Micro-Mass-Production: The Creative Revolution

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Historical Background

Between the early 1700s and the beginning of the last century, the industrial revolution changed the way that people lived and worked. The agrarian economy gave way to the industrial economy bringing with it the advantages of mass production and scale. With this came the division of labor into discrete tasks, taking the handling of tools away from the control of artisans and replacing them with machine controlled operations. But a machine has no inherent intelligence. It's the technological equivalent of the unskilled laborer, not a decision maker in the creative process.

The machinery of mass production was so vast that individual artisans could not afford to be part of the industrial revolution unless they relinquished their ability to control the process in every detail; agreeing, instead, to share it with investors, machines and a labor force of limited skill. The huge capital investment in production machinery began to drive design decisions. Thus, the moment-by-moment decisions made by artisans gave way to rules, standards, and procedures. In the process artisans lost the ability to create unique pieces in response to varying needs. With the advent of mass production, conceptual development was separated from execution. No longer could the artisan conceive of something and then fabricate it, perhaps modifying the idea as the fabrication process went forward. Instead, concepts were fed into the new industrial process; the designer and the artifact became separated.

The arts and crafts movement of the late 19th century was, in large part, a rebellion against what many considered to be the sacrificing of artistic skill and vision to the needs of the machine and the mass production process. Ironically, the arts and crafts designers who desired to make a better world for the average man through better, more artistic products were never able to produce products that were affordable for the masses. Their products, instead, became priced for the elite. Some artisans, like Morris, attempted to use some principles of mass production, like standardized parts which could be combined by the artisan in a number of different ways (with the detailing completed by individual artisans), but these attempts were insufficient to make the furniture affordable. So, the mass production model of the 19th century became the model for the 20th century as well. Power sources changed, the tools evolved, but the production model remained the same.

Toward the end of the 20th century, authors began to tout the virtues of flexible manufacturing and flexible specialization. The goal was the creation and application of universal tools: machines that were capable of producing a variety of things rather than specializing in the production of a single thing. In the old model of mass production, the combination of single purpose machines and unskilled labor came together to produce standard goods. As the cost of machines and labor increased this method began to lose its competitive advantage.

Flexible manufacturing and flexible specialization, made possible in large part because of advances in computer-controlled technology and robotics, had the ability to respond to market fluctuations and tying up less capital in machinery dedicated to single functions. However, it still relied on standardization. It dealt with fluctuations in volume but not in the design itself. Ironically, these changes were being driven by manufacturers in response to market demands and desire to reduce production costs and increase profits. Thus, manufacturing becomes mere object production that requires labor, initially of people then later of machines. The concept of an artisan is not found anywhere in this equation. Both the artisan and the machine are viewed as interchangeable production tools based upon economic necessity. At present, manufacturers are looking toward rapid prototyping as another means of cost reduction. If industrial designers do not get involved in using and directing these processes, we will miss the opportunity to leverage these technologies not only to shorten the design and development cycle, but more importantly to once again link the creator with the artifact and the user. For the first time in history, as a result of digital tools, we have the ability to bridge the gap between the economy of mass production and the artistry and control of the entire process by an individual designer.

New Tools for a New Century

In the past many production tools have been available on an industrial scale (and cost). The predecessor of the modern injection-molding machine was patented in 1872[1]. To make injection-molded plastic parts requires expensive molds and presses, expansive manufacturing facilities, and extensive lead times. However, the new generation of rapid prototyping machines is much more nimble and affordable than past generations. They require less space, less capital, and provide faster turnaround times at much smaller scales of production. Rapid prototyping processes are already being used to create rapid tooling that is then used in traditional manufacturing processes. As early as 1994, for example, Pratt & Whitney was using these techniques to reduce cost and save time in their investment casting process. Rapid prototyping processes are now on the verge of becoming direct manufacturing tools, a process that does not require tooling, but instead allows the final parts to be produced directly from the electronic file.

The base technologies have been in place for a number of years. The big change is in the cost, the speed, and the types of materials that are available to work with. Historically, rapid prototyping processes have been used to provide models and preprototypes for clients, test fit and function, and provide materials for focus groups. With the coming advances in materials, model fidelity, and speed, these processes can, increasingly, be used to provide final parts for a variety of production quantities, depending on the process. Up to this point, the term rapid prototyping has been used as a catchall. In fact these systems mirror traditional techniques and can be divided into three major processes: formative, subtractive, and additive.

Computer-controlled formative processes are in varying states of development at present. The term formative is used to describe processes that use opposing pressures applied to a material to modify its shape without the addition or loss of material. Computer-controlled bending and casting are examples of formative processes.

Computer-controlled subtractive processes produce parts by the selective removal of material. Examples include computer-controlled mills, lathes, lasers, and plasma cutters. These processes have been available for over 40 years. The biggest change in this category is that they have become more affordable and more efficient.

Computer-controlled additive processes create parts by adding material to a substrate or to the previously formed portions of a part. These processes include stereolithography (the selective curing of liquid material), selective sintering (the bonding of a powder at specific locations through melting) and aimed deposition (a precisely deposited stream of material forms the object). When used as a production tool these methods free designers from some of the tooling driven design constraints that are inherent in traditional mass-production techniques. Traditional constraints such as draft angles and the need for multipart molds required to create complex geometries (including hollow objects) are minimized or negated by many rapid prototyping processes.

There are, already, a number of examples in which rapid prototyping has been used to produce final products. Boeing’s Rocketdyne division has produced hundreds of parts for the international space station using rapid prototyping technology. These techniques have also applied to the manufacture of parts for military applications including components of the F-18 fighter[2].

Siemens, the world's largest producer of hearing aids, uses selective laser sintering, to produce its hearing aid housings. A mold is taken of the customer's ear canal. The mold is then scanned, translating it into a digital format that is used to model and "print" the housing[3]. This illustrates the ability of rapid prototyping to produce individual-specific versions of standardized products.

Using rapid prototyping techniques, production is not geographically bound. Because the resident form of the idea is electronic, the output doesn't have to be local or even machine specific since the same electronic file can be utilized by a variety of different rapid production machines.

Scenarios for the Future

It is important to distinguish what we are talking about from what the May 2005 newsletter from trendwatching.com extolled as the virtues of the new "customer-made" phenomenon[4]. We are not talking about cafeteria-style choices offered to consumers. An example of this can be found at Nike.com where Nike allows you to choose the colors of various components for a pair of spikeless Nike zoom waffle track shoes, or MBUSA.com that lets you choose the color and special option packages you might like for your new car. From a product design point of view, these are personalizations of preexisting designs. Calling these activities "design" ignores the fact that substantive design requires substantial training and expertise that goes far beyond cosmetic application[5]. Rapid production techniques are different. To extend the shoe analogy for a moment, suppose a designer had the ability to acquire a digital model of a customer's foot allowing us to design and fabricate a custom sole directly from the computer and with which other carefully tailored shoe components are combined. Thus adding value with little or no difference in cost compared to traditional mass-produced shoes.

With this illustration in mind, there are three important questions. The first is what might this design/production model look like? Second, who will control the machines? The third is where will the design intelligence reside? Obviously, the answers for each of these questions will have a profound effect on the remaining two. These scenarios could combine to form a variety of design/production models. Five distinct possibilities are discussed.

Model 1. *Central Designer; Distributed Production; Central Assembly*
This is not a new model. In 1941, the German U-boats were sinking approximately 700,000 tons of shipping per month. The solution was to design ships that could be manufactured so quickly that the supply of new ships would exceed the number of ships that could be sunk. These new ships were called "liberty ships." The project made use of a distributed manufacturing network that fabricated 250,000 parts for each ship. Entire cross sections of the ship were constructed, and then transported to the central assembly location where they were welded together to form the ship. Using this process, 2,751 liberty ships were constructed during the second half of World War II. This model has been used by large corporations throughout the latter half of the 20th century; parts are gathered from subcontractors and then assembled into the final product. This model uses a single set of plans and specifications that require exact part production.

The model strives for volume and economy through exact repetition. It does not respond well to individual design changes. This concept is at the very heart of mass production. In this model, the designer(s) exert complete control over the final product, provided that they stay within the production abilities of the manufacturers. They get exactly what they designed for, but they may miss opportunities to benefit from the expertise of the manufacturer(s) or to capitalize on the regional trends. Final cost is dependent on hourly labor and machine costs. The value to the consumer is the economy resulting product compared to other within its class. Even though this model relies on the mass production of identical parts, it can still benefit from the rapid production technologies as already discussed.

Model 2. *Central Designer; Distributed Production; Distributed Assembly*
This is a low-volume model that, initially, appears to be a variation of the central designer model. In this case, much of the intelligence begins with the designer, but, ultimately, the local producer/assembler plays a critical design role. The value to the end-user will be a combination of the value added by the designer and the value added by local producer/assembler. An example would be purchasing a house plan from a house plan catalog. When purchasing house plans, one is buying the documentation of a design that has been created by an architect (the designer). This plan may be changed by the future homeowner, a local architect, the builder, or even dictated by local regulations. It is the combination of the initial design and choices made afterward that will determine the ultimate success or failure of the final product.

Model 3. *Distributed Designer; Distributed Production; Distributed Assembly*
This model describes an interconnected network of independent designers and fabricators. A group of consulting designers may work concurrently between themselves to design a product that is then produced by a single or group of fabricators elsewhere. These groups will likely be dispersed geographically, sharing information in a digital form. Increasingly, the designer has the potential to provide rapid manufacturing services for limited runs. A variation on this model would have designers collaborating on design and sharing their own in-house production capabilities.

Model 4. *Open Design*
This model has its roots in the open source software movement. An individual designer creates and distributes it in electronic form. Another designer sees the idea and develops or modifies it while attributing the origin of the idea to the first designer. In this model, there is no direct avenue of financial return. Your activity does not inherently provide a revenue stream. It does, however, provide a low-cost way to create and then serve a market, to establish oneself as an expert or to locate collaborative partners. This model promotes development and experimentation through the free association of interested designers and producers.

This model has numerous examples. Ronen Kadushin, an advocate of open design, shares on his website, a number of designs for foldable products[6]. The digital description for each of these designs may be freely downloaded. All may be fabricated by whomever chooses using these files, but may not be produced for profit without first making arrangements with the author. Any future design variations must include an acknowledgment that the design ideas came first from Ronen Kadushin (this type of acknowledgment is known as an attribution). The biggest impediment to this type of product development is the difficulty in obtaining financial compensation for one’s efforts. To be viable in the long term, there must be a mechanism for profit. If concepts are not protected, this design model may end up benefiting the producer to the exclusion of the designer.

Despite its limitations, this model has the real potential to create “natural partnerships” as manufacturers and designers collaborate to produce and sell open source designs.

Model 5. *The Designer-Producer*
In this model, the designer uses rapid production techniques to design and fabricate pieces that are assembled, into a final product. This is an emergent model that relies on improvements in the rapid manufacturing technologies to provide more diverse design/production opportunities. Initially this model may be most beneficial in low volume production.

As an example, the design firm hired by a vinyl film manufacturer to create a tool to aid in the application of vehicle graphics could become both designer and producer of the tool itself.

Another example of this is the use of rapid prototyping techniques to create bone grafts that exactly match the patients bone surfaces. Here, the hospital staff uses CT or MRI scan data to drive the production of the bone replacement, in-house[7].

A Call to Arms

As design educators, we have the responsibility to provide vision and to prepare students for leadership positions within the profession and the industry of the future. So what does this mean for education and for the design process? As design educators, we need to identify tools and prepare design strategies that most effectively leverage rapid production technologies for the design/production process. Moreover, we must also be engaged in the future development of rapid prototyping technologies as a design tool--a tool that has the potential to reunite the designer and the design process with the real time production of the final artifact. In so doing, we will be uniting the skills, sensitivity, and insight of the artisan with the advantages of mass production for the first time in history. If we fail, these processes will be developed and refined by manufacturers, perhaps to the exclusion of designers and the insight that they can provide. Examples of nondesigner approaches to such technologies may be found in *Fab*, a book by MIT scientist and inventor Neil Gershenfeld[8].

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