Additive manufacturing as an enabler for enhanced consumer involvement

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Additive Manufacturing as an Enabler for Enhanced Consumer Involvement


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Abstract

The proposed paper will draw on previous work done by the authors to use functional prototypes, produced using additive manufacturing (AM), as a means to draw customer input and preferences into new product development. This technique was referred to as Customer Interaction through Functional Prototypes (CIFP). The CIFP philosophy, as originally developed, has been proven both in consumer and medical products. In recent years, the authors have developed further concepts of AM-enabled enhanced consumer involvement within their respective research teams. The paper will discuss the extended use of CIFP in the VUT’s Technology Transfer and Innovation Directorate to support grant holders of the Industrial Development Corporation (IDC) Support Programme for Industrial Innovation (SPII) and Technology and Innovation Agency (TIA) to develop innovative new product concepts. The paper will then go on to discuss a novel method of consumer interaction developed at Loughborough University referred to as Computer-aided Consumer Design (CaCODE). This technique allows non-designers to take an existing product design, e.g. a pen, and modify its shape, in real-time, until they create a customised version of the product that meets their needs. The modification is limited within pre-defined parameters to make sure that any final design is functional and producible using AM.

Keywords: Additive Manufacturing, Consumer Involvement, Innovation, Customisation

1. Introduction

In recent years, advances in additive manufacturing (AM) have enabled much more representative prototypes to be developed. This has come primarily through materials development, but also through improved accuracy and finish of AM models. This has meant that fully functional prototypes can be produced which are very close to the end product, both in terms of material properties and visual appearance. Indeed, where the end product will be produced using AM, the final validation prototypes may actually be indistinguishable from the series production items. One consequence of this is that customers (whether clients or end users) can evaluate the prototypes as if they were using the end product, even in the final use environment. If this evaluation can be undertaken early in the product development process (essentially, as soon as a CAD model is available) then customer feedback can be used to help drive the remaining design iterations of the product. This has previously been termed “Customer Involvement through Functional Prototypes” (CIFP) and has been demonstrated to be effective with consumer products (Campbell et al, 2007), medical implants (Truscott et al, 2007) and professional use products (de Beer et al, 2009).

In these uses of CIFP there was a clear distinction between the designer and the customer, with the designer leading the product design evolutions. However, with the advent of Mass Customisation (MC) involving personalisation or individualisation, the terms “user co-design” or “customer integration” have become more familiar [Franke and Piller, 2003]. There is also an opinion that “with user-design systems, the professional designer is replaced by the user,”
[Randall et al, 2007]. Research at Loughborough Design School has indicated that such wholesale replacement is not currently feasible and that collaborative consumer design is required, where part of the product design is done by the designer and the remainder by the consumer. This latter approach connects consumers’ choices with the capabilities of the company and extends the philosophy of concurrent engineering to sales, marketing and end users. Thereby, it brings the voice of customers into design and manufacturing as recommended by Tseng and Du [1998]. Therefore, the authors have developed further concepts of AM-enabled enhanced consumer involvement within their respective research teams. This paper will discuss the extended use of CIFP to support entrepreneurs in developing innovative new product concepts and a novel method of consumer interaction, referred to as Computer-aided Consumer Design (CaCODE), which complements the use of CIFP.

2. Extending the CIFP Philosophy

The original CIFP philosophy was aimed at supporting designers within a conventional industrial environment. Typically, they would be working in a design consultancy or manufacturing company where they will have been presented with a brief from an external or internal client. Fully representative functional prototypes, produced using AM, would then be used to enable either the client and/or end users of the product to provide feedback on aesthetics, ergonomics or functionality. This can happen at several stages within the product development process as shown in Figure 1.

![Figure 1. Use of CIFP within the product development process (Campbell et al, 2007)](image-url)

This version of the CIFP methodology maintains a clear divide between the designer, who will be developing the design solutions and producing the CAD models, and the customer, who will be brought in on several occasions to evaluate the prototypes. In more recent projects, this divide has started to erode with customers performing some of the actions normally...
undertaken by the designer. With reference to Figure 1, these customer design interventions are most often seen at the earlier stages of the process, but can happen throughout. A typical example of early intervention is when an entrepreneur comes to the designer with a clear idea of market requirements, product design specification and perhaps even some concept designs. For customer intervention in the latter stages of detail design, product manufacture and delivery, the term “consumer designer” has been coined to reflect the idea that the same person may be the designer, manufacturer and user of the product. The application of CIFP within both of these scenarios is discussed in the following sections.

3. Using CIFP to Support Entrepreneurs

Within the Vaal University of Technology, the Technology Transfer and Innovation Directorate has an ongoing remit to support grant holders from the Industrial Development Corporation (IDC) Support Programme for Industrial Innovation (SPII) and the Technology and Innovation Agency (TIA) in developing innovative new product ideas. Numerous SPII and TIA projects have been supported with design, prototyping and tooling expertise, leading to the development of an extensive knowledge base that has been used to support other types of projects. Many of these projects are initiated by entrepreneurs who come to the VUT with innovative ideas, which need to be converted into viable product offerings. CIFP has played an integral role in supporting such entrepreneurs, as illustrated by the following project examples.

3.1 Example 1: Motorcycle locking system

The initial design idea was for a locking mechanism to secure a motorcycle to a trailer for transportation behind a car. The client entrepreneur had already sketched a solution to the problem and the original request to the VUT was for a functional prototype of this design to be produced using additive manufacturing. The designers at VUT were sceptical about the design but agreed to create a CAD model and build the prototype using AM parts and standard metal components. The prototype did not perform as the client had expected and he agreed that a major re-design was needed. This was undertaken by VUT designers and once again a CAD model and prototype were built. The new lock design operated well but the material properties of the lock cover were not sufficiently robust for a full “impact test” to check the security of the design. Therefore, a silicon rubber moulding was taken from the prototype lock cover and used to create further copies in a polyurethane resin material (Figure 2), which had similar properties to the polymer that would be used for final production. These met the performance requirements and convinced both the client and investors that production tools should be produced. The project showed that clients can lack professional design acumen and that even a negative outcome from a CIFP evaluation can be valuable.

Figure 2. Lock cover from motorcycle locking system
3.2 Example 2: Interlocking toy system
The original idea from the client entrepreneur was to create an interlocking toy system that could make use of the internal cardboard tubes from kitchen and toilet rolls. The client entrepreneur had already created a 3D design using the Sketch-up software. Research was undertaken to determine the internal diameters of cardboard tubes and it was found that sizes varied across international markets. A standard South African size was chosen and a refined design was generated using a 3D CAD package. The VUT designer created a number of connector designs (straight, 45 degrees, 90 degrees, T-piece and cross-piece) with tapered sections to fit into the cardboard tubes. A Dimension 3D printer was used to create prototypes in ABS plastic and silicon rubber moulds were used to produce prototypes for field testing in several different colours of polyurethane resin (Figure 3). After the testing showed that the cardboard tubes held their shape very well, it was decided to re-design the connectors without the taper. New samples were built on the Dimension machine to confirm that this re-design worked. “Soft” tooling was produced using CNC machining that incorporated the split planes and draft angles required for injection moulding. Around 300 parts were shot in four different colours so that a complete toy box could be shown to potential investors. Funding was received from investors and production tooling was developed so that the product could be launched on the market. The ability to use fully representative functional prototypes indicated that some design features which intuitively seemed to be correct, actually turned out to be unnecessary.

3.3 Example 3: Electronics enclosure for hand-held product
The electronics for a hand-held market sampling device had already been developed and the client entrepreneur now needed an enclosure to be designed. The client had a 2D drawing of his preferred solution, which was cylindrical in form and incorporated a screen, LED lights and push-button controls. An initial foam model was created for ergonomic evaluation and this showed problems with reaching the push buttons. A re-design was undertaken and a fully-detailed CAD model was developed. Prototype parts were built using laser sintering in polyamide and all the electronics were assembled into them. The AM material chosen was very representative of injection moulded parts in terms of wall thickness, the ability to use the final fasteners and in its robustness. The prototype was evaluated by both the client and
the VUT designer who suggested that an adhesive membrane pad should replace the push-buttons and LED lights, as well as covering the screen, to reduce the possibility of dirt ingress. A new design iteration was produced with the buttons on the membrane pad repositioned to allow for even easier reach. New laser sintered prototypes were produced, finished and painted and then assembled with the electronics (Figure 4). The product is now undergoing field trials. The main findings from this project were that physical models are essential for ergonomic evaluation and that professionally-finished AM models are sufficient for field testing, provided a suitable material is available.

![Figure 4. Fully assembled functional prototype](image)

**4. Coupling CIFP with CaCODE**

Recent research at Loughborough University has identified a desire for consumers to become more involved in the design and manufacture of their own personalised products, and the need for new digital technologies to facilitate this (Sinclair et al, 2011). Presenting such consumer-designers with functional prototypes of their designs for evaluation (i.e. utilising CIFP) is desirable but requires the design to have been embodied in a fully defined 3D digital model. Since most consumers are incapable of using conventional CAD systems, the capture of their design intent is problematic and the idea of starting from a “blank sheet” is highly intimidating to many. To overcome these issues, and hence facilitate prototype manufacture, the concept of “Computer-aided Consumer Design” (CaCODE) has been developed. With CaCODE, the consumer is presented with one (or several) existing designs of a particular type of product, and given the ability to vary the design geometry through an easy-to-use “click-and-drag” interface. The concept is similar to that employed by Digital Forming (2012) and Nervous System (2012). To date, CaCODE systems have been developed for two simpler product applications (beaker design and pen design) and specified for two more complex products (wrist splint design and mobile phone design). The beaker design and pen design systems are discussed below.
4.1 CaCODE for Beaker Design
Assuming that the beaker shape will be rotationally symmetrical, the only items needed for definition of a full 3D model are a base diameter, a 2D spline curve, to define the profile, and a material thickness. All of these are standard functions within most CAD systems so, in theory, any CAD system could have been selected as the platform to develop CaCODE. However, one system in particular (Rhino with the Grasshopper extension) offered the ability to create a user-friendly customised interface without the need for API programming. Therefore, a Grasshopper application was developed that first presents the user with a shaded image of a "neutral" beaker design, and then allows them to modify it by clicking and dragging control points to redefine its profile curve and base diameter (Figure 5). When the user has completed the design, it can be exported as an STL file for manufacture as a functional prototype. If the consumer had access to their own AM system, this could happen within hours but a more likely scenario is that they would submit the data via an on-line interface to a bureau who would manufacture the beaker and post it to them. At this stage, any deficiency in the aesthetics, ergonomics or functionality of the beaker could be used by the consumer to drive an improved design of the beaker.

![Figure 5. CaCODE interface for beaker design](image)

4.2 CaCODE for Pen Design
The second application for CaCODE was an asymmetric pen and again Rhino with Grasshopper was used. However, this time the shape of the product was determined by several dimensional parameters that were modified by the user using click-and-drag slider bars (Figure 6). As with the previous example, any input from the user resulted in an immediate reshaping of the product on screen. Since the pen had to fit comfortably within the user’s hand and also accommodate a standard sized internal cartridge, upper and lower constraint values were placed on all of the dimensions. This established an important principle in that the user did not have unlimited control of the shape to ensure that all the possible solutions would be feasible, at least from a geometrical point of view. As CaCODE is applied to more and more complex products, the ability to limit user freedom in the interest of safety, ergonomics, functionality or some other critical aspect of design will become increasingly important. It is neither reasonable nor desirable to expect consumers to be able to design every aspect of a product.
5. Conclusions and Future Directions

The ability to convert the initial designs of entrepreneurs into feasible products and to give consumers the ability to generate their own designs directly brings customer interaction to a new level. In combination with additive manufacturing and new design tools such as CaCODE, CIFP could be redefined to mean Customer Initiated Feasible Products. The role of the customer has been elevated from a passive recipient of “expert” designs to the active originator of design innovation. The knowledge input of the expert designer is still crucial and can be incorporated either through conventional design practice (as in the three project cases at the VUT) or through building design rules into CaCODE software. In this way, the final design of the product becomes a true collaboration between customer and designer. An ideal environment for such collaboration to take place is the Idea to Product Lab™ (I2P) currently operating at the VUT. The I2P facility provides access to and training for entry-level CAD and entry-level AM for school learners, students and individuals wanting to create first samples of innovative ideas. Plans are afoot to roll-out the I2P approach across South Africa and internationally (de Beer, 2012).

In the future, it is anticipated that more consumers will want to have a direct influence upon the shape of the products they buy. This means that software solutions will be needed that go beyond product configurators, which mainly facilitate choosing colours, patterns, textures and other options from pre-defined lists. One hypothesis is that designers will need to create deliberately “unfinished” designs that leave room for consumers to add their own personalised input (Sinclair, 2012). The extent to which consumers will be able to or will want to create such personalised products is largely unknown. It is happening in a few specialised areas already but the feasibility of its application to more commonly used products such as mobile phones has not been determined. Future research will concentrate upon assessing the usability and desirability of the CIFP and CaCODE method amongst entrepreneurs and the general public.
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