OPPORTUNITIES OFFERED BY ADDITIVE MANUFACTURING IN CREATIVE BUSINESSES: INFORMING DESIGNERS

Richard ANTHONY[1], Dr Martyn EVANS[2], Dr Allan RENNIE[1] and Eddie KIRKBY[3]
[1]Lancaster Product Development Unit, Engineering Department, Lancaster University, Lancaster, UK
[2]ImaginationLancaster, Lancaster Institute for Contemporary Arts, Lancaster University, Lancaster, UK
[3]The Manufacturing Institute, Manchester, UK

ABSTRACT
An understanding of the opportunities offered by new and rapidly developing manufacturing technologies is essential to successful new product development. Designers, be they students or those in the early stages of their career, need to understand the potential that such technologies offer. Depending upon the nature of their curriculum and the norms of the sector in which they become employed, the level of knowledge of new manufacturing technologies varies greatly amongst students and graduate designers. Creative businesses for example often find themselves at a disadvantage compared to more technically-focused sectors when it comes to knowledge about new manufacturing technologies. This can lead to creative businesses not recognising the potential advantages that such technology offers. This paper identifies the challenges facing designers, operating in/for creative businesses, when considering adopting Additive Manufacturing (AM) technologies and identifies strategies to assist them. The authors assert that an understanding of AM is of particular relevance to product designers as they often act as the interface between business and the manufacturers. This paper will draw out the key challenges and opportunities of AM for product designers operating within creative businesses and provide guidance for its use. This guidance will assist in the understanding of AM within creative businesses, support design students in the assessment of the appropriateness of AM for the production of goods suitable for creative businesses and underpins the integration of AM into their business.

Keywords: Additive manufacturing, rapid manufacturing, creative industries

1 INTRODUCTION

This paper explores opportunities offered by Additive Manufacturing (AM) to creative businesses and provides guidance for designers (students or early career) to assist in the understanding of AM when working in such contexts. The paper presents an overview of Additive Manufacturing (AM), and specifically details Rapid Manufacturing (RM being the application of AM technology for the direct production of end use parts, components, tools and assemblies) as a key application; discusses potential applications of AM in general and in creative contexts; presents a case study of the use of AM in a creative business; and provides information for designers which develops an understanding of and potential applications for AM. The paper provides conclusions for opportunities offered by AM for designers and creative businesses and suggests guidance for their adoption.

2 ADDITIVE MANUFACTURING

AM describes a group of technologies whereby three dimensional objects are physically created directly from digital data (in the form of a computer aided design (CAD) model). In simple terms, a CAD model is 'sliced' into a series of cross-sections or layers, with each layer sequentially fabricated on the AM machine, one on top of the other, until the object is complete as per the original CAD data. Historically, AM has been used mainly for the production of prototypes and in tooling applications, but as the technology has improved and become economically viable and more widely accessible, it is increasingly being used to manufacture end-use products, this application being referred to as RM. RM has found many promising applications within the medical, automotive and aerospace industries but such applications often require extensive testing to ensure suitable levels of safety and reliability, certification and testing, materials traceability, etc., resulting in a slow uptake in such areas [1]. More creative applications often do not require such rigorous evaluation making them a prime area into which RM can be exploited. Currently RM has received limited adoption within the Creative Industries (CI), defined as industries which have their origin in individual creativity, skill and talent which have a potential for job and wealth creation through the generation and exploitation of intellectual property [2]. Creative companies may lack the technical know-how that other more technically-focussed sectors have. This leads to many creative businesses, and designers employed by creative businesses, having limited knowledge of the capabilities and opportunities that AM may offer.

2.1 What are the opportunities offered by Additive Manufacturing?

3D CAD modelling combined with AM provides a range of opportunities for designers as it is capable of creating very complex geometries that would be difficult or impossible to do by any other means. AM removes many of the traditional manufacturing constraints designers and engineers need to consider such as draft angles and split lines, instead they must now consider the likely positioning of support material (if used) and its removal, as well as the removal of unused material, also the inherent poor surface roughness produced by many AM processes needs to be considered along with any post-processing requirements, etc. All these factors can be affected by design complexity and part orientation within the AM machine build volume. Also RM has different cost constraints than other more traditional techniques, meaning it is often better suited to low-volume, high-value, customised applications [3]. The cost of AM varies between processes yet it is clear that over recent years, the overall cost of AM technologies has become more competitive [4]. This will mean that such technologies will become economically viable for a broader range of applications, and as such will provide more opportunities for designers to utilise these approaches.

Due to its inherent flexibility AM presents many possibilities for user customisation and ultimately user-defined end products. Such possibilities allow for a previously unfeasible level of customised products. As bespoke products can be manufactured simultaneously it is likely that businesses and individuals will seek to take advantage of this to maximise the benefits of using AM. New ways of working will need to be devised to allow for large levels of individuality and customisability between products, and also to allow the consumer to easily and effectively take an active role in the design of products.

Consideration needs to be given to how AM could fit in to an existing manufacturing set-up. AM is fundamentally different from other forms of manufacture meaning that production can take place in a greater number of locations, rather than a single large plant. This can result in a form of distributed manufacture which avoids the need to have large central manufacturing and associated distribution hubs. Time and money could be saved by fabricating products in or close to the locations where they are required, thus resulting in an economically viable localisation of production. In the future, it is not inconceivable that production could take place in the home by the individual consumer who has made the product in question on a desktop 3D printer. In the shorter term, previously difficult to access market places such as ‘third world’ locations could be reached allowing their economic development to accelerate. Also important environmental advantages could be obtained by decentralising manufacture, although this is currently not fully understood [4].

2.2 What are the challenges presented by Additive Manufacturing?

As outlined above, the adoption of RM would ultimately result in the need for fundamental changes to manufacturing working practices. In addition, a range of more operational challenges would need to be addressed to allow businesses to fully exploit RM. Two key challenges include education and the resource implications of utilising AM technologies:

- Currently design students are educated in design for manufacture and design for assembly but RM has the potential to change the design and manufacturing paradigm [4]. Tooling is no longer required and assemblies can be consolidated into single components. New teaching approaches are thus required to encourage and enable students to exploit the potential of AM. Yet this is problematic as contemporary design curricula often pay cursory attention to RM due to the resource implications of embedding such technologies strongly within the curriculum.

- Due to the high purchase cost of AM equipment, universities and also many commercial companies (particularly smaller ones) are unable to purchase equipment themselves. The likelihood is that they will use external AM bureau to ensure access to a full range of AM technologies. This raises other issues such as cost and quality control. Not only is the use of bureau normally more expensive than using in-house equipment, but companies are reliant on the bureau to produce their parts to the highest possible quality. It is possible that much of the time savings that AM facilitates could be lost whilst utilising an external bureau [5]. For larger companies, difficult decisions will need to be made to decide: a) whether there would be sufficient return on the investment to make the purchase viable, and b) which technology to go for to best suit their specific needs [5]. AM equipment also requires ongoing maintenance which can make up a significant proportion of the overall cost involved.

It is clear that although RM presents a range of opportunities for students, designers and businesses to engage with new manufacturing technologies, there are challenges that may prevent or slow down their wide spread adoption. As the technologies mature and the range of available build materials further increases, these issues will become more widely understood.

3 OPPORTUNITIES FOR CREATIVE BUSINESS

With manufacturing increasingly taking place overseas in areas with cheap labour forces, UK based businesses need to find ways to make manufacturing more economically viable. One way of doing this is by manufacturing more targeted products which link more closely to the consumers' needs, which in turn makes the products more valuable [4]. Many craft based businesses creating products such as textiles, ceramics, jewellery, metal and glass have business models that bear similarities to potential RM models. The items being created are often individual, manufactured locally and in low volumes. For such reasons, some designers are starting to utilise AM technologies to create 'high tech' craft pieces. Artists such as Bathsheba Grossman [6] are creating small, complex sculptural objects that are manufactured in metal; while Lionel Theodore Dean [7] has developed a series of titanium pendants that visually relate to one another but are in fact unique in their own right.

Another creative application of RM is within computer games. MMORPG games (massively multiplayer online role playing games) are increasing in popularity due to the more widespread use of broadband internet [8]. Within these games, players can create their own character and personality and interact with other players from all over the world. With some of these games the manufacturers have made it possible to export the design of an individual's character (their 'avatar') so it can be physically realised using AM [9].

These above examples demonstrate the use of AM within creative applications, and as such evidence the need for designers to understand the potential of these technologies more effectively. The challenge often faced in universities to raise the awareness in design students of the potential of AM within the design process is two-fold: how to provide an understanding of a range of AM technologies when the majority of university departments have limited resource? and how to ensure the translation of the theoretical application of AM technologies into the design process?

4 GUIDANCE FOR THE USE OF ADDITIVE MANUFACTURING

Thus far, this paper has discussed the opportunities and challenges of the use of AM and has also attempted to demonstrate the need for designers to develop an understanding of AM technologies. Although this understanding is important, in many instances, designers need to be able to make decisions regarding the viability of AM technologies in terms of manufacturing fit, and be able to assess the appropriateness of a specific AM technology over another. The following tables provides an 'entry point' for this decision making process by presenting an overview of AM and its potential for creative businesses (Table 1), and comparative data for a range of AM technologies (Table 2). The intention of these tables is to support the designer in the overall assessment of AM technologies, and specifically its application within creative businesses.

Table 1. Use of Additive Manufacturing within Creative Businesses

	Description	**Implications**	**Impact for a creative business**
Volume of Production	More suitable for low volume production (as little as one).	Products manufactured in short runs.	One off and limited edition items can be easily produced at lower costs.
Complexity	Capable of high levels of complexity at	Complex forms can be offered to clients	Higher accuracy and more complex

	little extra time or cost.	that traditional processes cannot achieve.	shapes at little extra time or cost.
Size	Better suited to smaller objects as size is directly linked to time and manufacturing cost.	Greater benefit gained from manufacturing smaller products.	Small pieces can be manufactured together to reduced time and cost.
Value	Better suited to higher value objects as it is still a relatively expensive process.	Opportunity to add value to products. May need to out-source manufacture.	Bespoke pieces accessible to greater number of people.
Customisation	No tooling so objects can be different each time at no extra cost.	Greater opportunity to create products that are better suited to consumer.	Highly personalised pieces just as easy as standard pieces.
Material	Limited materials available.	Products may be compromised by choice of materials.	Limited choice not such a problem. Also secondary finishes can be used. (i.e. plating)
Post-processing	Many techniques require additional finishing to improve strength and surface finish.	Consideration needed for tech. choice, geometry and build orientation.	Consideration needed to aid any post-processing and maximise final quality achievable.

Table 2. Comparison of Additive Manufacturing (AM) technologies

	SLA	**SLS**	**FDM**	**SLM/ DMLS**	**LOM**	**3DP**	**Objet**
Production Speed	Average build speed	Can be stacked, fast build speed	Slow build speed	Fast build speed	Fast build speed	Can be stacked, very fast build speed	Fast build speed
Complexity and accuracy	Min. layer thickness 0.1mm, smooth surface finish	Min. layer thickness 0.1mm, average surface finish	Min. layer thickness 0.13mm, rough surface finish	Min. layer thickness 0.025mm, average surface finish	Min. layer thickness 0.05mm, rough surface finish	Min. layer thickness 0.1mm, rough surface finish	Min. Layer thickness 0.05mm, smooth surface finish
Max Size	210 x 70 x 80cm	56 x 56 x 76cm	91 x 61 x 91cm	25 x 25 x 40cm	81 x 56 x 51cm	150 x 75 x 70cm	50 x 40 x 20cm
Indicative cost	From £34/hour	From £0.92/cm^3	From £1.54/cm^3	From £60/hour	From £0.84/cm^3	From £6.17/cm^3 (stainless steel)	From £1.70/cm^3
Material	Thermoplastics, Acrylates	Nylon, Polyamide, Polystyrene; Elastomers; Composites	ABS, Polycarbonate, and Polyphenylsul-fone; Elastomers	Titanium, Aluminium, Stainless Steel, Cobalt Chrome and Tool Steel.	Thermoplastics, Paper, Ferrous metals, Non-ferrous metals, ceramics	Stainless steel, Bronze, Elastomers; Composites; Ceramics	Thermoplastics such as Acrylic (Elastomers)

5 CASE STUDY – A FLUTE KEY

The following case study describes the use of AM within a creative business context, specifically a high-value musical instrument – a handcrafted wooden flute. Lancaster University was contacted by a local manufacturer who wished to explore alternative manufacturing methods. This was undertaken as part of a student project supervised by university staff. A key aim of this approach was to enable knowledge transfer between the university and flute manufacturer but also to develop the knowledge of the potential of AM within creative businesses in the student. The case study focuses specifically on the design and manufacture of a flute key although other sections of the flute are also being explored through AM technologies.

5.1 Flute key

A designer and manufacturer of wooden flutes contacted the university wishing to investigate alternative ways to manufacture the keys for the flute. Currently the individual components of the keys are manufactured using traditional methods, i.e. they are milled and turned by hand from brass, silver soldered together, polished using a spindle mounted calico mop with jewellers rouge, and then plated with silver. This is a costly and extremely time consuming process.

5.1.1 Design & Manufacture and Post Processing

To explore the appropriateness of AM for the manufacture of the flute key, three AM technologies were selected based upon factors including part complexity and accuracy, material properties, surface finish, size, etc such that a comparison could be made. The three processes selected were: 1) Selective Laser Melting (SLM) using 316L stainless steel, 2) Three Dimensional Printing (3DP) using 420 stainless steel, and 3) Investment Casting (utilising a wax master produced by AM) using sterling silver.

The SLM and 3DP keys required post-processing to obtain a suitable (and customer-desired) surface finish. The SLM key required initial finishing with a hand held grinder to prepare the areas that had been in contact with the support structure. The key was subsequently polished using a buffing wheel and buffing compound. The 3DP key (see Figure.2) was purchased from a service bureau that carried out some initial post-processing; this involved polishing with corn, plastic and ceramic media. Despite this the 3DP key was then finished in the same way as the SLM flute key to enable like-for-like comparison. The investment cast key arrived finished and thus required no post-processing.

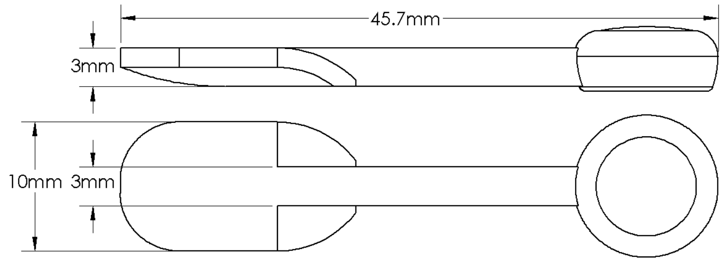

Figure 1. Flute key design

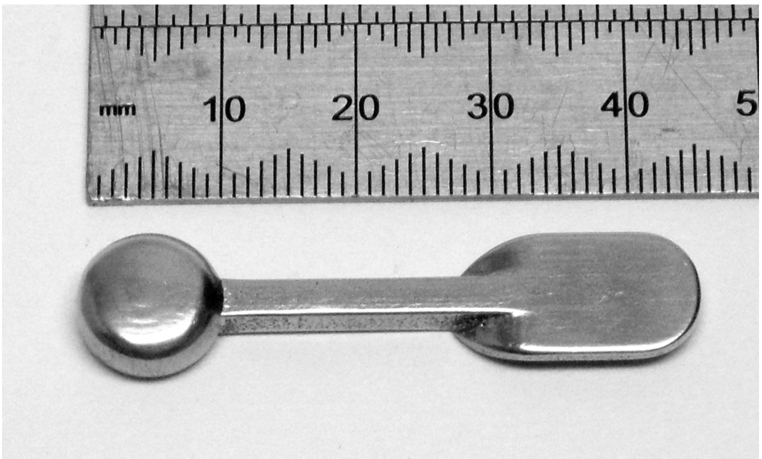

Figure 2. 3DP Flute key in 420 stainless steel

5.1.2 Conclusion

The use of AM technologies successfully produced the flute keys more quickly than the current method and has the potential to manufacture multiple keys simultaneously. The use of AM provides dimensionally accurate keys in a considerable reduced timescale. However, the flute manufacturer often needs to tailor the shape of each key to match the particular flute it is being fitted to and in this case the properties of brass are more suitable than stainless steel and sterling silver. The quality of finish after polishing for the SLM and 3DP keys was comparable to the original with both key producing a similar finish. The polishing process required for both the SLM and 3DP keys could be carried out by the flute manufacturer as it is the same method as currently used. The investment cast key had the best surface finish of the three, was build with a more favourable material and required less labour, making it the most appropriate process of the three AM technologies.

Having gained a better understanding of the possibilities offered by AM, the flute manufacturer went on to explore its use with other aspects of his flutes overall manufacture. This has resulted in ongoing work centred on the development of stereolithograpghy (SL) master patterns of the flute bodies, with the intention of using them in conjunction with a copy milling process.

6 CONCLUSION

This paper has presented some of the potential opportunities offered by AM and has explained the main challenges which need to be overcome to achieve its successful adoption. The main points identified in the paper include:

- There is currently a knowledge gap between current manufacturing practices within creative businesses and the awareness of the potential of AM. By increasing the awareness of designers, and in particular design students, there is an opportunity to address such a knowledge gap and enable creative businesses to take advantage of AM.
- The use of real-world design challenges (as outlined in the above case study) provides design students and academic staff with a clear link between the theory of Am technologies and their

application within practical settings. This also provides benefits to collaborative partners as there is knowledge transfer of AM technologies.

- Creative businesses are well placed to engage with RM as their business model often requires low-volume, high-value items. RM provides high levels of customisability without the need to invest in tooling. The combination of low-volume, highly customisable products suit the needs of creative businesses well.
- Designers working for creative businesses can transfer knowledge of RM through exemplar projects that draw upon the craft skills prevalent within creative businesses. For example, if a jeweller produces products via RM, they can still use their well developed finishing skills to complement these new approaches. Engagement with RM should not be seen as a replacement for traditional designer-maker skills but act in a complementary manner.
- RM technologies can assist in the creation of new and novel design solutions but design creativity is still required to provide a vision of what to manufacture. Design students need to be aware of the potential offered by, and constraints presented by, AM technologies if they are to develop creative and viable products.

Awareness of RM amongst design students is often limited to exposure to equipment and reliant upon the type of technologies universities (and staff) have access to. This paper attempts to overview the potential application of RM in areas that are familiar to product design students. Through the use of a case study (a flute key), key factors that must be considered when engaging with RM are highlighted. The authors do not propose that AM should replace all forms of manufacturing but assert that there is potential to engage with such technologies where appropriate. The use of AM technologies in creative businesses provides potential for designers to act as a mediator between the creative business and manufacturer. To this end design curricula needs to explore the use of AM technologies through collaborative engagement upon real-world projects – with creative businesses and also through AM bureaus. By providing design students with training and understanding in the use of (some) AM technologies, there is potential for this understanding to be transferred to a broader range of AM technologies via the use of AM bureaus. Of the three AM technologies utilised within this case study, only one was provided 'in-house' by the university while the other two were outsourced to a AM bureau. This provided access to a wide range of AM technologies without the need to for the university (and potentially the creative business) to purchase all of the equipment required. In an increasingly 'crown-sourced' technological environment, understanding of such development is of key importance to design students.

REFERENCES

[1] Reeves P. Rapid manufacturing for the realisation of 'user described' entertainment and recreational content. In *International Conference on Additive Technologies, ICAT 2008,* Slovenia 2008

[2] Creative Industries Task Force. *Creative Industries Mapping Document*, 2000 (Department for Culture Media and Sport, London).

[3] Ruffo, M., Tuck, C. and Hague, R.J.M. Cost estimation for rapid manufacturing - laser sintering production for low to medium volumes. *Journal of Engineering Manufacture,* 2006, 220(9), 1417-1427.

[4] Wohlers, T. *State of the Industry, Annual Worldwide Progress Report,* 2010 (Wohlers Associates, USA)

[5] Objet. (2011) Fender *Cuts Rapid Prototyping Costs in Half with Objet 3D Printer.* [online] Available at: http://www.objet.com/Pages/Case_Studies/Consumer_ Goods/Fender_Musical_Instruments_Corporation/ [Accessed 22 February 2011].

[6] Bathsheba. (2011) *Bathsheba Sculpture LLC* [online] Available at: http://www.bathsheba.com/ [Accessed 7th February 2011].

[7] DEAN, L. (2011) *Digital Creativity by Product Artist Lionel Theodore Dean.* [online] Available at: http://www.futurefactories.com/ [Accessed 07 February 2011].

[8] WISEGEEK. (2011) *What is a MMORPG?* [online] Available at: http://www.wisegeek.com/what-is-a-mmorpg.htm [Accessed 07 February 2011].

[9] FIGUREPRINTS. (2011) *Frequently Asked Questions.* [online] Available at: http://www.figureprints.com/Help/FAQ.aspx [Accessed 07 February 2011].