1. INTRODUCTION

At the heart of the maker movement stands the transformative technology of 3D printing. The accessibility and low cost of new machines popularized in the do it yourself (DIY) culture allow increased access to a process that used to be reserved for designers and engineers using it mostly for prototyping ends. The market is currently dominated by extrusion-based equipment due to the processes simplicity and low cost, with Fused Filament Fabrication (FFF) representing the less expensive machines and fused deposition modeling (FDM) representing the higher end equipment. The process is employed in low cost machines such as RepRap and Makerbot™ and can be compared to a hot glue gun on a robotic arm, as a thin filament of plastic is extruded in layers of two-dimensional patterns one on top of the other so as to form a 3 dimensional shape. Whereas low cost 3D printing has sometimes been described as hype, the reality is that 70,000 low cost machines were shipped last year, with a projected rise in sales to 140,000 units per year in 2016 (DiChristopher, 2013). With this mass proliferation of 3D printing, it begs the question what it means to be a designer in a world where anyone can make a part on a 3D printer? This paper addresses how we respond to this opportunity and associated pressure in industrial design higher education in particular. At the heart of this examination is that 3D printing in and of itself should not be viewed as a silver bullet, but instead as a genuine process alongside traditional manufacturing techniques, requiring a better understanding of both the process and technology.

2. THE MASS DEMOCRATIZATION OF PRODUCTION

In Makers: The New Industrial Revolution, Chris Anderson argues that while ‘the past ten years has been about new ways to create, invent and work together on the web”, the next ten years are about making physical things through the digital access of the web (Anderson, 2012). This is perhaps best exemplified by 3D printing. In schools it offers an opportunity to make things in a safer and more controlled manner that removes a lot of the mechanical hazards associated with shop classes, it also extends digital literacy to manufacturing. As design educators we can expect that high school students will increasingly be presented with the opportunity to learn 3D CAD software and also have the access to 3D printing tools. This is a fact not lost on Bre Pettis, the CEO of Makerbot. With a background in teaching he started the Makerbot Academy, whose self-proclaimed mission is “…to put a Makerbot desktop 3D printer in every school in the United States of America”. Students will increasingly enter university expecting the same access to 3D printing as 2D printing. They are already purchasing or building their own 3D printers and it is not inconceivable to imagine dormitories filled with these devices.
3. THE TRANSFORMING LANDSCAPE OF MANUFACTURING

The bigger promise of 3D printing is that it will completely change the face of manufacturing by allowing things to be made on demand and locally. The main barrier to democratized production has been the tooling associated with economies of scale and its associated costs and long lead times, now many household items can at least in theory be produced and repaired at home. Whereas this is undoubtedly exciting, we as design educators have to be circumspect of the hype and contradictions about the nature and extent to which this is happening.

What is obvious to those intimately involved in this “new industrial revolution” is that while there is magnificent change in what is being made, how it is being made and where it is being made, there is also a huge response from industry. This response is not just about leveraging the new opportunities afforded by the new industrial landscape of small and localized production, but also to segment the various needs and requirements of mass manufacturers as well. The pioneer in the industry; 3D Systems now produces a full range of additive fabrication machines ranging from the low cost Cube 3D plastic spool printer sold at Staples to high end production Direct Metal Sintering (DMS) machines. These machines sit at the opposite ends of the spectrum in terms of cost and application. Similarly new and emerging technologies such as LENS from Optomec “use the energy from a high-power laser to build up structures one layer at a time directly from powdered metals. The resulting fully functional 3-dimensional components have mechanical properties that are equivalent or superior to forged materials” (OPTOMEC, 2006).

As new technologies continue to evolve, recent acquisitions and mergers in the industry indicate market dominance by large players that eye opportunities for market segmentation. Established commercial 3D printer companies have purchased many smaller consumer oriented manufacturers as these large firms seek to extend their market reach into homes and small businesses. Designers correspondingly need to appreciate that this represents new opportunities both inside old and new industries alike. It does for example distinguish between what can be made in the home and what needs to be outsourced. As an example massive online factories such as Shapeways™, described as a “Willy-Wonka wonderland for 3D printing” (Brewster, 2013), make advanced high-end precision and materials for manufacturing custom products available to the general public at a cost. Other such service companies include RedEye™, which is a division of Stratasys™.

4. 3D PRINTING: WHAT IS IT FUNDAMENTALLY?

Additive fabrication technologies all work on the same basic fundamental principles. The starting point is a 3 dimensional CAD (computer aided design) file that is sliced into thin layers. The two dimensional profiles created during slicing are then reconstituted as a physical 3D object by printing each profile successively on top of the previous, creating a layered version of the original design. In a majority of systems the print head is moved in relation to the printing platform in an X, Y and Z coordinate system, in a manner that is analogous to how a CNC machine operates. With few exceptions the positioning systems operate in a similar manner and the main difference in technologies is of material processing as they cure, fuse or extrude...
Printable materials include a range of powders, liquid resins, and extrudable materials. The processing must be able to take place while the part geometry is being traced. This is accomplished differently by each technology with some using a laser to apply heat or UV light, digital projectors are also used, print heads similar to inkjet printers, syringes, concrete extruders and nearly any process which can deposited or form materials accurately with digital control.

The vast majority of low cost machines in use employ Fused Filament Fabrication, where an extruder melts a continuously feed plastic filament of ABS or PLA from a spool or cartridge. Initially the process was perfect for prototyping injection molded parts, due to the ability to print complex shapes and thin walled parts in plastic. At the same time the machine cost and material costs were prohibitively expensive for any production related application. These barriers are quickly eroding and advances in research are addressing other shortcomings such as material strength and variability as well as throughput and surface quality. Does this mean that other forms of plastic manufacturing processes are becoming antiquated?

5. COMPARING 3D PRINTING TO OTHER PLASTIC MANUFACTURING PROCESSES

At first glance 3D printing is the perfect plastic manufacturing process allowing thin and thick wall transitions, undercuts and a range of other geometrical benefits that are difficult or unattainable with injection molding as an example. It also removes the high cost and risks associated with the tool making process as well as associated lead times. As a result it is relatively easy to design something, print it, test it and then modify the design to improve the function. This is a perfect alignment with a fail often to learn quickly approach, but presents other challenges for design education.

Currently we teach students about plastic processes and materials by giving them theoretical knowledge based on science. When students learn about injection molding they learn how the process works and what the limitations of the process are. They learn about the strengthening properties of ribs and assembly opportunities provided by bosses and how to predict processing weaknesses such as weld lines and sink marks and how to design accordingly. They also learn the importance of working with molding experts and the necessary liaison with manufacturers. This is as relevant to education in today’s global manufacturing landscape as it was before, since designers have to oversee and manage international supply chains. With a shift to 3D printing, two questions come to mind: do we still need to worry about teaching mass production processes in general and is there a science to 3D printing?

In regards to the first question, there is no question that 3D printing will continue to evolve and may have certain inherent advantages over injection molding, but that does not mean that injection molding is antiquated as a production technique. If in fact we fail to see this, we may mistakenly overemphasize a new process in place of a proven and established process that is inherent in almost every product we currently buy. The practicing designer and educator Dave Franchino, recently published a case study of replacing a broken ventilation fan blade on a lawnmower. In the end the part was difficult to redesign, cost too much to replicate and ultimately failed due to structural reasons (Franchino, 2014).
What this shows is that replacing an injection-molded part with a 3D printed one is not always as easy it may seem. Factors such as strength and cost often supersede simpler objectives such as replicating the form.

In regards to the second question, 3D printing is currently being treated more as an art, because science has not adequately caught up with the rapid advance of the technology. As we learn more, we are also able to train designers in how to design parts for the process.

Don Paulson’s pioneering work at General Motors in the early 1960’s showed that injection molding was a process that could be understood scientifically. This new technology had undergone successive improvements and advances including the development of the reciprocating screw injection-molding machine in the late 1950’s. At the time no one had any idea how to scientifically predict the outcome of changing molding variables. This was because the machines themselves had a lot of controls and varying any of them, such as molding pressure and injection time would invariably affect part dimension in some manner. It was not until he proved that plastic polymers are affected by only four variables that a more scientific understanding of the process would happen. If injection molding serves as a precedent then as machines improve and become more standardized, the variability of the fabricated printed parts will be reduced and more optimized (Muccio), but factors in part design based on material and inherent process properties will still dictate part performance. With this in mind we need as educators to make the distinction between 3D printing for personal use and 3D printing as a new industrial process called Digital Additive Manufacturing (DAM), where parts have an expected level of performance. The latter will require a deeper knowledge and emergence of professional expertise.

Part of the research for this paper has been the focus of an interdisciplinary masters thesis between industrial design and mechanical engineering at our university. The methodology has centered around pushing the boundaries of what can be printed on a RepRap extrusion-based machine. The open source nature of this machine has allowed more control over process variables and hardware configurations. Using these capabilities several design studies have been conducted. As an example an injection molded guitar pick was reverse engineered so as to be 3D printed. Guitar picks are typically thin walled stamped or injection molded parts, raising the question if a 3D printed part would be strong enough? The first iteration was printed on his machine, using standard printing variables. The outcome was somewhat predictable in that the guitar pick failed quickly when used. The normal design iteration for 3D printing would be to strengthen the pick by using a different material or increasing thickness. This however is not an option given that guitar picks must be thin and flexible to function properly and since the
material choices for printing are currently quite limited. By taking a scientific approach and studying the broken pick under a microscope, it was clear that the failure was a result of how the machine had printed the part. By adjusting the printing parameters in successive iterations, the end result was a fully functional mostly hollow 3D printed guitar pick. This advanced type of printer control, makes a big difference on part performance if understood. This underscored the importance of specialized knowledge.

Similarly engineering ASTM polymer mechanical testing standards can be applied to 3D printed test specimens. This is an important quantitative method that isolates the material and processing variables by standardized means. Such research allows the detailed examination of structural properties associated with changing printing variables. This will give designers additional highly technical, but important information about the effect of strength to weight ratio differences with infill percentages and anisotropic part performance due to printing direction as examples.

Scientific research in the engineering domain has grown rapidly. This is evidenced in the high number of journal entries referencing additive manufacturing technology in engineering as exceeding 29000 articles. Several engineering challenges for the development of DAM primarily fall under:

- 3D CAD model construction and software development
- Build time and throughput
- Material processing (for example filament fusion)
- Material development including advancements in other fields such as biology and food industry
- End of life recycling of used or failed parts back into new feedstock
6. DESIGNING IS NOT JUST KNOWING CAD

For the broader maker movement one of the main hurdles to producing 3D printed objects is CAD. Open source software and other readily available low-end software, simply does not have the capability to easily create geometry of more complex shapes. Correspondingly Makerbot has introduced Thingiverse® an online community for sharing designed parts that in turn can be somewhat modified and then printed (http://www.thingiverse.com/about). In addition scanning is a way to skip the design phase, by copying an existing geometry and is growing in popularity in spite of its technical limitations. We can also expect to see easier to use more accessible CAD tools developed by the open source community or made accessible through cloud based computing.

For design this is however not the issue. Design is not merely being able to create a 3D form in CAD. What we design and how we design is all related to creativity and process. 3D printing has an enormous potential to transform the process, but it will not replace the design thinking that goes hand in hand with the tool. We need to examine the technology in the context of how design itself has evolved particularly in the last 10-15 years, becoming exponentially more complex and demanding in a global and increasingly technologically connected world. It would stand to reason that someone who is not intimately familiar with the design process would also not know what it entails. This is perhaps why a better understanding of design in the larger context of society is needed. This can become a double-edged sword, unless design curriculum adapts to this new wave of incoming makers. Incoming students may be increasingly creative and capable, especially in terms of technology, but will they understand and accept the benefits of a design process that they are not familiar with such as design research, sketching and other forms of ideation and testing? On one hand they will shape and influence the process on another they may not accept the benefits of other design methods unless it is repositioned in this new context.

In terms of design and society as a whole we may also wish to influence the world of K12 education, so as to bring a better understanding of design thinking and approaches to kids starting in elementary schools. This is precisely why initiatives such as STEM to STEAM and the DesignEd Coalition are important.

7. DESIGNERS EMBRACING THE MAKER MOVEMENT

Design students are increasingly pushing the boundaries of 3D printing and what it allows them to do in terms of novel new design solutions. As a result they augment tinkering and making with a more structured design approach. The student project shown below is used as a case study to make this point. The design process included design research and interdisciplinary design collaboration with the biology department in the field of biomimicry. The final solution is a modular multipart 3D printed set of parts that can be used to create usable products for the home, such as a lamp or small table. The unique flexible building blocks have connectors that allow assembly into various different creations much like Lego™, but for adults. The product, named Biobuild, is designed to be sold in kits as a starting point for DIY makers who can then add to the system with custom printed parts in case they own their own 3D printer. The students design training and knowledge of design process, acknowledges
design fundamentals such as modularity, end user needs, new design methods such as biomimicry and finally some marketing aspects. Firstly the idea of using discrete blocks, overcomes the size limitation of the printer, by printing smaller pieces (the blocks and connectors) that can be assembled into something larger, much like in nature. Secondly the product itself allows the end user to create something that they can customize into their own creations, without having to worry about knowing CAD. Furthermore the product marketing has been considered in terms of packaging and ability for people with their own 3D printers to expand the kit. This really points to how 3D printing as a tool and a process, can be approached holistically as a new manufacturing opportunity.

One aspect of this particular design effort was to push the envelope on materials. The working model could only be realized once a new flexible filament from Makerbot was employed. According to Hod Lipson at Cornell University, the future possibilities of 3D printing lies exactly in the design and manipulation of custom materials, “the advent of high-resolution multimaterial printers will open up such a vast new design space that it is difficult to anticipate the properties of the materials that will be possible, let alone exploit them for design” (Lipson & Kurman, 2013). The company Objet, recently acquired by Stratasys, makes the Connex printer that allows designers and engineers to prototype material compositions as well as geometries. This adds a new dimension to possibilities and benefits of understanding 3D printing process in more detail.

It is clear that these new tools have the potential to encourage positive risk taking to push the product design envelope by reducing the costs of failure and lost manufacturing time. Low rate production runs can be undertaken earlier in the design process for user testing and quicker user feedback – similar to the rapid “app” development process now prevalent in mobile computing.

8. CONCLUSION

With the advent of injection molding after World War II, the plastics industrial revolution was at hand. As a result of the historical developments and scientific understanding of the process, it is now routine to train industrial designers and engineers to be aware of design factors that influence the design of plastics parts in order to manage part quality and expectations.

Plastics initially had a bad name because of lack of proper design and processing; parts were often designed as replacement parts for metal and without proper understanding of the material properties either during production or as finished parts. Charles Eames apparently
compared plastics to the way Aztecs viewed liquor “a means of self expression too dangerously intoxicating for the young” (Freinkel, 2011). At the same time plastics have increasingly become the most common form of manufactured material included in almost any product we manufacture today ranging from simple trinkets to complex aerospace systems.

Industrial design students will be able to create unique artifacts utilizing low cost 3D printing that they would not have been able to propose, examine or verify prior to the mass proliferation of printing as a Digital Additive Manufacturing process. They can now justify such designs based on the notion that it is a bona fide manufacturing process. At the same time their knowledge of printing parameters and design guidelines are mostly absent, making this more art than science. Accordingly they need more manufacturing expertise as part of their education that will both distinguish them from the masses as design experts.

Inherently Digital Additive Manufacturing will continue to make inroads on other forms of production, but beyond the hype it is simply just more knowledge that needs to be positioned in the context of other manufacturing methods. Conversely other plastic material processes, will continue to be important, not just injection-molding, but blow-molding, rotational-molding and vacuum forming, for a variety of reasons including production volume and processing control, part size and structure and other important material considerations. Just like designers need to know and understand those processes in detail when designing for them and just like they need to know the benefits and shortcomings of different processes, they need to understand that 3D printing is a new process that has inherent strengths and weaknesses.

Important research is being done to help develop better design guidelines for the 3D printing process. Ultimately these guidelines will be folded into the design curriculum alongside more traditional manufacturing techniques, so as to allow students to compare and contrast benefits and constraints of these exciting new technologies.

References