looking to design a product that could be considered as having its own unique appearance, one that reflected their own personality. Figure 2 also reveals that participants also looked for a pleasant product with delightful shapes and patterns that could improve the appearance of the product.

5.1.2 *Co-design activities*

Participants were asked about the co-design activities that they considered when they interacted with the product during the personalisation process. Participants were able to select several answers that they thought were appropriate. Figure 3 shows the types of co-design activities that were considered by participants during the personalisation process.

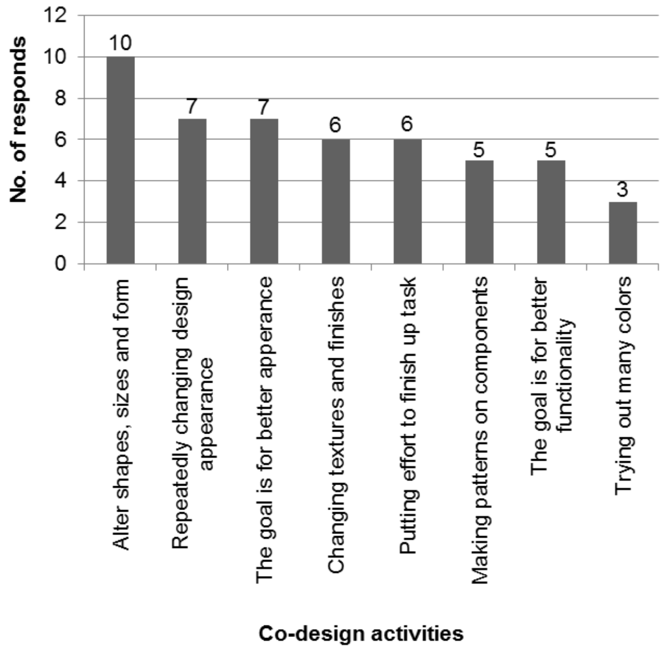

Figure 3. Types of co-design activities considered during the personalisation process

Figure 5 shows that the participants considered various attributes during their interaction with the product. It is seen that all 10 participants were actively involved in altering the shape and form of the product, and tailoring it to the right size based on their preferences. It was also noted from observation that they repeatedly changed the component's design to improve its appearance according to their desires.
Figure 3 also reveals that the participants' goal of the personalisation activity was mainly to enhance their product's appearance rather than its functionality. The responses shown in Figure 3, suggest that participants were able to interact with objects in a positive way. They tried to actively participate in the design process by involving themselves in various types of co-design activities. By playing an active role in the co-design process, they were able to generate design ideas and create new design concepts. Through this activity, it has become evident that the participants were able to complete the task, design products and give expression to their own creativity.

5.1.3 *Hedonic elements*

To measure whether participants had developed any emotional relationship during the personalisation process they were asked about their sense of enjoyment and being entertained. Participants were able to select several answers that they thought were appropriate. Figure 4 shows the types of hedonic elements that were involved during the personalisation process.

Figure 4 below shows that participants enjoyed the co-design activities. Participants also felt that it was fun to create their own design. Product personalisation was also able to fulfil their design imagination, and equally important was that the personalisation process was perceived as an enjoyable activity. Through this feedback, it can be seen that product personalisation can elicit a sensation of enjoyment and pleasure that reflects the entertainment aspect and emotional worth of the activities. Product personalisation can be seen as one way to enable end-users to fulfil their creative desires as the activity offers almost unlimited design possibilities to be explored by the end-users.

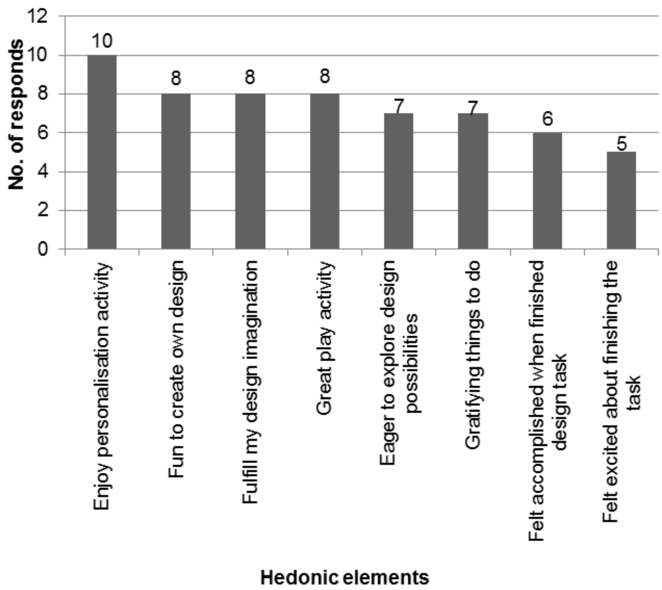

Figure 4. Types of hedonic elements involved during the personalisation process

From the experiential aspect, enjoying the personalisation process is seen as an equally important aspect of adding value to 3D printed products. It is a process where end-users get involved in an emotional relationship when they participate in self-design activities. It has been suggested that software developers and designers who intend to develop AM-enabled personalisation toolkits have to make sure the toolkits offer a high quality of interactive experience to end-users [64]. It is paramount for end-users to enjoy the personalisation experience in order to obtain high hedonic value from the interaction regardless of the resulting product.

5.2 **Product Value**

In the second session, each participant was presented with his or her 3D printed product. Besides the 3D printed personalised product, they were also provided with a comparable standard mass-produced product, so that they could make a comparison between the two designs. Participants completed a questionnaire to gain their feedback concerning the value of the personalised product facilitated through AM. The purpose was to find out their opinion on the value of the 3D printed personalised product they had created from both emotional and monetary viewpoints. To achieve this purpose, data was obtained on the participants' feedback about the types personalisation attributes that they thought had contributed to the added value of the 3D printed personalised products. They also indicated their perceived value of their own 3D printed personalised product and their willingness to pay for such a product. Participants were able to express their opinion based on their evaluation on the personalised product and its comparison with an existing standard mass-produced design.

5.2.1 *Personalisation attributes*

In the questionnaire, participants were asked about the types of personalisation attributes that had contributed to the added value of the3D printed personalised products. They were asked to score each of the attributes using a Likert scale of 1 to 5, where 1 was “Very Little” and 5 was “Very Much”. The scores were averaged across all participants and the results are shown in Figure 5.

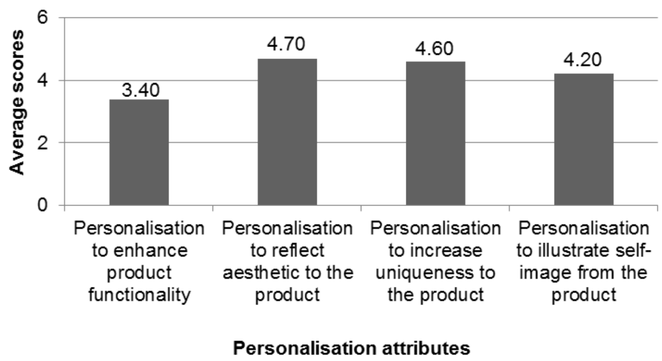

Figure 5. Personalisation attributes and their contribution to the added value of 3D printed personalised products

Based on the results shown in Figure 5, it seems that participants think that all the attributes are important as reflected in the high average scores. Personalisation to reflect beauty and aesthetic features of the product gained the highest average score of 4.70, closely followed by personalisation to increase uniqueness of the product at 4.60. Participants indicated that personalisation to enhance product functionality was least important with an average score of 3.40.

This suggests that although 3D printing can be used to support several aspects of product personalisation, participants are more interested in product appearance and uniqueness rather than functionality. This can be achieved by allowing them to choose their own materials, colours, personalised patterns and product shape. This high concentration on aesthetic attributes, means it is possible to achieve a high degree of uniqueness with a relatively small differentiation of design features compared to the standard product [42]. The uniqueness of a 3D printed product gives end-users an opportunity to feel different from others as well as attracting more attention through the creation of creative shapes, beautiful colours, attractive materials, and impressive surface finish [34].

5.2.2 *Participants' Perceived Value for 3D printed personalised products*

Participants were asked to make a comparison between the standard product design and the 3D printed personalised design in order to measure their perceived value for the products. They were asked to rate their opinion of four aspects based on a measurement scale of 1 to 5. The average results across all 10 participants are shown in Figure 6.

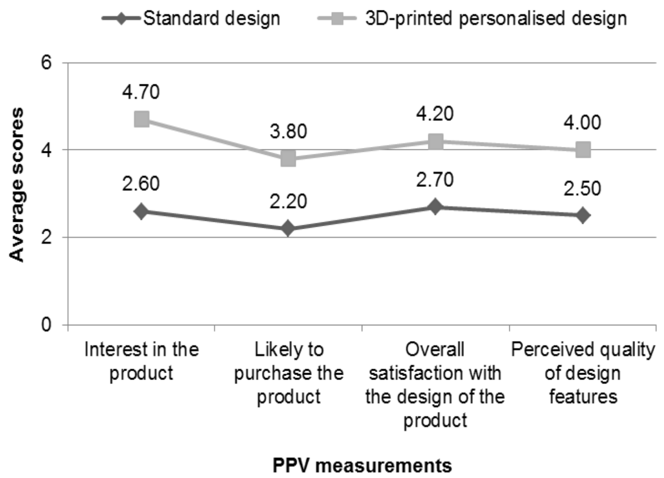

Figure 6. Comparison of Participants' Perceived Value (PPV) between Standard Design and 3D printed Personalised Design

Overall, the results show that participants gave higher average scores for all Participants Perceived Value (PPV) measurements for the personalised products. The largest difference between the standard and personalised products was for "interest in the product" where the personalised product score was 80.8% higher. Participants also gave high average scores for "overall satisfaction" and "perceived quality of design features". Participants gave the lowest score for both designs to "likely to purchase" with the personalised product scoring over 70% higher than the standard product. Based on the results, it can be said that participants definitely had a higher opinion of 3D printed personalised products compared to their standard mass-production counterparts. This indicates that AM technology is able to assist in providing higher added value to the personalised designs.

5.2.3 *Measuring participants' willingness to pay*

The value of product personalisation was also measured through the end-users' willingness to pay (WTP) for the product [40]. During the session, participants made a physical comparison between the standard products and the personalised products. They were then asked how much they would be prepared to pay for the personalised products. In order to have a valid measurement, standard products were selected that were similar to the personalised counterparts in terms of materials, sizes, design, patterns, surface finish and price. Participants were asked how much more they would be prepared to pay for their personalised product compared to the price of the standard product. The difference between the production cost (including shipping) and the participants' WTP price yielded the value increment or decrement for each product (ΔWTP). Results for WTP measurement are shown in Figure 7, averaged for the three categories of the tested products.

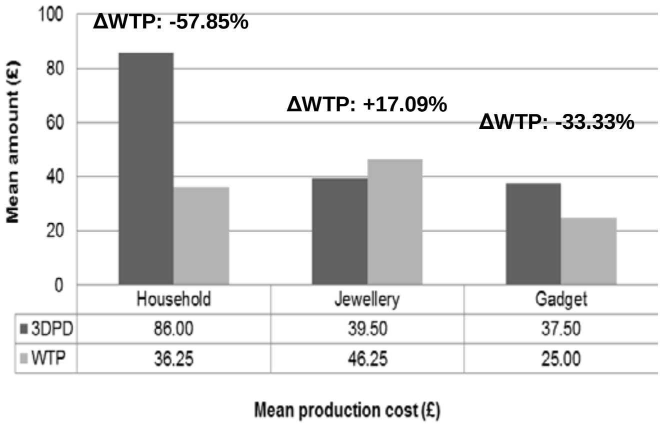

Figure 7. Comparison between production cost of 3D printed Personalised Design (3DPD) and participants' Willingness To Pay (WTP)

As can be seen in Figure 7, only the Jewellery category indicated a value increment with an added value of 17.09%. The mean participants' WTP was £46.25, while the mean production cost for the 3D printed products was £39.50. This indicates that participants were willing to pay an average of £6.75 more than the production cost. However, the other two categories, Household Goods and Gadgets both show significant negative values of -57.85% and -33.33% respectively. This indicates that in the Household Goods and Gadgets categories, the increased perceived value for the personalised products was not enough to justify the increased 3D printing production costs.

5.3 **The Key Value of 3D Printed Personalised Products**

To assess the key value drivers for 3D printed personalised products, participants were asked to rate their opinion of various statements. These statements explained the characteristics of product personalisation that are facilitated by AM technology and were based on the value components that were developed in the value taxonomy. By using a Likert scale, participants could express their opinions by rating the statement from "Strongly disagree" to "Strongly agree" (1-5 rating). The results indicated how strongly each value component contributed to the overall increase in value associated with product personalisation (see Figure 8).

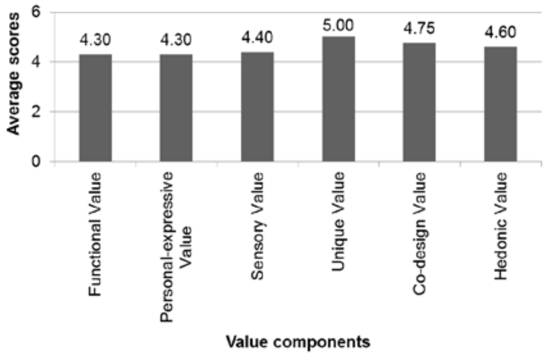

Figure 8. Value components of Product Personalisation fabricated through AM/3D printing technology

In general, the results show that participants gave high average scores to all the value components. This indicates that participants regarded all the value drivers as being important. Unique Value is seen to have highest average score of 5.00, closely followed by Co-design Value at 4.75 and Hedonic Value at 4.60.

From the viewpoint of Product Value, the results suggested that personalised features designed by participants using AM-enabled tools and systems are able to provide additional unique value to end-users. This is supported by the ability of AM to produce highly complex forms, its flexibility for part fabrication and its ability to provide specific design features according to end-users' desires. This resulted in the creation of product differentiation, i.e. not looking like anyone else's product and being exclusive to an individual. These personalised attributes cannot always be sufficiently supported by traditional manufacturing systems. Even if they could, end-users would not receive the product in such a short period of time. In addition, through traditional manufacturing, the more complicated the object, the more it costs to make [65]. The achievement of high unique value also correlates with the key motivation of product personalisation, i.e. to acquire distinct design features by producing bespoke products that are tailored to end-user's specific needs.

The results also indicated that participation in the co-creation process of product personalisation through AM is also able to provide high Experiential Value to end-users. This is due to the ability of AM-enabled tools and systems to allow end-users to participate in the design process. This is in contrast to the traditional design process, where amalgamated end-user requirements are translated by a designer into a single product. Thus, it is difficult for end-users to convey their design ideas into the product.

High Experiential Value can only be obtained when end-users play an active co-creating role throughout the personalisation process through asserting their skills in making the designs using their own hands [66]. From the opportunity to co-design the products, end-users could derive enjoyment from their active participation during the personalisation process. Supporting mechanisms such as AM-enabled design toolkits must be able to achieve high hedonic value by making the personalisation process an enjoyable activity able to fulfil users' creative imaginations.

6. CONCLUSION

This study has attempted to shed light on end-users' perceived value of a consumer product design being personalised and fabricated using AM technology. It has done this by examining the definitions, concept and measures relevant to value in the context of consumer product design. Based on the results obtained, it can be concluded that through end-users' involvement in personalising a consumer product through AM-enabled tools and mechanisms, they were able to acquire additional value by producing a bespoke product that was tailored to their individual preferences and no one else's. The additional value was in the form of the personalisation experience and product benefits to the end-users.

The importance from this study is that end-users who took the opportunity to be involved in product personalisation using AM technology enabled them to develop alternatives to the standard mass-production designs. Under these circumstances, end-users are able to reproduce a bespoke product that is tailored to their personal needs. Products with personalised design features provide a combination of additional attributes from the basic design. Consequently, end-users will gain extra benefits from it and contribute to higher product value.

Although the authors recognise that other manufacturing processes are available, this study showed that AM is a key tool for producing unique designs because of its exclusive capabilities to produced complex design features without a need for tooling. Supported by AM-enabled design toolkits and suitable materials, personalised AM products can bring "freedom of expression" to end-users by creating physically exciting products and this enables them to enjoy a positive co-design experience that embodies personal taste and style [25]. This could encourage end-users to be more involved in the self-design process and gain the benefits from individual designs as well as taking advantage of AM technology. Based on the proposed value taxonomy, it was apparent that end-users can identify which types of value aspects they want to add depending on the purposes and types of product they personalise.

A major limitation found from the study was that fabricating a product using AM technology requires a higher financial investment from users. The study showed that end-users were not willing to pay very much more for a personalised AM product compared to a mass-produced product. Therefore, although personalisation added value in two out of three product categories, the extra amount they were willing to pay was not enough to cover the extra cost of 3D printing. It will be necessary for system providers and service bureaus to reduce costs to stay within the extra willingness to pay price if 3D printed personalised products are to become popular. This might be addressed as the quality of AM parts approaches the quality of familiar mass-produced items.

It is also recognised that a wider scale experiment would be beneficial to enhance the results of this study. This study is explorative in nature; involved a small sample and was limited by the relatively high cost of producing 3D printing parts. However, it has achieved something new and hopefully these exploratory experiments will prove valuable in paving the way for larger scale trials in the future.

The lessons learnt from this study will pave the way for the development of an added value identification methodology for product designers. It will enable them to identify the design features in a product that will potentially add value if the product were to be personalised and fabricated using AM. It will act as a design support tool to aid designers in providing value adding "personalisation features" in order to satisfy end-users' individual needs.

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Korisnikov doživljaj vrednosti samostalno dizajniranog personalizovanog proizvoda kreiranog korišćenjem aditivne proizvodnje

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Apstrakt

Kako krajnji korisnici postaju sve više uključeni u personalizovani dizajn, aditivna proizvodnja (AP takođe poznata kao 3D štampa) postaje alat koji omogućava realizaciju ove usluge kroz manipulaciju trodimenzionalnog dizajniranja korišćenjem alata koji su jednostavni za upotrebu. Shodno tome, krajnji korisnici mogu da osmišljavaju personalizovani dizajn koriščenjem različitih AP sistema. Ovaj rad koristi eksperimentalni metod da istraži kako krajnji korisnici doživljavaju vrednost personalizovanih proizvoda kreiranih korišćenjem 3D štampe na osnovu vrednosti proizvoda i iskustvene vrednosti. Rezultati pokazuju da su krajnji korisnici dali veću vrednost personalizovanim proizvodima kreiranim korišćenjem 3D štampe po svim vrednovanim kriterijumima. To ukazuje da proizvodi kreirani korišćenjem 3D štampe povećavaju utisak dodatne vrednosti u poređenju sa standardnim masovno proizvedenim proizvodima.

Ključne reči: *Aditivna proizvodnja, uključivanje krajnjih korisnika, doživljaj vrednosti, personalizacija proizvoda*