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ADDITIVE MANUFACTURING IN PRODUCT DESIGN EDUCATION: OUT WITH THE OLD IN AND IN WITH THE NEW?

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ABSTRACT
Recent years have witnessed significant advances in both Rapid Prototyping (RP) and the closely related Additive Manufacturing (AM) technologies. The subsequent impact on both Product Design practice and pedagogy has been profound. These technologies present an opportunity to develop new approaches, and some would say revolutionise, the design and manufacturing of products; enabling greater design freedom, making the manufacture of what was impossible possible, reducing development time, accelerating time to market. Could it be however, that the wonder of 'growing' products direct from a vat of liquid resin or tub of powder has clouded our judgement in regard to AM and its place in Product Design curriculum?
Using a number of commercially orientated case studies this paper briefly attempts to put additive technologies into context. It will explore where AM fits in terms of production volume and the development of high or low value products. The paper will attempt to identify where, at this moment in time, conventional manufacturing technologies still have to be taught in order to provide Product Design graduates with appropriate knowledge for today's manufacturing environments.
In addition the paper will attempt to identify methods to reconcile the teaching of both AM and conventional manufacturing technologies and put into context opportunities for tool-less manufacturing for design graduates.

Keywords: Additive manufacturing, rapid prototyping, product design education

1 INTRODUCTION

In the 1980's the move from manual drafting to 2D CAD on highly priced computer systems was seen as revolutionary. The same was true of photo realistic graphic rendering and animation in the late 1990's; to the point that the novelty of such illustrations could divert attention from what was actually a poor piece of design. Today such illustrations and animations are commonplace; they have lost their allure and are simply the norm at any level of design practice. Are we likely to witness an analogous demystification with today's AM technologies or is there a genuine paradigm shift in commercial design and manufacturing? There has certainly been growth in AM applications, but at what point are we really at with these new technologies in relation to more traditional manufacturing techniques and how should we as educators be helping students manage the old and the new?
In 2005, Hopkinson et al described Rapid Manufacturing (RM) as a possible catalyst for a 'new industrial revolution for the digital age' [1]. With this in mind it is worth quickly mapping the development of these technologies to date. The first commercial stereo lithography (SL) machine being produced by 3D Systems in 1987 [2] essentially to produce 3 dimensional prototypes from computer generated data used primarily for checking and evaluating design proposals to be manufactured by other technologies: 'to expose and facilitate the elimination of design errors', quotes Bohn in 1997[3]. Around 2005, RP seems to be making way for RM, with the emphasis changing from mere prototypes to utilizing these digital techniques for 'end result' manufacturing purposes. Only a few years later the literature is starting to refer more to AM, typically Hopkinson 2010 [4]. In 2012 Campbell et al refer to 'improvements in existing technology that justifies the transition from RP to AM' [5]; AM in this context referring to layering technologies and materials that directly produce useable parts. In 2009 Tacket states ''within a few short years, Direct Digital Manufacturing (or AM) will become the standard process for product development and manufacture'' [6]. Campbell et al build

on this by suggesting that 'designers need to be made aware of the unique features of AM and be encouraged to ignore the "design for manufacturing" limitations they have been used to' [5].

In 2001Wohlers and Grim issued a short report on the state of RP as they saw it; they refer to speed, accuracy, post processing, surface finish, material properties, size and cost as limitations that create barriers stifling the development of rapid production' (or RM) [7]. It's interesting to note that these barriers are referred to again by Drizo and Pegna in 2006 [8] and Reeves refers to RM still being in its infancy in 2007[9]. With reference to AM specifically, Campbell et al in 2012 continue to acknowledge these same issues, 'the major limitations to AM are speed, accuracy, nonlinearity (different resolutions for XYZ axes, wall thickness), material properties and system cost' [5]. It comes as no surprise then that the UK's Technology Strategy Board (TSB) is keen to meet these challenges addressing what they refer to as 'the so-called dirty secrets of additive manufacturing' [10]. An article in a US digital manufacturing report builds on this, even using the word 'hyperbole' in the context of AM [11]. From the perspective of higher education the majority of the literature on the subject aims merely at raising awareness. The literature generally offers a description of RP, RM and AM accompanied with a list of technologies that that particular institution possesses. It's only relatively recently that emphasis is drifting away from the technology itself and more to its application with the notion that markets can be re directed toward novel business models such as mass customisation [12].

Many of these applications are indeed valid but they represent a tiny fraction of New Product Development (NPD) opportunity for designers at this moment in time.

2 NICHE PRODUCTS CREATING OPPORTUNITIES FOR DESIGNERS

Mass manufacture is characterised by the production of large quantity at low unit cost. Rather than dictating cheap inferior merchandise, economies of scale can encourage significant investment in product development allowing sophisticated design, precision manufacture and exacting quality control. Mass production has made high quality goods affordable. At the same time however the availability and omnipresence of these goods has perhaps brought a sense of devaluation and disposability. Pre-industrialisation artefacts would reflect the individual skills of the artisan; idiosyncrasy that encourages emotional attachment. The tool-less manufacturing flexibility of AM allows for more personal approaches to production such as mass-customisation, with outputs tailored to an individual's need or desire or mass-individualisation with each artefact rendered unique in some way. FutureFactories' Tuber lamps are an example of the later. The design is a LED pendant luminaire made up of intertwined tuboid volumes (Figure 1). The form exists as a virtual meta-design created via a combination of parametric CAD and computer programming. Shoppers are presented with this 'living' design in gently writhing metamorphosis as part of an online buying experience. The customer is free to freeze the morphing at a moment of their choice creating a unique configuration which may be purchased. When an order is placed the relevant production data is generated and transmitted to an appropriate manufacturing facility where the product is printed and mailed to the customer. Examples of the design have been acquired by MoMA, The Museum of Modern Art in New York and DHUB and the Design Museum of Barcelona for their respective permanent collections.

Figure 1. Tuber plastic left, Tuber metal right

3 THE STATE OF PLAY FOR AM AND CONVENTIONAL TECHNOLOGIES IN RELATION TO PRODUCTION VOLUMES

The following case studies present a number of scenarios where RP, RM, AM and 'conventional' technologies have played their part in NPD. They address the issue of production volumes identifying where AM can currently be used in relevant, cost effective applications and where the technology's 'dirty secrets' can be avoided or 'designed out'.

3.1 Case study 1 – Hand held X-ray device – company XR

Company XR is a major manufacturer of scientific equipment, one of their divisions produces hand held x-ray devices, used typically in the metals recycling industry. This project required a rapid NPD exercise to halt an ongoing erosion of market share. The manufacturing volume for the new product was 1000 a year, which seems relatively low in terms of injection moulding, so would RM or even AM have been an option? The selected manufacturing route would have to produce durable components (scrap metal yards) with the quality expected of a high value scientific device. Selective Laser Sintering (SLS) in Nylon might have been durable enough but at this moment in time, this production process simply does not provide an acceptable aesthetic finish. The use of SL to produce pattern masters, silicon or epoxy moulds and UV stable Polyurethane (PU) castings, might also have been an option, providing good strength and cosmetic finish, however parts produced in this manner would be fifteen times more expensive than their injection moulded equivalents (even after tooling cost amortisation). However to produce parts via the PU casting route would only take three weeks, as opposed to fourteen for injection moulding and speed to market was essential; it was therefore decided that the first two to three months of production would be via the PU casting route to be followed closely by injection moulded versions. Figure 2 demonstrates a comparison between the PU cast and final injection moulded versions, virtually identical except that ultimately the injection moulded parts were fifteen times less expensive.

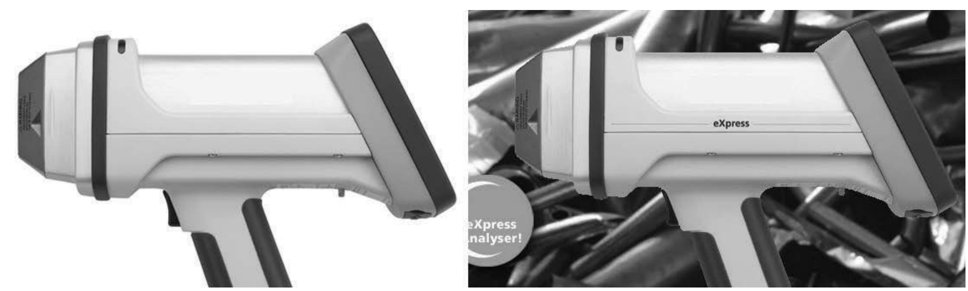

Figure 2. PU cast version left, injection moulded version right

Even though RM played its part in the NPD process, the cast PU parts had to be designed with injection moulding in mind. Interestingly SLS Nylon parts were used for evaluations during the development process [13].

3.2 Case study 2 – Plastic beer keg coupling – company PBKC

Company PBKC are a large manufacturer of plastic injection blow moulded bottles for the European drinks market. In addition to this PBKC manufacture their own range of injection blow moulded kegs for the beer industry. PBKC had identified an opportunity to develop a system for use with Micro Breweries that would emulate the way in which 'Real Ale' is supplied and dispensed from pubs throughout Europe. Annual sales potential of these coupling/keg combinations would be considerable and the only way that this quantity (parts produced in seconds) could be achieved with sufficient accuracy (+/- 0.05mm in places), consistently and at low part cost (cents), would be with high quality multi-cavity injection mould tools.

Component design was complex requiring multi axis tooling and complicated cores to create the various features of the system. Figure 3 illustrates an SLS Nylon prototype alongside a prototype produced in Acetal resin off a single impression prototype mould. The SLS prototype was useful for visual context only as it could not replicate to any degree the accuracy and surface finish of the injection moulded item.

Figure 3. SLS prototype left and injection moulded prototype right

3.3 Case study 3 – Pressure redistribution mattress – company PRM

PRM manufacture pressure re distribution mattresses for the prevention of bed sores for those requiring long term recuperation from surgery or illness. These mattresses are managed by a controller containing power management, electronics, compressor and an air distribution manifold circuit.

The pre-existing air distribution manifold circuit was complicated, comprising over fifteen components and connections to four mattress connectors, all occupying a relatively large amount of space and requiring considerable assembly time. PRM needed to re design the controller to reduce its size in order for it to occupy less space on the side of a typical medical bed. Yearly production volumes would be in the order of three to four hundred.

Using AM SLS Nylon parts it was possible to replace the fifteen components and all four mattress connectors with only three components; based on these yearly volumes, the savings on assembly labour and reduced parts more than compensated for the relatively expensive SLS process. The surface finish of the component (a dirty secret) was not a major concern in this case as the part is an internal one. Figure 4, illustrates the simplification and reduction in size from the old to the new controller.

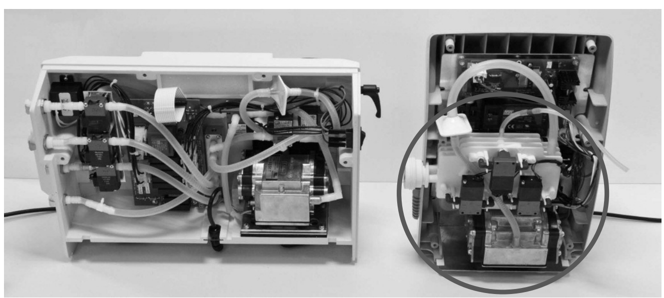

Figure 4. Old controller on the left, new controller on the right

The manifold outlined in red in figure 4, is a single piece SLS component; the internal air ways are tortuous and complicated making it virtually impossible to remove non fused powder from within the manifold (another dirty secret). To manufacture the manifold cost effectively it was essential to develop a method of removing this powder quickly and effectively, this was achieved resulting in a generic method now subject to a patent application.

4 THE TEACHING OF RP AND AM AT DE MONTFORT UNIVERSITY

The BA (3 years), BSc (4 year sandwich) and MDes Product Design (4 years) courses at De Montfort University (DMU) have access to a comprehensive range of RP and AM technologies including 3D composite printers, FDM machines, 3D Acrylic printers, SLA and SLS machines and a Selective Laser Melting (SLM) machine. These technologies are further complemented with laser and water jet cutting, 3, 4 and 5 axis CNC machining, 3 axis high speed routing and 3D laser scanning.

Manufacturing process and materials technology are taught intensively in the first and second years of all courses, RP and AM being taught as part of this, they are not 'picked out' as being anything special, their strengths and weaknesses are discussed equally to the strengths and weaknesses of other manufacturing technologies

In contrast to this, where visual language is taught to second year Product Design students, RP is introduced as a method of realising concept designs as an alternative to manual prototyping skills. In recent years tutors have noticed a rising aspiration to create increasingly extravagant forms often controlled by the use of parametric CAD to manage and manipulate geometry, this has led to an increasing demand for digital manufacture; many of the forms currently being created could not be replicated using more manual techniques. This has not been discouraged as it provides both students and staff with an opportunity to 'keep an eye' on the creative potential in these technologies as they mature, develop and improve.

As with all prototyping provision at DMU, students have relatively free access to RP and AM equipment; access tends to be limited only by cost (students are required to fund the cost of the raw RP and AM materials) and by relevancy (it is not unusual for students to try to have items manufactured by RP or AM that could be much more cost effectively produced by other means). It is therefore a requirement for tutors to 'sign off' computer models as being appropriate for RP or AM and in this way reinforce what has been taught in the technology and visual language modules.

Students therefore establish a thorough understanding of the opportunities and constraints relating to RP and AM in years one and two of the course and have scope to put their understanding of these technologies into practice in all years but especially with their design work in year three.

Whilst digital manufacturing techniques have become central to undergraduate model making practice, the introduction of AM as a production methodology remains a difficult proposition. Design for manufacture still exists within AM [14] but the benefits can be subtle; good design can increase efficiency making AM a viable proposition, but the lack of it may not prevent production. Poor design is equally possible in conventional manufacturing, but conventional tooling requires design decisions which can be assessed. Almost any form imaginable can be produced by AM and production issues could potentially be ignored entirely. AM based projects are appearing in post graduate programs however; the greater depth of inquiry at this level enables students to respond to the flexibility of digital design and manufacturing technologies and to justify the use of premium production methodologies with added design value [15].

It is not until the MDes year at DMU that a module dedicated to AM is delivered. Here students are required to utilise a variety of emerging digital technologies to reverse engineer a computer mouse in the design and development of its casing. 3D scanning is used to digitise a handmade model, the data from which then underpins internal technical development.

As part of this development, students are required to explore the range of RP and AM technologies and experience their positive and negative attributes in relation to the development of their ideas. MDes students can then utilise these technologies further (if they wish) in a major design project, but only if it is technically and commercially appropriate to the design in question. Figure 5 illustrates where two AM technologies have been compared in the development of the computer mouse and where a student has used AM for the manufacture of a single piece, flexible, aqua shoe concept as part of their major project where this tool-less technology has validity.

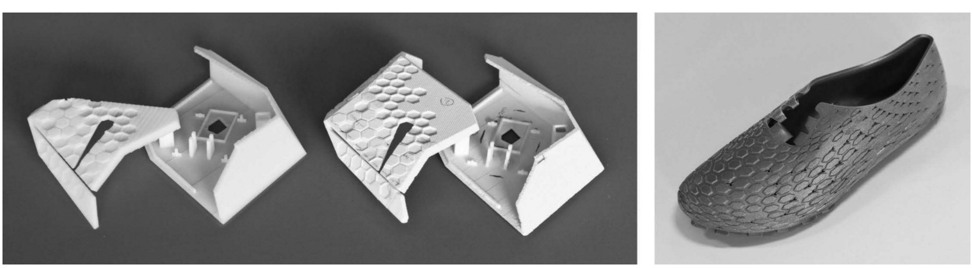

Figure 5. Mouse concept produced in FDM (left) and composite 3D print (right). AM used for aqua shoe design (far right)

5 DISCUSSION - CONCLUSION

This paper has illustrated opportunities for AM in the development of niche products for a new generation of designers who now have access to technologies that are making it possible to satisfy their creativity in the production of these artefacts; the paper has also alluded to the place of RP, RM and AM in more 'main-stream' NPD and the need to be aware of AM's dirty secrets and to work with them, around them or to address them. Loy states, 'to keep a degree level industrial design program current requires that the teaching responds to developments in industrial practice. More than that, it requires that the teaching promotes innovative, informed practice in the application of new technology' [12]; this is indeed true RP, RM and AM technologies are simply new tools for the designer, and there is a need to explore their potential both technically and aesthetically but they have to be taught alongside existing manufacturing technologies in a commercial context so that design students can balance cost effectiveness, scales of production and the new opportunities in new markets for niche AM products. What is clear is that it is not valid for designers to be encouraged to ignore 'traditional' design for manufacture processes at this point in time; they have to be introduced to the opportunities and constraints inherent in all levels of production. Teaching should not be restricted to innovative practice in the application of new technology but all appropriate methods, old and new. RP, RM and AM simply need to be added to the list of options along with their opportunities and constraints, alongside injection moulding, extrusion, etc., they are just new colours in the palette of the designer – how long will it be before these technologies become passé in themselves, just like photo realistic graphic rendering and animation?

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