Validation of design support tool to aid industrial designers in the development of an AM-enabled personalisable product designs

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Keywords: design support tool; product personalization; additive manufacturing

ABSTRACT – This paper presents the validation of the *Value-added AM-enabled Personalised Product* (V+APP) *Design Method*, which was achieved by exposing the design workbook to expert designers and asking them to evaluate its usability, applicability and effectiveness. The aim of the validation is to determine the validity of the proposed method from industrial designers about its impact on professional design practice. Focus groups were identified with strategic samples of professional designers to gather an in-depth understanding of the issue. Based on the results, the study revealed that knowledge management and decision aid tools that adapted to the specificities of AM play an essential role in creating value-adding design features to personalisable AM products. It is vital for industrial designers to adopt AM knowledge in the early design process so that they are able to fully exploit the unique and value-added design characteristics enabled by AM.

1. INTRODUCTION

Additive Manufacturing (AM) technology is well known to have enormous potential for the personalisation of consumer product designs. This ability has generated public interest in using AM as a personal fabrication tool to produce personalised 3D-printed parts. Previous study shows that personalised consumer products using AM-enabled design tool and system are able to provide higher end-users' perceived value when compared with standard mass-produced products [1].

From an industrial design perspective, a simultaneous product and process design method is needed to assist expert designers in defining and exploring the design possibilities enabled by AM [2]. Establishing creative design decisions in the early stages of product development is one of the strategic approaches that enables efficient process-based design and provides better design direction for designers [3]. To demonstrate the design strategy, the development of design methods, tools, and activities has to be adapted to the specificities of AM [4].

A formal design aid tool to assist designers in finding the best way to achieve high value for 'personalisable' product designs has been developed. The development of the design aid tool is focused on the Product Value standpoint [1]. It was aimed at helping designers come up with the ideas and solutions for identifying personalisable design attributes that best utilise the unique capabilities of AM. It also provide guidance to designers on how to maximise the added value of the product through the amalgamations of shapes, forms, patterns, structures, and material compositions [5]. The added value identification method was given the name *Value-added AM-enabled Personalised Product* (V+APP) *Design Method* (*V+APP Design Method*).

The implementation of the proposed method in the form of a design workbook provides the opportunity to evaluate its potential impact on a designer's work when developing a personalisable product design. The *V+APP Design Method: Design Workbook* was created based on the structural and the procedural aspects of the *V+APP Design Method*. The main section of the workbook contains design questions and guidance that stimulate designers to adopt AM benefits and values at every design phase of product development. This would help designers to efficiently identify and generate possible design features that could enhance the value of the personalisable product.

The study aims to seek validation of the *V+APP Design Method*, which was achieved by exposing the design workbook to expert designers and asking them to evaluate its *usability* – the ease of use of the tool, *applicability* – the suitability of the proposed method for the development of high value AM-enabled personalised products, and effectiveness – the ability of the design aid tool to achieve the objectives of the proposed design method.

2. RESEARCH METHODOLOGY

Ten professional industrial designers with AM-related expertise and experience in designing 3D-printed product designs that suitable for personalisation participated in the study. The characteristics of the participants ranged in levels of expertise from novice to intermediate and advanced. These characteristics determined their exposure to the skills and understanding about AM in designing consumer products for personalisation.

Participants were involved in a session containing two parts of the study: (i) performing the test on the *V+APP Design Method: Design Workbook*, and (ii) assessment and evaluation through a set of questionnaires. They were asked to go through the design workbook and follow the flow of the workbook step-by-step. They were encouraged to go through all the design questions in the workbook as if they were answering them for a product they had previously designed and were now trying to make personalisable. They could use

the *design guidance* provided in the workbook as 'design hints' as well as their experience and knowledge in designing 3D-printed products to answer the design questions. Participants were also asked to use *design notes* and the additional empty pages provided to record any design decisions they made. Therefore, they could document their decisions and choices as they progressed.

Once they had completed the design workbook, they then need to evaluate the workbook by completing a questionnaire to gain their feedback. Participants were asked to express their opinion on the usability, applicability and effectiveness of the proposed method and tool.

3. RESULTS AND DISCUSSION

3.1 Assessing the Usability of the Design Aid Tool

This section aimed to assess the usability of the design aid tool, where the measurement was based on five statements. Participants were asked to indicate their agreement or disagreement on the Likert scale. The responses were collated for all five statements and the results are shown in Table 3.1.

Table 3.1 Participants' Responses on the Usability of *V+APP Design Method: Design Workbook*

Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S1. The textual and graphic information provided in the design workbook is easy to understand.	0	0	3	4	3
S2. Overall contents provided in the V+APP Design Method was well integrated.	0	0	4	2	4
S3. I would imagine that most designers would learn to use this method very quickly.	1	0	3	2	4
S4. The presentation of the Design Workbook is attractive to the user.	0	0	2	4	4
S5. The Design Workbook is useful for recording my design outputs.	0	2	2	3	3
Total responses	**1**	**2**	**14**	**15**	**18**
Total responses (%)	**2**	**4**	**28**	**30**	**36**

Overall, the results in Table 3.1 reveal that the participants mostly agreed with the statements given in the questionnaire, with 33 out of 50 responses indicating Agree or Strongly Agree (66%).

This result shows that participants regarded the design workbook as both usable and easy to use. Based on the results, the statement 'the presentation of the Design Workbook is attractive to the user' received the highest responses of 8 (Agree and Strongly Agree), closely followed by 'the textual and graphic information provided in the design workbook is easy to understand' with the total number of agreed at 7. Apart from several neutral responses and 1 strongly disagree, most of the participants thought that the overall content of the workbook was well integrated and able to be learned very quickly. Most participants also agreed that the workbook is useful for recording their outputs, despite some participants indicating disagree and neutral responses.

These results suggest that the key feature needed to allow the design workbook to be usable is that it should provide instant access to information. Furthermore, the presentation of the workbook should also be simple, attractive and visually inspiring because the graphic representation of process-enabled information is one of the most effective ways to transfer knowledge to industrial designers.

3.2 Assessing the Applicability of the Design Aid Tool

This section aimed to assess the applicability of the design aid tool. Participants were asked to indicate their agreement or disagreement using the Likert based on four attributes. The responses to all four statements were collated and presented in the Table 3.2.

Table 3.2 Participants' Responses on the Applicability of *V+APP Design Method: Design Workbook*

Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S1. I felt confident in applying the V+APP Design Method to my selected design task.	0	1	3	3	3
S2. The contents provided in the V+APP Design Method is relevant to the personalisable product design.	0	0	2	2	6
S3. The organisation of information in the V+APP Design Method is suitable for practical implementation.	0	1	3	2	4
S4. The V+APP Design Method was able to assist me in preparing design inputs and interpreting design outputs in a more organised way.	0	0	3	3	4
Total responses	**0**	**2**	**11**	**10**	**17**
Total responses (%)	**0**	**5**	**27.5**	**25**	**42.5**

Table 3.2 shows that most of the participants considered that all the measured attributes are important, with 27 out of 40 responses being Agree or Strongly Agree (67.5%). These results indicated that the *V+APP Design Method: Design Workbook* is applicable and suitable for practical implementation.

As seen in Table 3.2, most of the participants indicated that they agreed or strongly agreed that the content provided in the workbook is relevant to the development of personalisable AM products (8 responses). This is followed by the statement 'the *V+APP Design Method: Design Workbook* was able to assist me in preparing design inputs and interpreting design outputs in a more organised way', which received a total number of 7 responses for agree and strongly agree. Despite some

participants indicating disagree (1 response) and neutral responses (3 responses), most participants agreed with the statements 'the organisation of information in the workbook is suitable for practical implementation', as well as 'I felt confident in applying the *V+APP Design Metho*d to my selected design task'. Overall, the results suggest that the workbook provides a practical approach for applying AM knowledge in the development of personalisable product designs.

3.3 Assessing the Effectiveness of the Design Aid Tool

This section aimed to assess the effectiveness of the design aid tool. Participants were asked to indicate their agreement or disagreement using the Likert scale and Table 3.3 shows a collation of all the results.

Table 3.3 Participants' Responses on the Effectiveness of *V+APP Design Method: Design Workbook*

Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S1. The V+APP Design Method has a clear objective that can be easily achieved.	0	0	3	1	6
S2. The V+APP Design Method was able to help me develop a personalisable 3D-printed product design in a more systematic way than a generic design process.	0	1	2	3	4
S3. The questions in the *design challenge* were able to assist me in identifying potential design features that could enhance the value of personalisable AM products.	0	0	2	3	5
S4. The V+APP Design Method can assist designers to develop specialised design skills by applying AM value and knowledge in designing personalisable product designs.	0	0	3	3	4
Total responses	0	1	10	10	19
Total responses (%)	0	2.5	25	25	47.5

As can be seen in Table 3.3, most participants gave positive responses to the measured attributes. Overall, 72.5% (29 out of 40) of the responses indicated that participants agreed that the design workbook was effective to aid designers developing personalisable AM products.

Based on the table, most participants indicated that the workbook has clear objectives that can be easily achieved, which gained 6 responses on Strongly Agree. The statement 'the questions in the *design challenge* were able to assist me in identifying potential design features that could enhance the value of personalisable AM products' achieved a high number of positive responses (8 Agree or Strongly Agree). Participants also gave positive responses on the statement 'the V+APP Design Method was able to assist designers to develop specialised design skills by applying AM value and knowledge in designing personalisable product designs', which gained a total number of 7 Agree or Strongly Agree. With the exception of 1 Disagree and 2 Neutral responses, the majority of the participants felt that the workbook was able to assist designers in developing a personalisable 3D-printed product design in a more systematic way, when compared to a generic design process.

These results indicate that the AM design aid tool should be effective in supporting designers when adapting the knowledge and benefits of AM into the design process. Such a design aid tool should also integrate systematic design hints to stimulate the designer's cognitive thinking to efficiently identify high-value design features in a product.

4. SUMMARY

In conclusion, the study has revealed the critical role of a formal added value identification method in aiding expert designers in identifying the potential value-added personalisation features in AM products. It is crucial for designers to adopt AM knowledge in the early design process so that they can fully exploit the unique characteristics and design possibilities enabled by AM. A well-focused interrogative design question posed to designers at every design phase is the most suitable way to stimulate a designer's creative thinking to identify good solutions for creating high-value personalisable AM products. It can be concluded that the *V+APP Design Method: Design Workbook* is applicable for practical implementation and is an effective instrument that enables value-added personalised AM product information to be presented to industrial designers.

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