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BREAKING THE MOULD: RESPONDING TO THE GROWING IMPACT OF ADDITIVE MANUFACTURING ON PRODUCT DESIGN EDUCATION

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ABSTRACT

Twentieth century manufacturing was dominated by the demand for faster, cheaper, more efficient production. Standardisation, common components, design for broad markets, design obsolescence: these ideas were fundamental to manufacturing in the last century. Plastics were predominantly injection moulded, and the integration of draft angles into a design, the design of tooling that did not require undercuts and the consideration of the parting line were fundamental to the tool box of the industrial designer. A decade into the twenty first century and manufacturing is experiencing what has been described in conferences and major exhibitions as the second industrial revolution, as advances in additive manufacturing change the production rules. In parallel global consumerism is changing, with collaborative consumption, co-design and the rise of the Maker Society.

Additive Manufacturing is no longer contained within rapid prototyping, it is providing a direct manufacturing alternative for all levels of production, particularly in relation to the individual. This opens the way for the re-localisation of production and the possibility of distributed manufacturing. Fused deposition modellers have become so inexpensive, compact and straight-forward to operate they are desk top and this revolutionises the way they are used by design studios and individuals.

This paper highlights changes in understanding, practice and approach that would benefit the educator in helping design students' positive evolution during the second industrial revolution. It summarises the practical considerations of using Additive Manufacturing faced by the Product Design educator, and introduces the economic and sociological impacts of changes in design, production and consumption.

Keywords: Additive manufacturing, digital fabrication, co-design, second industrial revolution

1 INTRODUCTION

Integrating Additive Manufacturing into the curriculum does not equate to introducing other production processes or technologies, such as reaction injection moulding in plastics or press braking in metals, both useful and both with implications for design education in how to design for their associated constraints and opportunities, because it is instrumental in a much broader change in production practice that is itself part of a broader change in consumerism that other process innovations do not have. There are constraints and opportunities associated with the different Additive Manufacturing technologies, as there are with other production processes, and these are outlined here for the product design educator. However, the spread of Additive Manufacturing is being termed the second industrial revolution because of its role in broader sociological, economic and environmental change and product design graduates need to have a contextual understanding and working knowledge of this too. This is a very large issue and is being addressed in considerable design research. This paper concentrates on salient points for the design educator as starting points for introducing Additive Manufacturing into Design studio based on:

1. How the different Additive Manufacturing technologies work and what the student needs to know to use them in the studio.
2. How the product design educator can encourage the students to challenge the technologies to create new ways of thinking, designing and making.
3. Why Additive Manufacturing is part of a wider change in society.
4. What the new business models will tend towards and how that effects product design education.

2 WORKING WITH ADDITIVE MANUFACTURING IN PRODUCT DESIGN EDUCATION

Subtractive technologies, such as CNC routering and laser cutting have been essential processes used in Product design education in response to developing industry practices. They allow the student to interact with digital fabrication are a workshop level, which acts as an introduction to more sophisticated robotic technologies. Export files can be created in basic 2D programs such as Vectorworks, Autocad and even illustrator as the drawings are basically 2D cutting sheets. For CNC routering, there needs to be the conversion step of creating a tool path with a dedicated program such as V-Carve, with laser cutters a print file is sufficient.

Additive Manufacturing in education continues this interaction with cutting edge technologies. Additive Manufacturing processes add, rather than remove material. All Additive Manufacturing machines add that material in layers [1]. The differences between different techniques are in the materials being used, how the layers are created and how those layers are then bonded together. Each layer is a cross section of the part as a slice of the original CAD data, with the accuracy determined by how thin the layers are. The export files are 3D data saved as an STL file. Initially the 3D programs, such as Solidworks, needed to create these files were professional level only and required a complex understanding of 3D solid modelling. However, accessible 3D software, such as Bonzai, is rapidly being created that makes modelling accessible for the amateur, and has good quality STL outputs. Google Sketch Up 3D has a plug in available to allow for the export of an STL and there is also a 'fix-up' plug in to improve the viability of the model. For the Product Design educator, this allows students working in related disciplines, such as Visual Communication or Fine Art to work with the technology with productive outcomes. This contributes to the interdisciplinarity of design education and is an opportunity to generate enthusiasm about what can be seen as a highly technical subject.

2.1 Fused Deposition Modelling (FDM)

In Fused Deposition Modelling material is heated, melted and extruded, as if out of a glue gun, and the shape is 'drawn' on a preheated platform, layer at a time. Any overhangs or holes in the vertical faces of the object will need to be supported by an accompanying scaffold support structure. This may be extruded in the same material through the same print head, or it may be through a second print head and be of a different material. If it is of the same material, then it will be physically removed on completion (peeled). Basic FDM machines, such as the Up!, that extrude a single material, are valuable for the Product Design educator as they normalise the process in the studio environment. Because they are simple to use, have no complex set up operations with only basic calibration, and utilise low cost spooled ABS or bioplastic, students can be left to create their own small models without technical support. This allows the educator to maintain student centred, 'Learning through Making' which has been identified as an important part of design education.

Students and design consultancies need to understand the value of this level of machine, but also its limitations. It is slow to run – the bottles shown below would take several hours to produce and each repeat will take the same length of time (as opposed to injection moulding where once the mould is created, repeats can be quickly produced). However, it is excellent for prototyping and for studio work relatively inexpensive (700 grams of material for an Up machine currently costs around $90). The bottle shown here is an example of prototyping in design studio. It shows second year student's work created by Fused Deposition Modelling and the model was used for ergonomic testing.

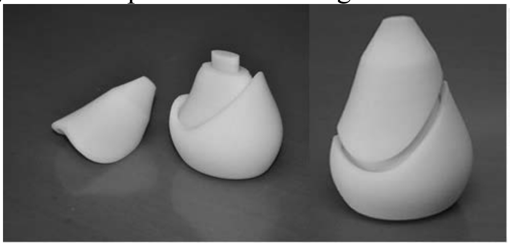

Figure 1. Bottle for ergonomic testing (c Xiao Xu Wang)

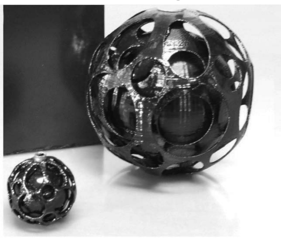

Figure 2. This student work was created using dissolvable scaffolding (c K. Fitzgerald 2011)

However, the limitation with basic machines, such as the Up! is that as the support material is the same as the print material, the scaffolding will restrict what the student can create. Internal scaffolding that cannot be broken away will be permanent, reducing the complexity potential of designs. If the FDM machine is more sophisticated, and can extrude a support material that is different, then a scaffolding material that can be dissolved is generally used. The major difference here is that structures within structures can be built and the support scaffolding removed, which would not be possible with the same material scaffold. In either case, build structures within a totally enclosed volume cannot be removed. For the Product Design educator, this means that to exploit the characteristics of these FDMs, the student should be encouraged to explore forms that have internal structures (but not totally enclosed spaces), taking them beyond what is practical for injection moulding. One way to explore this for the Product Design educator is to link it with biomimetic studies of natural growth patterns, for example in coral, or to look at generative mathematical algorithms that create patterns, such as those used by the architect Chris Bosse [2]. The second year student work shown in figure 2 was created using dissolvable scaffolding.

2.2 Selective Laser Sintering (SLS)

In Selective Laser Sintering, the material to be fused is first powdered in a proprietary mix. The object is still built up in layers, but there is no extrusion - the powder is instead fused by laser. The design is still sliced into layers and the laser traces the form of the object, rather like drawing on a flat piece of paper, where the paper is the layer of powder. The powder that is not fused together by the laser remains in place and acts as an effective support structure. Once the object is complete, this residual powder can be just be 'shaken' off.

The major difference with this technique from the Product Design Educators point of view is that it enables complex, interlocking, but most significantly, not actually attached, parts of an assembly to be created in one operation. To most utilise the potential of this technology the student should be encouraged to create moveable parts within an assembly, for example as gears. This is a fascinating experience for students and requires a complete rethink of design and its organisation in creating an assembly. This can be done at a small scale, but also at a very large scale, with engine parts for example. In Integrated assemblies in Additive Manufacturing several parts can be replaced by a single, more complex part even when the components have to be free to move with respect to each other. This reduces assembly costs and associated assembly tooling costs. As in conventional production part consolidation can lead to a significant reduction in on-costs that the student needs to be aware of and work with.

2.3 Stereolithography (SL)

This was the first process to be developed. This process uses a vat of liquid resin where the bed is moved down layer by layer and the top of the liquid is lasered to create the form of the object. The key point for this process from an educators point of view is that the resin acts as the support structure so highly complex, detailed outcomes can be created. This technique has been favoured for high cost model making, for example by architects, to show highly detailed, complex structures. The other key point from the educators point of view is the high costs associated with it making it prohibitively expensive in a studio environment.

2.4 Direct Metal Laser Sintering (DMLS)

This technology operates as the SLS but uses powdered metal. In this process, the delivery platform is lowered as each layer of metal alloy is sintered onto the surface of the part being built. An atmosphere is inert nitrogen is necessary with less than 1% oxygen to stop the metal powder oxidizing during the build. A 250Watt CO2 laser is used to sinter the metal alloy powders creating a considerable amount of heat during the process [3]. Titanium is currently the most significantly experimented with metal in this field with medical implants as the major area of development. Whilst titanium is prohibitively expensive for the educator to even consider, it is possible to work with cheaper metals with the online provider Shapeways. On line providers, such as Shapeways, are still excellent partners in design education and open up the materials students can use to include ceramics and glass.

3 ADDITIVE MANUFACTURING AND CREATIVE PRACTICE

World leaders in the development and use of Additive Manufacturing, Gibson et al [4] describe the advantage of the technology is in its provision of 'complexity for free'. This is because with any of the technologies described above creating a solid cube of material would be more expensive that creating a highly complex internal structure, or even structure within a structure as the cost is in the volume of material and the length of time it takes the print head to run the object path. The revolution in creation is that, unlike conventional manufacturing processes, the build is 'freeform' as there is no additional cost to produce complex associated tooling for any geometrical complexity included in the design. This is also the case for hierarchical complexity in that hierarchical multi-scale structures can be built at the same time from microstructures through geometric mesostructures (sizes in the millimetre range) to the large-scale part structure itself. This is revolutionary and has design and build potential for direct manufacturing that is only just starting to be explored.

Gibson et al describe the design objectives of using Additive Manufacturing as to: 'Maximise product performance through the synthesis of shapes, sizes, hierarchical structures and material compositions, subject to the capabilities of AM technologies.' The most significant example of geometric flexibility is customisation of product to the unique needs of an individual. Scans are used in medical applications to create for example, a replacement jaw bone, or scaffolding for the growth of cells to help repair a heart. On a commercial level, scanning a person's hand could lead to the development of ergonomically individual mobile phone cases. It is this individualisation that has parallels with social changes and attitudes that links Additive Manufacturing to a broader cultural consumer revolution.

4 THE TRANSFORMATION OF THE CONSUMER SOCIETY

Hugh Aldersley-Williams, in the RSA Design Projects article 'The New Tin Ear: Manufacturing, Materials and the Rise of the User-Maker' [5], suggests that, in terms of localised making and consumption, the twenty-first century will be more like the fourteenth century, with a craft based, cottage industry society, than the industrial twentieth century, and that the industrial revolution has been a 'temporary interlude' as distributed manufacturing again becomes prevalent and demand for mass customisation replaces mass production. Additive Manufacturing is a significant part of this, where an individual can side step the expensive investment in tooling needed in, for example, injection moulding, and manufacture the object they need as a one off. This encourages a cottage industry approach, which could theoretically change the entire face of production worldwide. If centralised production was no longer necessary, then that has implications for the development of infrastructures in towns, for the patterns of marketing and the environmental costs of distribution and for working patterns. It could even support the re-ruralisation of countries. This is not as futuristic as it may sound. At a 2011 forum in Brisbane, the Defence Materials Technology Centre called for farmers in regional, rural areas to have Additive Manufacturing machines to create aircraft parts [6].

Designer Geoff Hollington described Additive Manufacturing as a 'radical and disruptive technology with the potential to transform both the global economy and the consumer society' [5] as individuals or at least local communities take control of creating for customised fitness for purpose and invested design. With mass production, conventionally manufacturing enterprises have centralised so that product development, production and warehousing are in one place. As manufacturing enterprises have grown, the number of locations have decreased, leading to concentrations of labour giving disproportionately high levels of employment in some areas and lack of employment in others. As this phenomenon has become globalised, there are entire regions of underemployment. The widespread use of Additive Manufacturing based on internet connections means that conceptualisation, development and production can be carried out in any geographic location [7].

This has socio-cultural implications and implications for burgeoning economies based on the re-localisation of manufacturing that correspond with the research of Justin Marshall at Autonomatic at the University College Falmouth which has led him to conclude that 'there comes a point where the way production is constructed at the moment can't survive. Smaller, more flexible models of production come in. They may map on to pre- Industrial Revolution models. That's where the regionality comes in, not that you express Cornwallness, but that you are producing locally for a local market.'[5]

For the Product Design educator, Additive Manufacturing provides a natural extension to the teaching of sustainable design practice over the last five years. Understanding that all design decisions, however small, have implications for the environment has been relatively easy to teach, with life cycle assessment providing the vehicle for increased awareness of sourcing raw materials, the problems of production by products and the issue of closed loop recycling. Teaching Product Service Systems thinking has become an integral part of the curriculum. However, for students, understanding the social impact of design has taken the curriculum into areas of strategic design thinking, politics and policy. The teaching advantage for Product Design Educators of the social revolution aspects of Additive Manufacturing is that the impacts can be clearly seen, and touch on vital areas of consumption, socio-cultural sustainability, urban planning and regional economic development with extensive literature on the subjects.

'Design education will also have to change its curriculum, perhaps moving closer to the learning style used in craft training – teaching students to create more meaningful, individual pieces rather than huge numbers of identically mass produced products. Designers will have to learn to develop systems that will be used by others rather than trying to remain the sole author of their own work. And while it might seem daunting for the designer to be further removed from the end product they design, it is in fact a huge opportunity for the designer to become far more closely involved with the process of production than before, with all the associated knowledge and awareness of material quality and behaviour implies. The challenge will be to create systems that enable the design integrity of the end result to be retained and perhaps the identity of the original design intention to be perceived, while still allowing a degree of freedom for individual users to adopt designers' work to their own ends.' [8]

Creating these systems will part of the changing role of the industrial designer. Product Design educators need to clarify for students the emerging opportunities for co-design, where designer set up the situation where individuals can work within viable parameters with a degree of freedom to affect change. This is a new role for designers and its opportunities and the related graduate attributes needed to work in this area are yet to be defined, but creating interdisciplinary projects where these roles are explored is a good starting point. It requires a different form of team working and is more closely aligned with the skills required for current participatory design projects. It will, however, have implications for links with IT academic streams to create Product Designers who have the IT skills needed to develop online, innovative access points for a range of organisations, as, for example, the UK company Digital Forming is currently doing [9].

5 POSITIVE GROWTH

Transition times are challenging. The internet, ICT developments and social and business networking platforms are changing communication and collaboration generating new ways of co-designing and participatory design practices, which in turn have led to a more open-source approach and collaborative consumption. As they deal with the second industrial revolution, Product Design graduates are also expected to be strategic thinkers, framing and responding to the 'wicked' problems of the world. The Product Design educator's brief has extended as the meta-challenge of sustainability (as described in Design Activism by Fuad Luke [10]) moves beyond the Domenski or Bruntland Commission definition of sustainable design to include Institutional policy and strategy to not only support, but actively promote social equity, ecological stability and economic viability. Biomimicry activist Janis Birkeland is quoted by Fuad-Luke: 'Positive development refers to physical development that achieves net positive impacts during its lifecycle over pre-development conditions by increasing economic, social and ecological capital.' He also points out that Product Design education has to respond to the responsibilities according to John Wood as 'Design mediates the flows of natural, financial, manufactured, manmade, symbolic and cultural capitals.'

The challenging scope of the role of the Product Designer in business today, far beyond the trade initiated by Wedgewood [11], for example, as a response to the needs of emerging batch and mass production, is to effect the setting of new values and, hence, inculcating societal change. The idea of design culture as an agency of change, directing design towards positive social and environmental benefit, rather than sustainability, indicates the necessity for Product Design educators to address these wider contexts and Additive Manufacturing creating the second industrial revolution provides an effective platform to do so.

Essentially, Additive Manufacturing provides Product Design educators with a way to work through some of these issues with students to understand the impact of the development of the newest technologies not only on the design of objects in the narrowest sense, but on the actual behaviours, inter-relations, economic relationships and patterns of manufacture and consumption that exist in the world. AM has had such a clear impact on social norms that it is a significant tool for the educator in ensuring that theory that responds to understanding issues such as socio-cultural sustainability can readily and accessibly discussed and debated.

Brand consultant Will Murray [12] suggests that societies are actually 'economies'. 'As one society merges into another society we are really seeing shifts in economic models as a fundamental driver'.

Without a doubt, Additive Manufacturing is part of the current shifts in economic models. Whatever the debate, Product Design education must include Additive Manufacturing and the complex impact of its place in the world. As part of this imperative and in order to effectively support the positive development of Additive Manufacturing and design to push it to achievements rather than allowing it to slide into the lowest common denominator, Product Design educators need to provide students not only with the contextual understanding but also with the opportunities to develop to an advanced level their practical understanding, knowledge and skills in Additive Manufacturing rather than be swept away by an over reliance on crowd sourcing and what Atkinson describes in his essay 'Orchestral Manoeuvres in Design' in the book Open Design Now as the 'cult of the amateur'.[13].

6 CONCLUSION

In design and process terms for studio-based education, the Product Design Educator can help the student to learn about Additive Manufacturing by constructing project parameters to explore the capabilities of Additive Manufacturing that set it apart from conventional production processes. These are about exploiting the ability with Additive Manufacturing and in summary cover being able to:

- Use complex geometry at no additional cost
- Work with hierarchical scaling in the one design
- Use customised geometry
- Design 'freeform' with fewer production constraints
- Consolidate parts, even creating joints with freely moving components
- Integrate additional features (e.g. fastenings)

Fuad-Luke challenges designers (and therefore Product design educators) to consider 'where, when and how they can contribute to socio-cultural and political change, and in doing so help build positive capital in each of the capitals identified'. Industrial Revolution 2.0 through Additive Manufacturing and Web 2.0 (contributory content sites such as Wikipedia and Facebook) are changing the world on every level and education, debate and discussion need to be front and centre of all Product Design courses to equip our students to rise to the challenges ahead and to contribute to the positive development of the design of products that respond to the opportunities of Additive Manufacturing and are not overwhelmed by the enormity of the change in practice and understanding.

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