Automated Design Tools for the Mass Customization of Housing
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Unlike today, many of the best minds of early twentieth century architecture were focused on the integration of new forms, materials, and technologies into innovative approaches to housing. Le Corbusier issued this call to action in 1923.

“A new epoch has begun... We must create the mass-produced spirit. The spirit of living in mass-construction homes. The spirit of conceiving mass-produced homes.”

In the 1940s, Walter Gropius and Konrad Wachsmann developed a factory based, mass-production system to manufacture highly customizable homes – the Packaged House. Gropius wrote,

“It is by the provision of interchangeable parts that (we) can meet the public’s desire for individuality and offer the client the pleasure of personal choice and initiative without jettisoning aesthetic unity.”

The effort failed spectacularly.

A factory was built to produce 10,000 houses per year, but less than 200 had been manufactured by the time the company closed its doors. They soon found that it was impossible to actually offer personal choice with their system. Customized solutions took far too much time to develop, and custom manufacturing was a logistical nightmare. The company eventually settled on a few standard models, which looked cheaper than conventional alternatives while being more expensive - not a strategy for success in the marketplace. Other post-war industrialized housing efforts met a similar fate.

More than a half century later, we have new computational-based design and manufacturing tools that may finally “offer the client the pleasure of personal choice and initiative” to an industry that – except for the very few – offers essentially no choice home buyers. Digital technologies now make it possible to replace both inefficient labor-intensive site production as well as inflexible mass-production with agile mass-customization, enabling formal and technological possibilities that Gropius could never have imagined. Ironically, computation may also offer the potential to reclaim the lost values of fine craft and detail that was swept away with the adoption of earlier non-digital technologies. Automated design tools may also permit architects to finally play a significant role in the design of houses for more than just the adventurous wealthy. While some of these new tools are beginning to be used by Frank Gehry and others for high profile institutional buildings, their application to residential design is in its infancy.

The previous article in this series, “A Machine-Crafted Home of the Future,” presented a scenario where a couple used web-based, automated design tools linked to mass-customization fabrication to take control of the process of creating a sophisticated, responsive home. But how might such a system be actually be developed for architecture?

**The shift towards customization**

Whereas mass production systems involve large assembly lines that create thousands of identical products, mass customization makes use of Computer Numerical Control (CNC) assembly line equipment to efficiently produce thousands of unique products. With Dell’s build to order systems, the consumer selects features for
their computer - memory, storage medium, processor, etc. - with simple web-based software. The resulting specification is then used to assemble customized machine. With Levis, the consumer can order custom jeans with the exact fit and desired features, and "batch quantities of one" are produced. Both Ford and BMW have announced plans for mass customization of the car. They envision show rooms where the consumer would "design" the car with the desired features, test-drive it using VR, finalize details, arrange the financing, and then transmit the order to the factory. Electrolux in Sweden offers a refrigerator with hundreds of choices available for finishes, handles, shelves, etc. – with the personalized order going directly to the factory floor for assembly.

As impressive as these early forays into mass customization are, they do not approach the complexities of creating a workable approach to the mass customization of housing. A Toyota, for example, is more or less the same worldwide, while expectations for a residence vary widely according to place and culture. Automobile chassises can be standardized, while a house “chasssis” would require much more variety. Automobiles are fully assembled in factory and shipped complete to the customer, while this is rarely possible for an object the size of a house. The automobile industry is made up of a few, large, well capitalized corporations who compete internationally with central control of decision making, while the housing industry is fragmented, local, and made up of thousands of small, less sophisticated companies. The automobile industry embraces innovation, while most players in the housing industry actively resist it.

Nevertheless, we can see the industry begin to move in this direction. In the early 1990’s, the Portuguese cabinetry company Barros & Barros developed software that asked users about their needs, such as types and quantities of apparel they want to store. The software knew the rules of good cabinet design, developed a customized solution, and generated a drawing that was used for fabrication. Similarly, Ikea and Home Depot now offer customized kitchen design services to create unique combinations of standardized cabinetry components – with a large selection of finishes, door types, and hardware. We see windows, doors, trusses, and many other architectural components beginning to be fabricated with automated CNC equipment. Large building material companies such as Owens Corning and International Paper are committed to moving from commodities to integrated systems and services – with complete building systems a logical consequence of this trend.

There are three necessary elements for the mass customization of housing: 1) a front end to query and assimilate the requirements of the user – called a Preference Engine, 2) computational tools that utilize of user profile from the Preference Engine, as well as site-specific information, to create a tailored design – a Design Engine, and 3) a production system to fabricate the components for assembly on the site. A future article in this series will present a chassis-plus-infill approach to the third step. Below is a strategy for the first and second.

**The Preference Engine**

The preference engine engages the customer in a dialogue to uncover needs, preferences, and values – and the tradeoffs they are
Variety of (mostly) 19th Century pitched roof forms adjacent to the Massachusetts Institute of Technology, Cambridge, Massachusetts. Photos by Kent Larson.
prepared to make. It takes people systematically through a series of design games, questions, images, and diagrams. The system would, ideally, approximate the dialog that a good architect may have with a client at the beginning of the design process (acknowledging that the economics of profession practice prevents all but a few wealthy clients from having any dialog at all with an architect). There could be an ever-expanding set of questions, but perhaps 1000 questions deal with the most important issues. Responses would determine the follow-up questions and information to be presented to the user.

Some questions will be factual and obvious.

Do you have children? What are their ages? Do you work at home? Do you like to cook? What is your budget?

Others are very subjective, getting at issues of values and aesthetics, and will make use of imagery and diagrams.

Which of these two spaces do you prefer?

Here it quickly becomes interesting. Why was one image chosen over the other? Is it the light? The color? The detailing? The sense of protection? A triggered childhood memory? Architects face the same issues, but have a richer set of perceptual cues to work with in a face-to-face meeting. On the other hand, face-to-face the same issues, but have a richer set of perceptual cues to work with in a face-to-face meeting. On the other hand, face-to-face meeting time between architect and client is always limited, while a computational system is infinitely patient. It is not entirely clear how best elicit useful, accurate information, and it presents some difficult and fascinating research problems regarding the psychology of learning and human-machine interface.

A web-based design system would provide carefully filtered and tailored information about each topic at hand, engaging the user in a dialog for weeks if desired. Companies developing new home technologies, materials, appliances, services, etc. are intrigued with a system that creates a direct link to customers for information about new offerings — a system that bypasses builders who are, more often than not, resistant to innovation. Finnish architect Jarmo Suominen, currently a House_n visiting researcher at MIT, has developed system that allows individuals to actively participate in the selection, planning, and furnishing of their apartment on the web. Created in cooperation with Finnish companies and municipal authorities, VirApS (Virtual Apartment System) promises to allow for an unprecedented degree of customization in multifamily housing.

If properly designed, a Preference Engine builds a reasonable user model by collecting and refining responses, and uncovering needs, preferences, values, and the tradeoffs that users are willing to make. This detailed user profile is then passed to whatever design engine is deemed to be appropriate.

The Design Engine

A Design Engine can be thought of as computation system that makes use of a set of rules encoded into a shape grammar that defines the architectural strategy of the designer. All skilled designers use a grammar of form — whether they recognize it or not - to create coherent compositions. Just as English speakers use grammar to form words into correct sentences that effectively communicates an idea.

The Quattro Libri by Andrea Palladio, for example, lays out a set of rules for the design of a Renaissance villa — rules for adjacencies, proportion of rooms, thickness of walls, spacing of columns, etc. Lawrence Sass (Ph.D. thesis, MIT Department of Architecture) systematically extracted these rules from Palladio’s text and the construction practices of the time. In the process, he developed the basis for their codification into a shape grammar, which could conceivably be developed into a Palladian Design Engine.

Efforts are also underway by Jose Duarte, an MIT House_n researcher, to develop a computer-based tool that enables the exploration of a design system based on the work of the architect Alvaro Siza. In the 1970s, Siza developed a system aimed at increasing user-participation in the design of mass housing at Malagueira. Devising implicit design rules, he used those rules to generate over 35 different layouts, ranging from one to five-bedroom houses - in an effort to incorporate the users’ desire for a custom house into the design process. But the system's potential to customize the dwellings was never fully utilized due to the limitations of conventional design and production tools. A design engine is now being developed that explicitly encodes Siza’s design rules into a shape grammar based on these rules, and to create a computational system that may fully tap the potential of Siza’s design system.

It is unreasonable to expect that any design engine would generate a single ideal solution that meets all of the needs and expectations of a user — a standard that practicing architects rarely achieve. The process would be iterative, with high fidelity visualization tools permitting the user to make informed judgments about the proposal and to critically evaluate the solution. The system would then follow up with the generation of additional solutions that take into account this additional criteria . . . and so on.

We envision a future in which many — perhaps thousands — of design engines would be created to make excellent design accessible and ubiquitous. This could take any number of forms. “Art star” architects may license design engines for mass marketing, much as many now do with furniture and furnishing design. Large, well capitalized corporations from outside of the housing industry — perhaps from the automobile or fashion industry - may develop “branded” product design engines that focus as much on lifestyle and image as function and price. House portal web sites may develop to help homebuyers evaluate various design systems, much as CNET.com is designed to help computer buyers evaluate vendors and products.

In a subsequent article, we will discuss how these solutions may also become affordable when linked to integrated, component-based, computer numerically controlled (CNC) fabrication techniques.

Elements extracted from the Quattro Libri dell’
Architettura by Andrea Palladio. From the Ph.D.
thesis work of Lawrence Sass, School of
Architecture and Planning, Massachusetts
Institute of Technology.
Diagrams showing the derivation of a single design using shape grammars applied to Alvaro Siza Vieira’s design system for the housing project at Malagueira, Portugal. From the Ph.D. thesis work of José Pinto Duarte, School of Architecture and Planning, Massachusetts Institute of Technology.