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Increasing product attachment through personalised design of additively manufactured products

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INCREASING PRODUCT ATTACHMENT THROUGH PERSONALISED DESIGN OF ADDITIVELY MANUFACTURED PRODUCTS

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Abstract

The research reported in this paper has demonstrated that emerging digital technologies are offering new methods for designers to work with end users to help them create personalised products. Additive manufacturing provides a manufacturing process that is capable of producing virtually any geometry with little or no cost and time differentials. The most difficult part of the process is the CAD modelling effort required to create highly complex personalised shapes. Conventional CAD struggles to support the user creativity required whereas the advent of Virtual Clay modelling seems to offer some potential in this area. Overall, the combined use of co-design and additive manufacturing results in an exciting new environment for creative designers and users to work together. They can work in a digital medium that mimics the flexibility of 3D physical modelling and yet offers the speed, repeatability and cost benefits of automated production. The increased emotional bonding that users have with personalised products has been shown to be a potential source of greater product usage life and hence improved sustainability.

Keywords: Additive Manufacturing, Participatory design, Emotional design, Product attachment, Computer Aided Design (CAD)

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1 INTRODUCTION

Over the past decade, additive manufacturing (AM) technologies (e.g. laser sintering, fused deposition modelling, selective laser melting) have been used increasingly to produce final components and products rather than just prototypes (Caffrey et al, 2016). When used in this way, it is no longer their ability to rapidly produce physical objects from computer-aided design (CAD) data that is of most benefit, but rather their ability to produce complex shapes without any requirement for production tooling (Hague et al, 2003). Examples of products that have been successfully produced using AM include custom design hearing aids, racing car parts, military aircraft parts and International Space Station parts (Hopkinson et al, 2005). In each of these cases, there has been a particular "value-adding" improvement to the product that has justified the relatively high cost of using AM. Value has most typically been added through the ability to custom fit to unique human anatomy, a radical reduction in parts count and assembly costs, reduction in product weight, and the economic production of small batch sizes (Campbell et al, 2013). In the context of the work presented in this paper, the value-adding effect of creating a personalised product design was of most interest.

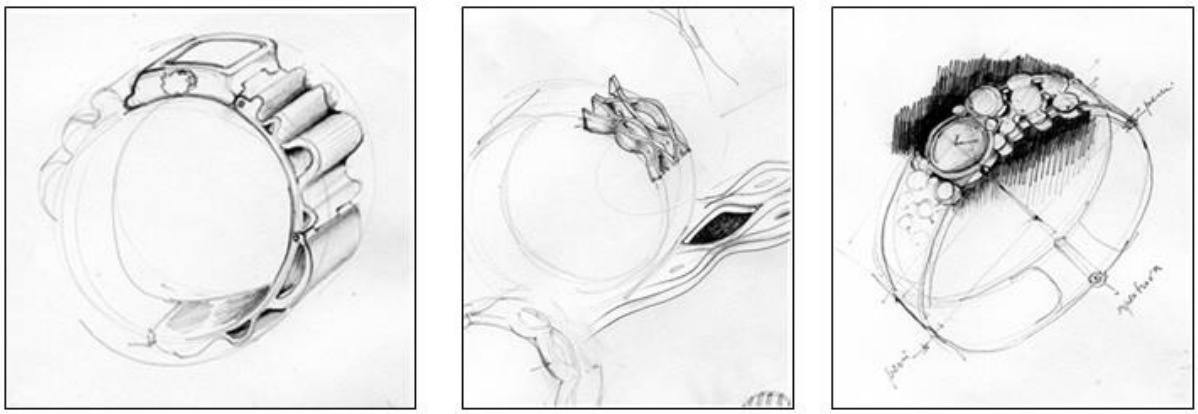
This research originated from inter-disciplinary collaboration at Loughborough University between the Additive Manufacturing Research Group (AMRG), the School of the Arts (SotA), and Loughborough Design School (LDS). Each of these brought their own area of expertise to the research project. AMRG has a long history in the field of direct manufacturing of final components using AM-based technologies. SotA has an established track record of innovation across a range of art and design disciplines including Silversmithing and Jewellery. Recent research within LDS has focused upon bridging the divide between designers and users through the use of digital design technologies. Therefore, LDS was in an ideal position to take the creative designs originating from SotA and convert them to a computer-friendly format for production in the AM facilities at AMRG. Additional expertise in haptic modelling as a way of generating creative designs directly within a digital format was provided by Dr Bahar Sener, now at the University of Liverpool.

The research presented here was part of a project aimed at demonstrating the capability of applying AM techniques to the production of customised products. Jewellery, and in particular watch design, was selected as an area were the ability to personalise products through AM could be used to give added value to the customer. A crucial element of this was thought to be the ability to tailor the watch design to the individual wrist geometry of the customer. The paper begins by discussing the design concepts that were generated and how these evolved into several different product designs. It goes on to describe the process chain that was followed to take these designs through to manufacture and concludes by highlighting the increased product attachment obtained, current limitations and future possibilities that exist.

2 DESIGN CONCEPTS

The increasing opportunities for personalising many products such as mobile phones, trainers, and jeans has led to an acceptance that individual consumer choices must be incorporated into formerly mass produced objects; a process first defined as mass customisation by Tseng and Jiao (2001). However, it is questionable as to whether there is such a broad range of options available to the watch buyer. In fact, until recently the personalised watch was considered a rarity, and a particularly expensive one at that. The options for any bespoke purchaser were limited to variations in style, dimensions, materials and thereafter an inscription. More recently, a potential watch customer can select from a vast range of different cases, faces, straps, buckles, and hands of differing materials, colours, and shapes. Yet, whilst these choices all relate to the fundamental aspects of a watch's design there are developments that move beyond the aforementioned fundamentals. Consider for example, the possibility to have an existing old gold watch restyled or alternatively having a personal photograph transferred onto the watch face. Nonetheless, these options would still oblige the customer to conform to the standard range of modular elements offered by any given company. Therefore, it is unlikely they will be able to purchase a genuinely personalised watch that could not be sold to another person without losing its integrity. Today, the situation is somewhat different and the possibilities for innovative personalisation are expanding (Hu, 2013). This is primarily due to two factors; firstly the advances in AM technology that have enabled complex durable parts to be produced at reduced per-unit cost, and secondly, the fact that the watch has,

in many circumstances, become regarded as a fashion accessory to be matched with an outfit rather than just a stand-alone functional object.
The proposed developments detailed in this paper sought to explore this possibility by creating watch designs that were genuinely personalised because they were unique to one individual. All of the proposed designs for the watchstraps were underpinned by the reproduction of the geometry of each customer's wrist. This idea originated from the desire to create a second skin for each customer. It was achieved by tailoring the watchstrap according to the geometry of the customer's wrist. This would result in a perfectly fitting product that was snug to wear, and therefore would not move around on the wrist during motion, as some watches often do. In order to offer the highest level of comfort to the wearer each strap had to be sufficiently flexible and lightweight in its manufacture to permit supple wrist movement and to allow evaporation of perspiration.
To reinforce the uniqueness of the concept, methods were sought to make the shape of each watchstrap unique for a particular customer. One idea was to incorporate geometry into the design that represented the genes of a specific customer. Genes are composed of DNA that provides the instructions for inheritance passed from parent to child through the generations. So the incorporation of DNA-based geometry into the strap could, in principle, introduce unique biometric data into the watch design. A number of designs were proposed for both men's and women's watchstraps, each one inspired by the structure of DNA, known as the "Double Helix". However, none of the designs actually incorporated unique personal information, only a generic embodiment of what personalised DNA coding might bring to a design. The men's watch design resulted from an extrusion of the helixes' silhouette. Viewed from above, one can observe a fairly standard watch face surrounded by a sinuously undulating strap. However, when viewed from the side it more explicitly relates to the geometry of the helix (Figure 1a). The design of the women's watchstrap was defined by a more artistic interpretation of the helixes; one in which the geometry of the helix was revealed throughout the length of the strap as opposed to running perpendicular to it (Figure 1b). A third, more metaphorical, design evolution was applied to both men's and women's watchstraps by extrapolating an idealised structure for the chemical formula of DNA. It moved away from the rigidity of a real chemical formula towards a symbolic representation of the interconnectivity of atoms within the Double Helix (Figure 1c).



(a) *(b)* *(c)*

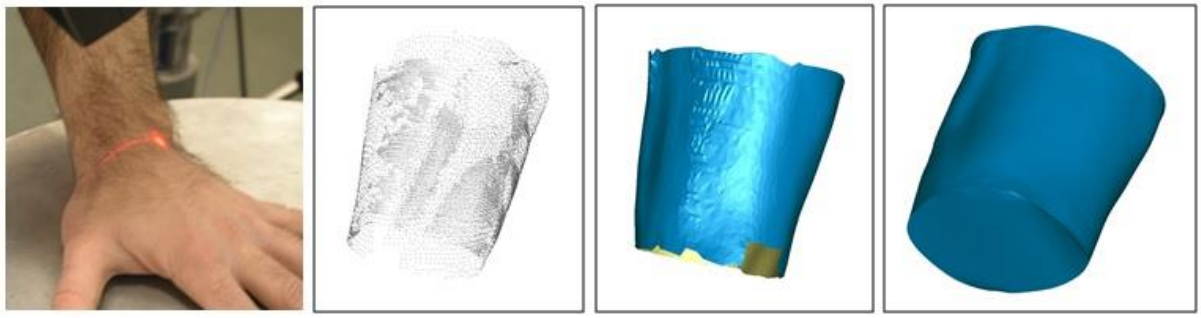
Figure 1. Concept designs for watch straps

In summary, what was significant about the proposed designs was the manner in which the customer-specific geometry of the underside of the watchstrap allows for the creation of a genuinely unique personalisation. This can, in turn, be further enhanced through an overall design for the watchstrap that reflects the customer's DNA.

3 FROM DESIGN TO MANUFACTURE

The ability to personalise the watch designs to individual wrist geometries was regarded as a unique capability of AM that warranted exploration. Therefore, before design for manufacture could begin, it was necessary to "capture" specific wrist geometries and use these to drive the CAD models required for AM. A technique commonly referred to as Reverse Engineering was used to achieve this. A three

dimensional laser scanning process (Figure 2a) was used to capture the geometry of one male and one female wrist. The raw data was filtered and processed to generate a "point cloud" of x,y,z co-ordinates (Figure 2b). This was then used to create an initial surface wrap model (Figure 2c) which, after further processing, enabled the generation of a triangular tessellation map following the STL format. Figure 2d shows the graphical representation of the final STL data for the male wrist that was scanned. The wrist geometry then acted as the starting point for two alternative digital modelling strategies, as discussed below.

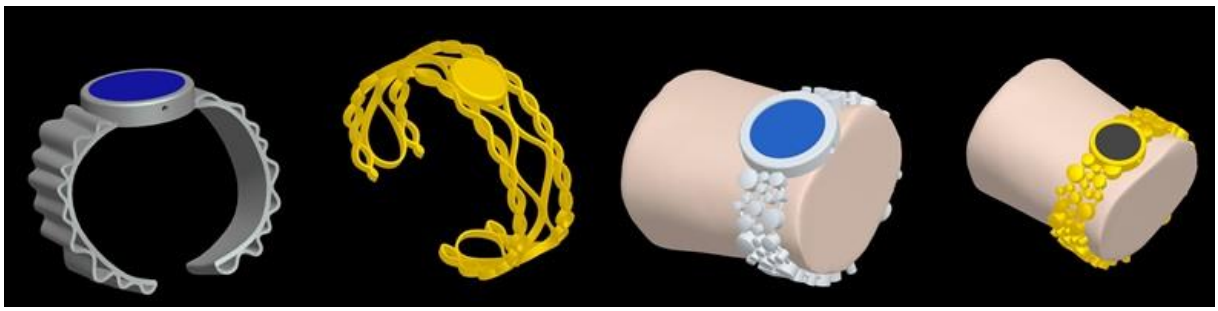


(a) *(b)* *(c)* *(d)*

Figure 2. Scanning and 3D data processing process

3.1 Strategy one: Conventional CAD solid modelling

Male and female STL wrist geometry was imported into the Pro/ENGINEER CAD system as an imported facet feature. Two parallel planes were used to cut through this feature to produce two sections through the wrist. Offset curves were created from these sections to act as guides for the creation of the strap base surface. These two stages were common to digital modelling of all three watchstrap designs. For the men's watchstrap design, the housing for the watch works was created as a revolved solid with a hole cut in it for the time setting dial. Next, the base surface was thickened to create a band that wrapped around most of the wrist. Two pairs of undulating curves were then sketched on the two section planes and ruled surfaces were created between them (one either side of the housing). Finally, these surfaces were thickened to create the finished watch model (Figure 3a). For the women's watchstrap design, an elliptical profile was used with the extrude feature to create the works housing. Undulating curves were then wrapped around the base surface and used with rectangular profiles to sweep several intertwining "DNA strands". Several alternative methods for creating the sweep features had to be attempted before Pro/ENGINEER was able to produce an error-free solution. Finally, the top edge of the housing was rounded to create the finished watch model (Figure 3b). For the unisex design, a random series of axes were created perpendicular to the base surface. These were then used to create revolved features to represent the atoms of the DNA structure. Once again, the housing for the watch works was created as a revolved solid with a hole cut in it for the time setting dial. Next, the interconnections between the "atoms" and the housing were created as a series of sweep features along curves projected onto an offset of the base surface. Once again, several alternative methods for creating the sweep features had to be attempted before Pro/ENGINEER was able to produce an error-free solution. Finally, the top edge of the housing was rounded to create the finished watch model. Both male and female versions were created following the same method (Figures 3c and 3d). All the design geometries were exported as STL files and built as prototype models using the laser sintering and the multi-jet printing AM processes (Figure 4). As can be seen, one of the prototypes was fitted with watch works to see what a completed product would look like.



(a) (b) (c) (d)

Figure 3. Renderings of CAD designs produced using Pro/ENGINEER



Figure 4. Models produced using laser sintering and multi-jet printing

3.2 Strategy two: Virtual clay voxel modelling

The second strategy made use of haptic modelling as a way of generating creative designs directly within a digital format, rather than converting a 2D manual sketch into a 3D CAD model. The previously scanned wrist geometry was imported in the form of an STL file into the FreeForm® Virtual Clay Modelling System V.9 paired with a PHANTOM® device. The geometry was used as a 'buck' (i.e. a fixed volume that serves as a reference when modelling) for the watchstrap to be built upon. Firstly, using the "Fit Curve" tool on the "Curves" palette, 3D design curves were created around the buck. It was important to make sure that the "Fit to Clay" option was activated for the curves to fit correctly to the surface of clay. This was followed by projection of the design curves onto two parallel sketch planes separated by the width of the strap. This enabled the creation of the profiles that would form the basis for the personalised fit watchstrap. The strap was then created by using "Loft Clay" tools from the "Construct Clay" palette. On completion of the strap geometry, the watch face was created and positioned in relation to wrist buck. In order to personalise the watch, a previously created pattern (in the form of a grey-scale bitmap image) was applied onto the watchstrap using the "Emboss with Image" command. 3D texturisation in the form of varying relief were created on the model surface. When the application of the pattern was completed, several surface finishing effects were applied to the pattern area using the tools from the "Sculpt Clay" palette (e.g. spike, attract, smooth) and the "Detail Clay" palette (e.g. round edge) provided within the system. These stages were repeated for the creation of a portfolio of four bespoke strap designs (Figure 5). This technique provided an excellent opportunity for very fast realisation of a number of strap designs, which would not have been possible without using the FreeForm modelling system. Finally, the surfaces were optimised in FreeForm and the geometry was exported in the STL file format. After the STL file was checked and verified, physical models of the designs were built using the multi-jet printing process (Figure 6).

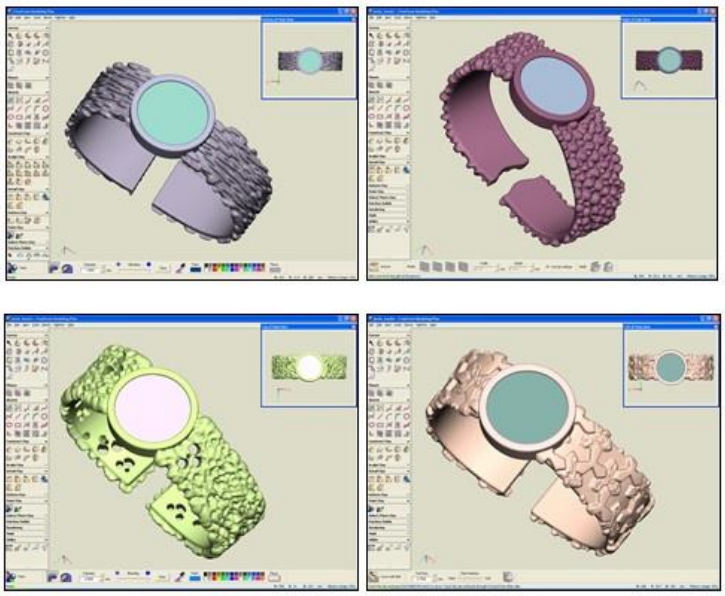


Figure 5. Renderings of alternative designs created using voxel modelling



Figure 6. Models produced using multi-jet printing

4 CONSUMER RESPONSE

The two ranges of designs were developed without any end-user input, apart from the scanned wrist data used as a CAD starting point. It was therefore important to gain user feedback on both the designs created and the mode of working that was employed.

4.1 Consumer responses to designs

The two ranges of designs were presented as examples of personalised products to two focus groups, convened to ascertain consumer attitudes to product obsolescence in general and the longevity strategies that could be followed. Both focus groups found it difficult to see beyond the perceived low-quality of the AM models and the lack of physicality of the CAD renderings. However, the ability to create designs that were tailored to individual wrist geometry was seen as a key benefit, mirroring research previously conducted by Paterson et al (2014). Although the watchstraps were personalised in the sense that they fitted an individual wrist, there was nothing about them that made them feel "personal". This could perhaps have been remedied by altering the DNA pattern or surface texture in some way to reflect personal tastes.

4.2 Consumer responses to mode of working

The major weakness of the approach that had been taken was seen as the lack of end-user input. What the users really wanted was a direct input into the design process to enable them to "stamp their personality" on the design. This desire has been recognised by Mugge et al (2005; 2009) as a potential aid to postponing product replacement when using a co-design approach. One method of implementing co-design is to have the end-user sit with the designer as they actually work on the product design. This is a rather impractical option for several reasons, including cost, inconvenience to the user and interference with the designer's standard operating practice. A more practical approach to co-design is for the designer to create a "product template" that contains all the key features of a design but enables some features to be modified or added by the consumer. This is the approach followed by Nervous System (2016) and has been employed within several projects at Loughborough Design School (Ariadi et al, 2012; Campbell et al, 2014; Sinclair et al, 2014; Yavari et al, 2016). This differs from conventional mass customisation toolkits in that the user has the ability to alter the external shape of the product, and not just select options from a configurator.

4.3 Further development of consumer input

Unfortunately, there was no opportunity to create a product template for watchstrap design. However, a similar application is available on the Nervous System website for bangle design. Ten non-designer users were given the opportunity to design their own products using this approach and an example output is shown in Figure 7. It should be pointed out that although the user was able to specify their wrist size, the bangle was not shaped to fit their wrist. The users were asked many questions about their engagement with the co-design process and their attitudes towards the products they had designed. In every case, the users stated that they found the process enjoyable and that they valued their own design higher than a standard product of comparable quality. It was also noted that most of the users felt proud of their achievement and had developed an emotional bond with their design. Similar results from personalised design have been recorded by Tseng and Ho (2011). Although the users were not specifically asked if this would lead to prolonged ownership and usage of the products, the authors believe that this is a distinct possibility worthy of further research.



Figure 7. Example of bangle designed by end-user using Nervous System website

5 DISCUSSION

The research reported in this paper has demonstrated that emerging digital technologies are offering new methods for designers to create personalised and “personalisable” designs. CAD tools are becoming much more flexible and easy-to-use and the whole concept of virtual clay voxel modelling lends itself readily to creating extremely complex shapes that are suitable for production using AM. This is because AM provides manufacturing processes that are capable of producing virtually any geometry with little or no cost and time differentials (Hopkinson et al, 2005). For this reason, it is sometimes referred to as freeform manufacturing. Therefore, the design for manufacturing challenge has been partially removed since there are no longer any shapes that are too complex to produce. However, the authors realise that there are still many AM limitations related to accuracy, material properties, surface finish, etc. The key

limitation on personalised design is the CAD modelling capabilities of the designer, both in terms of proficiency and time availability. For example, in this research, an experienced CAD designer had problems replicating the complex watch strap geometries that were envisaged in the original concept sketches. Of course the system used, Pro/ENGINEER, was more tailored to regular, engineering shapes and the use of a Computer Aided Industrial Design system may have offered greater flexibility. The "Virtual Clay" FreeForm modelling system that was used offered a new level of flexibility for replicating the 2D concept designs or indeed enabling direct creative expression within the digital medium. The system has also been shown to provide an opportunity for modification of design concepts through real-time collaboration with consumers (Sener and Van Rompuy, 2005). However, it is still demanding in terms of designer skills and time, and does not facilitate "hands-on" end-user participation in the design process. To truly bring end-users into the form-creation process, the authors believe that "product templates" combined with "computer-aided consumer design" interfaces are required (Ariadi et al, 2012). This enables consumers to work in a digital medium that is akin to them taking a physical product and stretching it around into a new shape that meets their individual requirements. Even if creates a more complex shape than the original design, AM can provide a cost-effective production route, at least for some products (Abdul Kudus et al, 2017). As the cost of AM continues to reduce, this approach will become feasible for an ever widening range of products. The result will be more products that are tailored to the needs and aspirations of the individual, and that create a greater emotional bond.

6 CONCLUSIONS AND FUTURE WORK

This research project has shown that the geometric freedom offered by AM facilitates watchstrap designs that can be uniquely personalised to the requirements of each individual customer. The most difficult part of the process is the CAD modelling effort required to create highly complex personalised shapes. Conventional designer-led CAD struggles to give form-creation access to the end-user whereas computer-aided consumer design linked to mass customisation toolkits seems to offer great potential in this area. The role of the designer then changes to being a facilitator of design personalisation through the generation of product templates, i.e. "unfinished designs" that will be completed by end-users. Such templates need to embody the design rules that protect safety and functionality and have currently only been employed for rather simple, mainly aesthetic products. Future work will translate this principle into more complex, highly functional products following the paradigm shown in Figure 8.

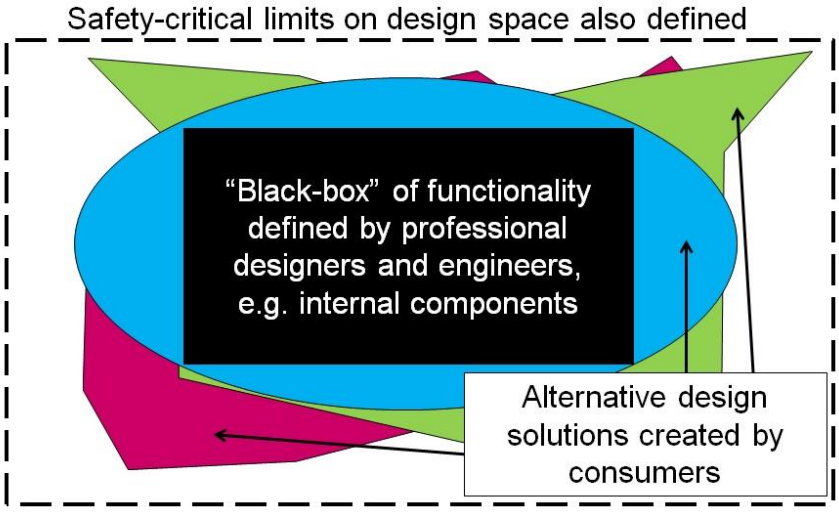


Figure 8. Paradigm for consumer involvement in design of functional products

The benefits of AM enabled personalisation are self-evident. A better fit can be achieved between a product and the shape of an individual's anatomy. Very complex geometry can be incorporated at no extra manufacturing cost. Images or shapes that have a personal meaning to the end-user can be readily incorporated into the product design. There is a unique opportunity to create products that result in a high level of emotional bonding and potentially greater product attachment. Future work in this area needs to find more precise ways of measuring the level of emotional attachment and how well this translates into increased product attachment and reduced product disposal rates. However, all this will

amount to very little if AM produced products are not made available at prices that everyday consumers can afford. There needs to be an order-of-magnitude reduction in AM costs before it can start to compete on a cost basis with most mass-produced components.

REFERENCES

Abdul Kudus, S.I., Campbell, R.I. and Bibb, R.J. (2017) "The Value of Personalised Consumer Product Design Through The Use of Additive Manufacturing AM Technology". *International Journal of Industrial Engineering and Management* (in press).

Ariadi, Y, Campbell, RI, Evans, MA, Graham, IG (2012) "Combining Additive Manufacturing with Computer-aided Consumer Design". In: Bourell, DL, Crawford, RH, Seepersad, CC, Beaman, JJ, Marcus, H (ed) *23rd Solid Freeform Fabrication Symposium 2012*, Austin, Texas, USA, pp.238-249.

Caffrey, T., Campbell, R.I. and Wohlers, T. (2016) *Wohlers Report 2016*, Wohlers Associates, Colorado, USA.

Campbell, RI, de Beer, DJ, Mauchline, DA, Becker, L, van der Grijp, R, Ariadi, Y, Evans, MA (2014) "Additive manufacturing as an enabler for enhanced consumer involvement", *South African Journal of Industrial Engineering*, Vol. 25 No. 2, pp. 67-74.

Campbell, RI, Jee, H, Kim, YS (2013) "Adding product value through additive manufacturing". In: Lindeman, U, Venkataraman, S, Kim, YS, Lee, SW, de Weck, O, Hong, YS (ed) DS 75-4: *19th International Conference on Engineering Design (ICED13)*, Design for Harmonies, ICED13, Seoul, Korea, pp. 259-268.

Hague, R.J., Campbell, R.I. and Dickens, P.M., (2003) "Implications on Design of Rapid Manufacturing", *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 217 No. C1, pp 25-30.

Hopkinson, N., Hague, R.J. and Dickens, P.M. (Eds) (2005) *Rapid Manufacturing: An Industrial Revolution for the Digital Age*, John Wiley & Sons Ltd, Chichester, West Sussex.

Hu, S.J. (2013) "Evolving Paradigms of Manufacturing: From Mass Production to Mass Customization and Personalization", *Procedia CIRP*, Vol. 7, pp. 3-8.

Mugge, R., Schoormans. J.P.L. and Hendrik N.J. Schifferstein, H.N.J. (2005) "Design Strategies to Postpone Consumers' Product Replacement: The Value of a Strong Person-Product Relationship". *The Design Journal*, Vol. 8, No. 2, pp. 38-48.

Mugge, R., Schoormans. J.P.L. and Hendrik N.J. Schifferstein, H.N.J. (2009) "Incorporating consumers in the design of their own products. The dimensions of product personalisation". *CoDesign*, Vol. 5, No. 2, pp. 79-97.

Nervous System, (2016). *Cell Cycle - WebGL design app - creating organic designs for 3d printing*, [online] Available at: https://n-e-r-v-o-u-s.com/cellCycle/?t=1 (Accessed December 2016).

Paterson, A.M., Bibb, R.J., Campbell, R.I. and Bingham, G.A. (2014) A Comparison of Additive Manufacturing Systems for the Design and Fabrication of Customised Wrist Splints, *Rapid Prototyping Journal*, Vol. 21, No. 3, pp.230-243.

Sener, B. and Van Rompuy, T. (2005) "'In Touch' With Consumers: Freeform® as a Co-Design Tool for Real-Time Concept Modification", *The Design Journal*, Vol. 8, No. 1, pp. 14-27.

Sinclair, MD, Campbell, RI, Yavari, H (2014) "Specification of an Additive Manufacturing Consumer Design Toolkit for Consumer Electronics Products". In Bohemia, E, Cooper, R, Liedtka, J, Rieple, A (ed) *19th DMI: Academic Design Management Conference Design Management in an Era of Disruption*, London, pp.1065-1088.

Tseng, M.M. and Jiao, J. (2001). "Mass Customization", *In: Handbook of Industrial Engineering, Technology and Operation Management* (3rd ed.). New York, NY: Wiley.

Tseng, Y-S. and Ho, M-C. (2011) "Creating Sustainable Emotional Value through Personalized Design". *Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing*. 30th November to 2nd December 2011, Kyoto, Japan, pp 257-260.

Yavari, H, Abdul Kudus, SI, Campbell, RI (2016) "User Involvement in Design: A Case Study of using an AM-enabled Mass Customisation and Personalisation (MC&P) Toolkit". In: Rennie, A and Bibb, RJ (ed) *14th Conference on Rapid Design, Prototyping & Manufacturing*, Loughborough University.

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