Mass Customization + Non-Standard Modes of (Re)Production

Thanks to parametric design and digital fabrication technologies it is now possible to mass-produce non-standard, highly differentiated building components with the same facility as standardized ones. Digital technologies have not only transformed the ways in which buildings and building components are conceived, designed, and represented, but also the ways in which they are manufactured, assembled, and produced. Digitally controlled machinery can fabricate uniquely shaped parts at a cost that is no longer prohibitively expensive: it is just as easy and cost-effective for a CNC milling machine to produce 1,000 unique objects as to produce 1,000 identical ones. Variety, in other words, no longer compromises the efficiency and economy of production.

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Non-standard modes of (re)production allow the creation and manufacturing of unique buildings, and building components, in series, differentiated through digitally controlled variation. A parametrically defined, digitally fabricated "custom" house could thus become available to a broad segment of society. Individual components could be mass-customized to allow for optimal variance in response to differing local conditions in buildings; examples include uniquely shaped and sized structural components that address different structural loads in the most optimal way, or variable window shapes and sizes that correspond to differences in orientation and available views.

If the homogeneity and repetitive seriality of our buildings and cities are direct reflections of the most common manifestation of industrial mass production, does this new model of mass customization mean that repetition is no longer necessary? What are the theoretical implications and practical opportunities offered to an architecture that can easily integrate uniqueness, iterative complexity, and endless variation? And finally, as the gap between design and manufacture is narrowed, what are the issues surrounding the potential reindustrialization of design practices?

NON-STANDARD MODES OF (RE)PRODUCTION

The sparse geometries of the twentieth century Modernism were, in large part, driven by Fordian paradigms of industrial manufacturing, imbuing the building production with the logics of standardization, prefabrication, and on-site installation. The rationalities of manufacturing dictated geometric simplicity over complexity and the repetitive use of low-cost, mass-produced components. But these rigidities of production are no longer necessary, as digitally controlled machinery can fabricate unique, complexly-shaped components at a cost that is no longer prohibitively expensive. As already mentioned, variety no longer compromises the efficiency and economy of production.

At a purely representation level, parametric design techniques provide for unprecedented levels of variability, variety, and complexity in contemporary architecture. Parametrics provide for a powerful conception of shape and form in architecture by describing a range of possibilities, replacing in the process stable with variable, singularity with multiplicity. Using parametrics, designers could create an infinite number of similar objects, geometric manifestations of a previously articulated schema of variable dimensional, relational, or operative dependencies. When those variables are assigned specific values, particular instances are created from a potentially infinite range of possibilities. Fixed solutions are rejected for an exploration of infinitely variable potentialities.

Parametric design is now well established in the both the profession and academia. It is commonly understood as an enabling digital technology for infinite variation of shapes and forms, either through the embedded, inherent ways in which geometry is represented within the chosen drawing and modeling software or via visual programming aids or scripting. Inexpensive digital fabrication technologies, such as CNC routing and milling, make variety and variability technologically and economically attainable in production, literally eliminating the long-prevalent need for repetition as the only means to control costs in building. As Catherine Slessor observed back in 1997, after Gehry's Guggenheim Museum in Bilbao was built, "the notion that uniqueness is now as economic and easy to achieve as repetition, challenges the simplifying assumptions of Modernism and suggests the potential of a new, post-industrial paradigm based on the enhanced, creative capabilities of electronics rather than mechanics."[1] If repetition is no longer necessary in building design and production, what is the role of grids and modules as conceptual principles of geometric organization and articulation in architecture? What are the "grids" and "modules" that correspond to the contemporary conditions of infinite variability and variety? Do we still need to have "grids" and "modules"—and if we do, towards what ends?

MASS-CUSTOMIZATION

It is just as easy and cost-effective for a CNC milling machine to produce 1,000 unique objects as is to produce 1,000 identical ones: the amount of machine time in production is nearly identical in both scenarios. This ability to mass-produce one-off, highly differentiated building components with the same facility as standardized parts (together with the emergence of parametric design) opened up the possibility of "mass-customization" in building design and production.

Mass-customization, the post-Fordian paradigm for the economy of the twenty-first century, was defined by Joseph Pine[2] as the mass production of individually-customized goods and services, thus offering a tremendous increase in variety and customization without a corresponding increase in costs. It was anticipated as a technological capability in 1970 by Alvin Toffler in *Future Shock* and was delineated (as well as named) in 1987 by Stan Davis in *Future Perfect*.[3] Almost every segment of the economy—and industrial production in particular—has been affected by mass-customization, sometimes in very radical ways.

Mass-customization is a particularly suitable production paradigm for the building industry, since buildings are mostly one-off, highly customized products. Mass-customization also offers a promise that a "custom" house will become available to a broader segment of society.

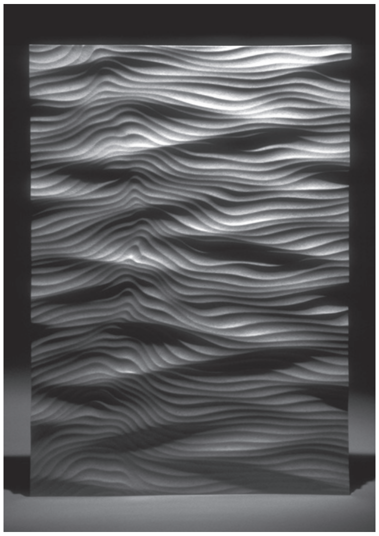
The technologies and "customization" methods developed in the consumer products industry have been applied to building products as well. Individual components could be mass-customized to allow for optimal variance in response to differing local conditions in buildings, such as uniquely shaped and sized structural components that address different structural loads in the most optimal way, or variable window shapes and sizes that correspond to differences in orientation and available views.

The digitally-driven production processes are introducing a different logic of seriality in architecture, one that is based on local variation and differentiation in series. Since 1990s, hundreds if not thousands of projects were completed with highly varied, highly differentiated components produced in series using parametrics and digital fabrication. As noted by Peter Zellner, it was already possible in late 1990s to

> produce "series-manufactured, mathematically coherent but differentiated objects, as well as elaborate, precise and relatively cheap one-off components;"[4] Zellner argued that in the process the "architecture is becoming like 'firmware,' the digital building of software space inscribed in the hardwares of construction." That is precisely what *Embryologic Houses* proposed by Greg Lynn at the turn of the century manifest: mass-customizable individual house designs produced by differentiation achieved through parametric variation in non-linear dynamic processes.

"DEMOCRATIZING" DESIGN

For Bernard Cache, "objects are no longer designed but calculated,"[5] allowing the design of complex forms with surfaces of variable curvature and laying "the foundation for a nonstandard mode of production." His *objectiles* (figure 1), designed in the mid-1990s, are non-standard objects,



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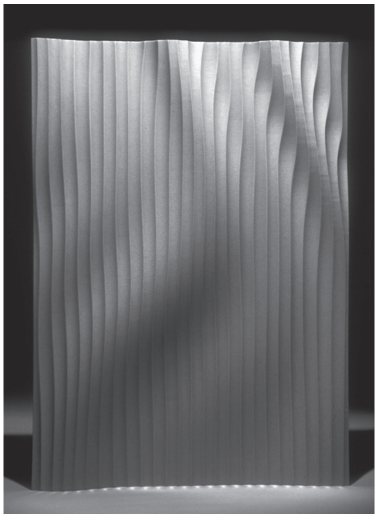

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Figure 1: *Objectiles*, designed by Bernard Cache.

Figure 2: The online interface for designing the *objectiles* (Bernard Cache, 1995).

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Figure 3: The *mTable* designed using a mobile phone and digitally fabricated (Gramazio and Kohler, 2002).

Figure 4: Dimensioning the *mTable* using a mobile phone.

Figure 5: *mTable*: creating the deformation points and holes in the *mTable*'s surface.

mainly furniture and paneling, which are procedurally calculated in modeling software and are industrially produced with numerically controlled machines. For Cache, it is the modification of parameters of design, often random, that allows the manufacture of different shapes in the same series, thus making the mass-customization, i.e. the industrial production of unique objects, possible.

Bernard Cache was one of the first designers to "democratize" design by making his parametric design publicly accessible over the internet—in 1995. Anyone could change online[6] the parameter values that control the geometry of his *objectiles* by simply manipulating the sliders that set parameter values (figure 2) and could immediately see the effects of assigning different parameter values.

Fabio Gramazio and Matthias Kohler from Zurich went a step further in 2002 with their *mTable* parametrically variable table design (figure 3). The table's top is flat—with holes—and an undulating underside. Their goal was to create a table "that customers can co-design."[7] They relied on internet and mobile communication and digital fabrication technologies for the customized design and production. They created an application for mobile phones so that customers could easily specify the size, dimensions, material, and color of the table (figure 4). Next, by placing "deformation points" on the underside of the table and by "pressing" them (figure 5), the customers could create holes with very thin edges by "breaking through" the surface. The phone app would then verify that the table with the holes is not structurally compromised. If satisfied with the design, the customer then transmits the parameters that define the table as a simple series of numbers to a website (at *mshape.com*), where the designed table is rendered in high resolution. A final step is the placement of the production order. The undulating underside of the table is then fabricated by a CNC milling machine (figure 6) using a 3D digital model driven directly by the data (parameters) transmitted from the cellphone.

As was the case with Cache's *objectiles*, an intentionally simple interface makes customers focus on the most essential design features of the *mTable*. While each table in the *mTable* design family (figure 7) is unique—i.e., with non-standard geometry—they all share an identical, "standard" underlying parametric model. Thus standardization acquires a new meaning in the contemporary parametrically controlled, digitally fabricated world of design and production. A single, "standard" parametric definition of the geometry can generate an infinite number of "non-standard" shapes or forms, all of which belong to the same design family—i.e., the same design space.

Gramazio and Kohler have turned a cellphone into a personal design tool and created an easily accessible interface to an underlying parametric model so that their customers could essentially co-design an object—a table with holes in this case. Their interest was to "examine the consequences of customer interaction when designing non-standard products." The project raised a number of interesting questions, such as the extent of responsibility that a customer was able and willing to assume in making certain design decisions and, more importantly, who ultimately is the author of the final design—the designer of the parametric system, or the "customer" who chose the parameter values for the design. It also raised questions about the nature of designing mass-customized products, where the emphasis shifts away from designing a particular form with a discrete set of dimensions to a parametric system that can produce a range of designs. The designers have to define dimensional ranges (minima and maxima) instead of discrete dimensions and create design rules that would limit the generation of "bad" designs. While the esthetic judgment is seemingly transferred to the customer, a designer retains principal control over key elements of the design. As Gramazio and Kohler have observed:

"The design concept and the formal consequences are carefully embedded in the software that provides a framework within which the customers can develop their own creative strategies, thus giving them control over the ultimate outcome of the design—the form. By deciding for themselves if and where the holes are placed, they assume partial responsibility for the aesthetic appearance, and functional efficiency of the tables. The designer, however, still retains control over which decisions are delegated to the customers and how freely they can intervene. This blurs the distinctions between designer and the customer, as the customer becomes a co-designer."

Such "democratization" of the design process has interesting implications for the building industry, especially in its most commoditized sector—the commercial provision of suburban housing. It is possible that we will soon see the emergence of websites where customers could customize the overall spatial layout and appearance of the chosen house design, selecting, for example, the size of the living room, location of the entry door, etc. down to the number of mullions in the windows (let alone the materials and finishes on the houses, which is already on offer). Such customer-designed homes could be then verified structurally or otherwise, and the geometry of various components automatically generated for direct, automated production using digital fabrication and assembly technology. The technologies to do that already exist. The challenges are largely cultural: whether most customers are really willing to assume a certain degree of responsibility for the design of their homes.

Such scenarios also redefine the central task that architects of mass-customized homes would have to undertake: Instead of designing with discrete dimensions, they would be designing with dimensional ranges in mind, with minima and maxima, as already discussed. And then there is the most important challenge—to insure that designs that emerge out of the operation of the parametric system are not only viable, but also "good." The aesthetic challenge will thus remain: We, as a society and a culture, don't have a capacity to weed out bad designs in the world of mass-produced suburban housing, let alone the mass-customized one.

In the Modernist aesthetic, the house was to be considered a manufactured item ("machine for living"). Mass production of the house would bring the best designs to a wide market and design would not no longer cater

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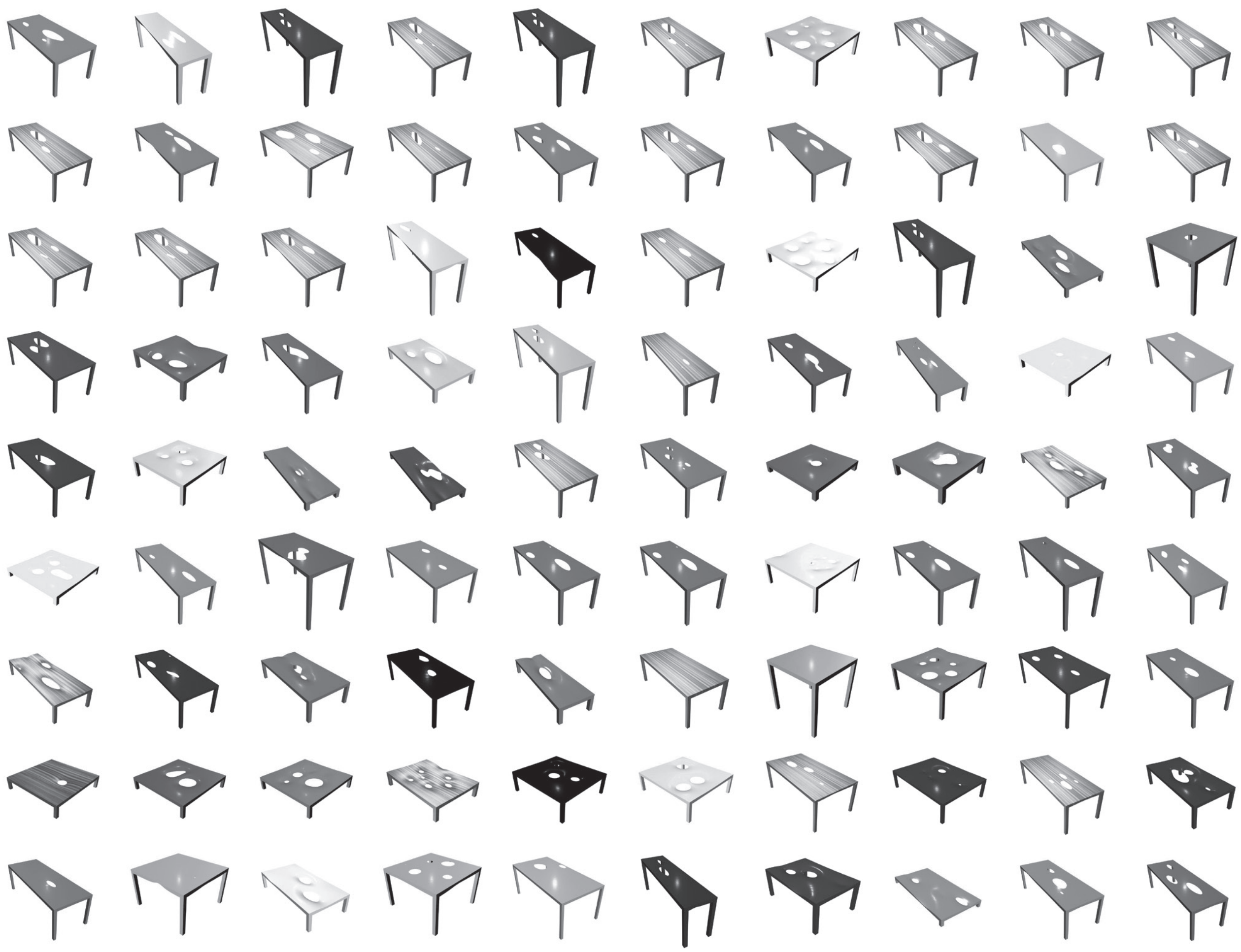
Figure 6: The CNC milling machine produces the *mTable*'s undulating underside based on the data transmitted from a mobile phone.

Figure 7: Many different *mTable* designs can be produced effortlessly.



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to the elite. That goal remains, albeit reinterpreted. The industrial production no longer means the mass production of a standard product to fit all purposes, a one size fits all. The technologies and methods of mass-customization allow for the creation and production of unique or similar buildings, and building components, differentiated through digitally-controlled variation. The technological capacity for designing and producing mass-customized houses is already here, but its cultural moment has yet to arrive. ◆

ENDNOTES

1. Catherine Slessor. *Digitizing Dusseldorf. op cit.*
2. Joseph B. Pine. *Mass Customization: The New Frontier in Business Competition.* Boston: Harvard Business School Press, 1993.
3. *Ibid.*
4. Peter Zellner. *Hybrid Space: New Forms in Digital Architecture.* New York: Rizzoli, 1999.
5. Bernard Cache. *Earth Moves: The Furnishing of Territories.* Cambridge: MIT Press, 1995.
6. The website objectile.com is no longer functional.
7. Fabio Gramazio and Matthias Kohler. "Towards a Digital Materiality" in *Manufacturing Material Effects*, B. Kolarevic and K. Klinger (eds.). London: Routledge, 2008, pp. 103-118.