From Standardization to Customization: Paradigm Shifts in Manufactured Architecture

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"As mechanization moved towards its peak, biologists recognized the deadlock into which this mechanical attitude toward research was leading them. Experiment had already proved that an organism was not entirely resolvable into its components; that it consisted of more than a simple sum of its parts. In the whole hierarchy of biological pattern, from the single cell to the complex human organism, there exist always centers directing the genesis of the various parts." [1]

-Sigfried Gideon in *Mechanization Takes Command*

Introduction

This essay investigates paradigm[2] shifts within the history of design and technology; specifically, processes, tools, and technologies utilized in the manufacturing of building components and their assembly into building systems. ***Components and systems that were once mechanized, standardized, and discrete, can now be more integrated, customized, and adaptable.*** The paradigm shift has been accelerated by advances within the last decade in computer aided design and manufacturing, and is most evidenced in architectural projects where previously utilized processes, tools, and technologies have been reevaluated from a contemporary framework.

This investigation will focus on portions[3] of the Eames House,[4] built in 1949 by Charles and Ray Eames, and portions of the Porter House, built in 2003 by SHoP Architects; these projects were chosen because of their extensive use of manufactured components [both standard and custom] and because both firms have conducted in house experiments with materials and techniques, as one would in a small workshop or studio. Further, both firms have collaborated extensively with manufacturers, fabricators, developers, and consultants. SHoP's in house computer aided design and manufacturing machines enable them to research, manipulate, and test designs and their potentials, especially designs incorporating complex geometries or patterns. Similarly to Eames, SHoP examines manufacturing possibilities and consults with developers, engineers, fabricators, and contractors from the beginning of the design process. Their similar attitudes towards borrowing from manufacturing technologies, as well as their historic location at the temporal endpoints of the paradigm shift, make them ideal case studies.

Before beginning, however, I would like to briefly contextualize the investigation within the larger landscape of manufacturing technologies and organizational concepts from which they borrow, and to outline the material processes, tools, and technologies specific to mass production, versus mass customization.

From Mass Production to Mass Customization

This paradigm shift is elaborated below by Stan Davis in the Foreword to Joseph Pine's book, *Mass Customization: The New Frontier in Business Competition*:

> The shift from mass production to mass customization as organizational concepts are parallel to the redefining of parts/wholes and either/or constructions.

Figure 1

Top Image:
Envelope of the Eames House by Charles and Ray Eames, 1949

Bottom Image:
Envelope of the Porter House by SHoP Architects, 2003

> In parts/wholes, the mechanistic paradigm, the whole is the sum of its parts. An alternative notion holds that the whole exists simultaneously in every-one of its parts [similar to genetic code]; for example, through this more holistic approach, the 'mass' is to 'whole' what 'customization' is to 'parts'; the whole and its parts go together.[5]

Within the history of manufacturing, the system of mass production is relatively new. For many years, products were made by craftsman or artisans. The Industrial Revolution brought about machine tools and mechanization; these inventions could either extend the craftsman's skills or replace them altogether. In parallel with mechanization came the factory system, where the American System of Manufacturing[6] was invented. The principals of this system are as follows:

- Interchangeable parts
- Specialized machines
- Reliance on suppliers
- Focus on the process of production
- Division of labor
- Skills of American workers
- Flexibility
- Continuous technological improvement

Two of the most effective components of the American System were interchangeable parts and specialized machines. One of the most innovative of these specialized machines was the milling machine, which

> ...may be considered one of the really distinctive contributions of America to the system of interchangeable manufacture. For it was through the use of these machines that a high degree of uniformity of metal parts was achieved, far beyond what was possible by hand filing.[7]

Henry Ford extended and adapted the American System of Manufacturing to his own system, which we know today as Mass Production or Fordism,[8] which added these principles:

- Flow
- Focus on low costs and low prices
- Economies of scale
- Product standardization
- Degree of specialization
- Focus on operational efficiency
- Hierarchical organization
- with professional managers
- Vertical integration

The dominating principle here was Flow, and this was achieved through the invention of assembly line technology.

> The Model T assembly line, rearranged the functional organization of the factory into a moving line where each worker assembled a piece of a car, which moved on to the next worker for the next assembly step and so on.[9]

With mass production's economic success through streamlining the manufacturing process, this caused

> ...the development and manufacture of standardized products, because any complexities or custom work would upset the production process and result in much higher costs.[10]

Up until the 1960's the paradigm of mass production was utilized. Soon demographics began to change, the oil crisis and inflation of the 1970's occurred, and perhaps most importantly, in the 1980's and 90's technological innovations in processes and products were increasingly on the rise. All of these factors caused manufacturers to rethink the mass production paradigm. A new competitive heterogeneous landscape was quickly developing in the 90's; and with it the introduction of even more advanced technologies, such as computer integrated manufacturing.

> In manufacturing industries, computer numerical control, direct numerical control, and industrial robots greatly increase manufacturing flexibility by controlling parts manufacture through software programming. Flexible manufacturing systems extend this by allowing all members of a family of parts to be manufactured at will and at random. Within a predetermined envelope of variety, there are no cost penalties for manufacturing any one part versus another, yielding a manufacturing system that can quickly respond to changes in demand. Computer aided design [and] computer aided manufacturing allows design modification and even new designs to be quickly developed with manufacturing requirements automatically generated from the design specifications. Finally, computer-integrated manufacturing links all the disparate computer-controlled 'islands of automation' into a single, integrated system that is fast, responsive, flexible, and very low cost at high volumes. These manufacturing technologies can yield economies of scope and scale simultaneously, what Hamid Noori calls economies of *integration*. Unit costs go down with the greater number of products manufactured because that increases the volume of the entire operation. In addition, mass customization, like the American System of Manufactures, contains elements of both craft and mass production. As with craft production, mass customization commonly has a high degree of flexibility in its processes; it uses general-purpose tools and machines as well as the skills of its workers; it builds to order rather than to plan; and it results in high levels of variety and customization in its products and services.[11]

Therefore, in the case of architecture, huge possibilities are opened up through borrowing CAD-CAM technology from manufacturing industries. For in most cases, through the use of computer integrated manufacturing, it does not take more time, or more money to design your own custom components, than it does to choose uniform components from a catalog. In fact, in some cases, it is even more efficient, less expensive, and better yet, of higher quality and precision than the standardized catalog counterparts.

Paradigm Shifts

Although there are many shifts, I have chosen to focus on a few. Within these shifts are major and minor ones, but the degree of their importance is constantly shifting as well. They are all, interconnected, *and take on a dynamic of their own*. The shifts include, [but are not limited to] the following:

Shifts in building components: [from standardized components chosen from a catalog to customized components generated from scratch]

Shifts in design tools: [from discrete analogical two dimensional drafting to parametric computer aided three dimensional modeling, and from small scale models based on representation to large scale working models and prototypes based on material, geometrical, and structural properties]

Shifts in fabrication and manufacturing processes and technologies: [from mechanical stamped/molded processes and technologies to computer numerically controlled processes and technologies]

Shifts in notational systems: [from plan, section, elevation drawings with dimensions to exploded axonometric, nested template drawings with no dimensions and indexed to Excel spreadsheets; from construction documents to file to factory, and from interpretation and translation to instructions for assembly]

Shifts in organizational structures and construction processes: [from discrete phasing and back end approaches to integrated collaboration front end approaches]

Shifts in Building Components

The main paradigm shift within this investigation is the shift from standardized to customized building components. In the Eames House the components were chosen from a catalog of off-the-shelf manufactured components. The materials, sizes, and specifications were limited. Therefore the Eames were simply configuring and/or reconfiguring standard components to meet the varying design criteria. In the case of the Porter House, SHoP generated custom components from scratch using parametric 3-D modeling software, *Solidworks.*[12] This allowed more choice of material, and finish, and greater possibilities within the parameters of that material; whether they are dimensional, geometrical, or structural. Most importantly, the software increases the manufacturing and assembly of complex, adaptable systems.

In the Eames House, the off-the-shelf components are limited in their application due to their standardization of size, material, or finish. At the time of its construction, this was, in theory, an efficient use of materials and technologies because of their availability,[13] low cost, and efficiency of construction. The manufactured components, although affordable and easily erected, still had problems due to idiosyncratic conditions encountered on site, and difficulties in matching with other off the shelf components. These problems had to be resolved in the field with welding, cutting, and/or re-positioning of the components, thus raising costs, wasting material, and increasing susceptible break down. Further, members of the Eames office were on site performing many of these modifications themselves. Therefore, the translation from drawing to building, as well as the true calculation of time and cost, is called into question.[15]

> The high-tech fantasy of off-the-shelf parts which the Eames sought to perpetuate by proclaiming costs that were ten times less than those for conventional, balloon frame construction, is as just as much an exercise in self-deception as it has proven to be in other, equally iconographic attempts at standardization, ***where customized adaptations were finally to be necessary.*** Published costs of $1.00 per square foot in comparison to $11.50 for wood framing at that time conveniently overlooked the additional hours spent in furnishing and fit-out by members of the Eames office staff,[16] which were not added to the cost. The much-vaunted construction time of one-an-half days, which is certainly remarkable, and did translate directly into a valuable cost benefit, should be re-evaluated against this additional labor, as well as Eames own criterion that the value of the house should be measured by the 'energy it costs'. In the wider view of architects pursuing sustainable values today, who believe

> that the amount of energy used to produce or manufacture a material must also be considered as a factor in its selection, their statement now seems prescient, but their choice of steel does not.[17]

The potential for the components to be reconfigured for different programmatic requirements was limited by variations in site conditions, connections with other parts, or even climate.[18]

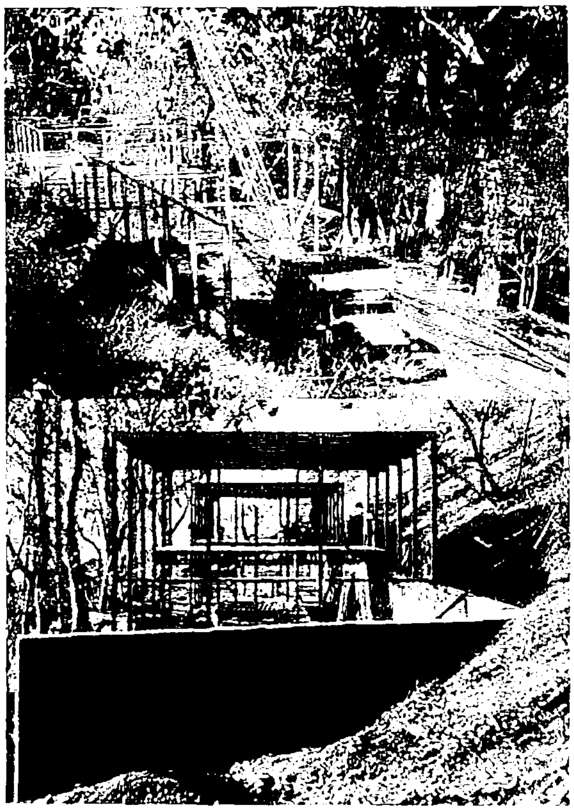

Figure 2. Delivery of manufactured parts to Eames House site and on site specific modifications such as the large retaining wall

In the case of SHoP's Porter House, the customized zinc facade system was designed as an integrated or composite system from the beginning. It was conceived as a rain screen or flashing system that serves as a protective layer from ice and water. The material choice, zinc, was also strategic in that it is typically used as roofing material in France, where it is processed. The system also incorporated lighting and what SHoP wittily termed the "pigeon slide"; a 30 degree slope on the window sill flashing so that pigeons may not take a rest, or [something else] on the building's unusually deep sills. The customized paneling system was based on simple rules that could accommodate many variations. The zinc sheet metal panels were laser cut into Fibonacci[19] tessellated patterns at 1 width, 2 widths, and 3 widths. In the end there were a total of 12 panel types which could accommodate 140 different conditions. 94% of the zinc material was used through nesting, and the system was installed in 10 weeks. The zinc panels were simply screwed to the furring channels, which were attached to the building's perimeter wall. This system is a bit tricky still, depending how well the slab is poured and how plumb the perimeter wall is framed; SHoP is in the process of detailing the system to be even more integrated.[20] This would involve a complex sandwich comprised of metal framing, insulation, an ice and water shield, and finally the zinc panels. This kind of integrated system could be totally manufactured off site and simply installed quickly on site, versus the Eames House where each component was a discrete element connected to another discrete element. In addition, because of the standard finishes of the components in the Eames House, they resorted to painting most of them. Therefore the components were not true to their material properties; [something the Eames successfully explored and executed in their furniture designs].

> Once the house and studio were completed, all the steel sections, the metal sash, and the flashing were painted a warm gray to unify the structural elements. Within the exterior walls of this neutral gray web, the contrasting stucco, cemesto, asbestos, and plywood panels were painted white, blue, red, black, or a middle-value gray.[21]

Painting after the assembly, necessitates continuous maintenance and even replacement of the components. Even though the materials of the panels are relatively inexpensive, the time and labor added to maintaining the system seems to defy the logic behind the economy and efficiency in using standardized manufactured components. Rarely did any of the Eames furniture designs paint natural material, and if so, it was folded into the process from the beginning, such as ebonizing versus painting the plywood chair series, a process and technique that takes into account durability and maintenance. In the Porter House by SHoP, because the material from the beginning was specified, or custom finished as pre-weathered sheets of zinc, the maintenance of the panelized system is minimal.

Top Image:

Paradigm of standardized discrete system: Eames House panels being inserted and painted individually after installation

Middle Image:

Paradigm of customized adaptable system: Porter House's pre-weathered zinc façade system with integrated lighting, flashing, and sills. The zinc facade system consisted of only two major details: that of flanging [folding and overlapping] and screwing the panels into the furring channels. The panels are simply screwed onto the pre laid furring channels. Having the screw holes pre drilled onto the panels by the laser cutter insures precision and tolerance during the assembly of the overall system.

Bottom Image:

Image of finished assembly of Porter House zinc facade system

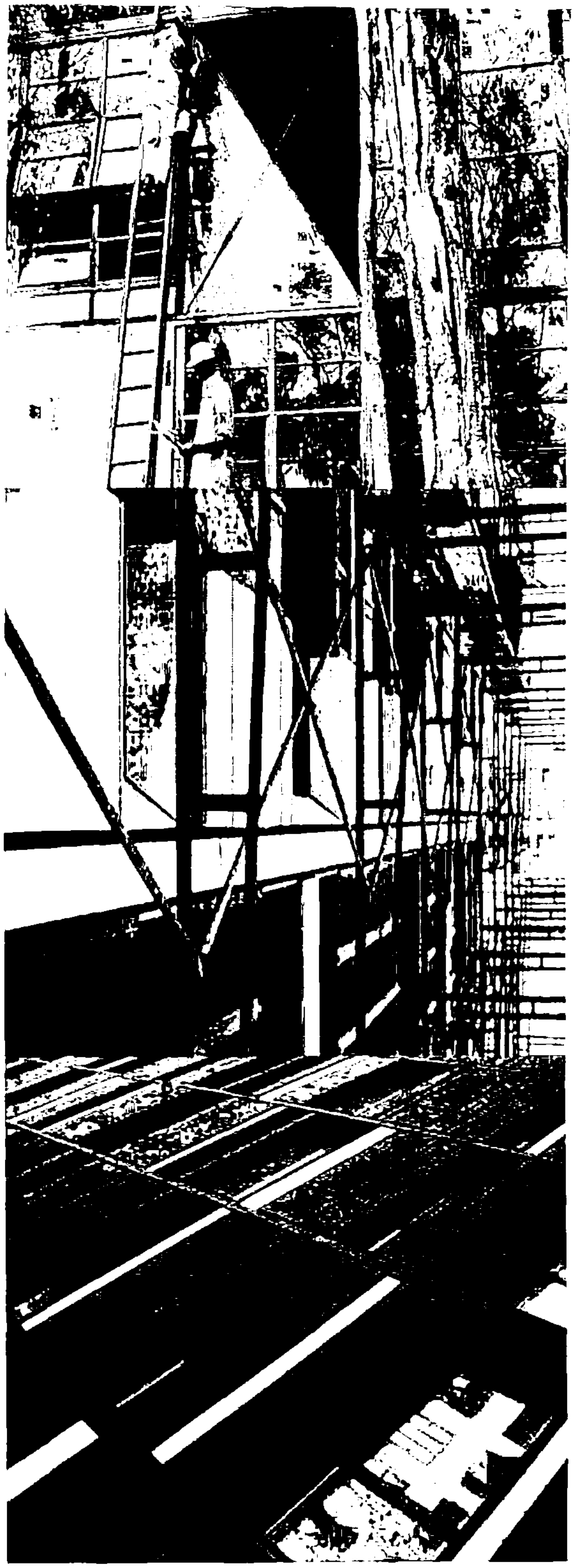

Figure 3

Therefore, as Porter House project manager Jonathan Mallie points out; having the predrilled holes keeps the use of a tape measure to a minimum. For every time one has to use the tape measure on site, there is an increased risk of making mistakes. SHoP's challenge is to build projects where there are no dimensions on drawings and no tape measures on site: to assemble architecture as one would a model airplane.

Shifts in Design Tools

Along with the major shift from standard to custom components are shifts in the tools that produce them: analogical tools have been superseded by digital and/or computational tools. Small scale models based on representation have been replaced by large scale working models and prototypes based on material, geometrical, and structural properties. In the case of the Eames House, the design tools were somewhat limited; most of the manufactured components were chosen from a catalog. Despite the few sketches and the models they produced, the Eames were most preoccupied with the two-dimensional façade, as if they were designing a stage set or composing a painting. Also there was little attention to the detailed connections, as one might find in the construction drawings for their furniture designs. It is likely that, under a design build paradigm, many of the details were simply figured out in the field. In addition, the models the Eames used during the design process were mainly utilized for composition or reconfiguration purposes; unfortunately, they did not make use of prototypes[22] which they so successfully utilized in their furniture and object designs. The one to one physical iteration is crucial in the execution of more integrated design strategies.

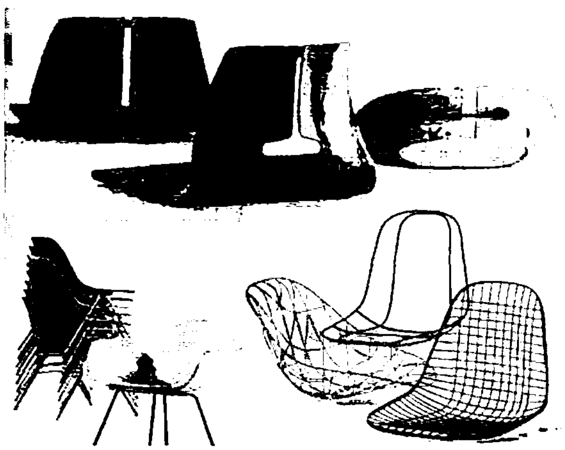

Figure 4. Evidence of iterative studies of material, geometrical, and structural properties of bent plywood, welded wire and molded fiberglass for chair designs by Charles and Ray Eames

In the Porter House, the main design tools were computer aided design, computer aided manufacturing, and data management software. Through the use of computer aided modeling and parametric design software such *Rhino*[23] and *SolidWorks,* data management software such as *Excel*,[24] and laser cutting technology,[25] the generation, fabrication, and organization of the components and their assembly into complex, adaptable systems could be executed with the precision, efficiency, and economy of more discrete, standardized, mass produced systems. Through parameterization, one change in design data would register across the entire system streamlining a once impossible task of making discrete changes accurately and efficiently. Without parameter based software if one local change does not simultaneously register across the entire system it could have huge overall, global repercussions thus breaking down the execution, efficiency, and precision in the generation and fabrication of customized complex designs.

SHoP has stated that:

> This is not a call to replace the human act of design with algorithms, but a critical search for a common language between design and execution." In addition, "Without making the intentional connection between the digital geometries on the screen and the execution of a technique to produce that geometry at building scale, the work seems limited.[26]

Therefore, even though the new design tools are very powerful, one should always be in control of that tool in order to maximize its potential. Again this does not mean to replace the sketch or the designer with the computer, but to allow the computer to act as a catalyst, translator, and organizer in the designing of complex systems.

Through modeling, the in-house laser cutting of the façade system's patterns could be studied. In addition, prototypes of the flanged zinc panels and flashing details were constructed. These processes gave SHoP an idea of how the system would actually work, and what the finishes looked like before the entire system was finally assembled. These processes allowed modifications to be made, *before* actual construction began. The prototype acting as catalyst in design processes is discussed by Michael Speaks in "Design Intelligence: Or Thinking after the End of Metaphysics," he states:

> For example, with rapid-prototyping, the search for prototypes that solve specific problems has today been replaced by prototypes, scenarios, versions, and spreadsheets that are instead used to innovate. The product is not so much the prototype as it is the innovations that occur as a result of thinking with and through the prototype. As MIT Media Lab Professor Michael Schrage argues in *Serious Play: How the World's Best Companies Simulate to Innovate:* 'Quickly and continuously converting new product ideas into crude mock ups and working models turns traditional perceptions of the innovation cycle inside out: instead of using the innovation process to come up with finished prototypes, the prototypes themselves drive the innovation process.'[27]

To clarify, modeling and prototyping is not about a formal representation or simulation, but what SHoP calls "Versioning."

"Versioning relies on the use of recombinant geometries that allow external influences to affect a system without losing the precision of numerical control or the ability to translate these geometries using available construction technology. While simulation remains a useful formal estimate of future organizational strategies, versioning of vector based information allow immediate results to be transformed and refined as the previous tests feed additional data through the framework of intentionality. Both the desired design objectives and methodology thereby become simultaneously accelerated and adaptive." [28]

SHoP's research of the zinc façade system's geometrical, material, and structural properties, as well as its size limitations, enabled them to maximize its potential as components and its assembly into an integrated, custom, and yet adaptable system: the research translates into data input, parameters, or top-down rules from which an output, or a bottom-up complex system emerges.

Shifts in Fabrication and Manufacturing Processes and Technologies

In the Eames House most of the components were mass produced. And since all of the components came in standard sizes, materials, and finishes; at the time the technology was not available to produce customized pieces in mass quantities: a custom piece had to be custom fabricated. Under the mass production paradigm:

> ...systems of gauges and fixtures were developed as key components of the new machinery. The gauges allowed both operators and supervisors to monitor machines so that any discrepancies could be immediately detected. To prevent small differences in how parts were fixed to the machines from multiplying across each operation, a reference point was designed into each part and the fixtures specially designed for the reference point. Together, the innovations underlying these first two characteristics of the American System greatly increased quality, uniformity, and productivity. [29]

> *...any complexities or custom work would upset the production process and result in much higher costs.*[30]

The machines used at the time, because they operated mechanically, had to be readjusted, or recalibrated manually to fabricate custom components. Through mass customization the process allows one to create and fabricate custom components with extreme numerical precision and tolerance. Through the file to factory approach, SHoP's CAD files directly controlled the fabricator's robotic laser cutter machinery; all changes could be updated in real time. Through laser cutting technology, the Porter House zinc panels were directly inscribed with an indexed number and fastening holes.

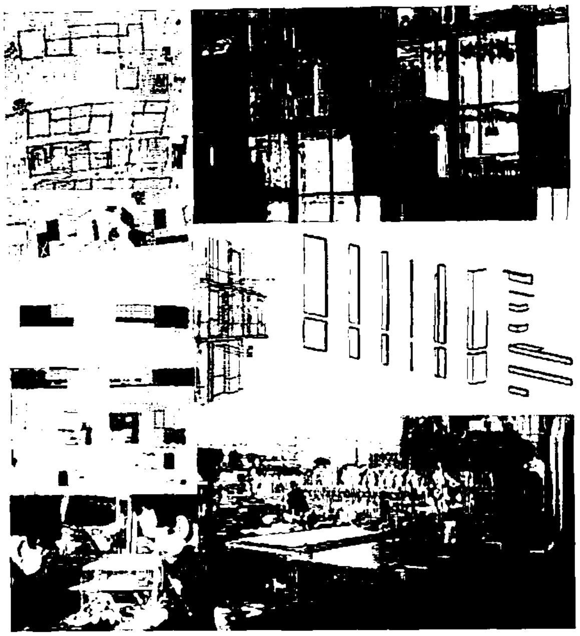

Figure 5

Left Images:
Shifts in Design Tools: Two dimensional pencil and watercolor sketches, orthographic drawings, and small scaled models based on representation versus physical properties were the main design tools used in the Eames House

Right Images:
Shifts in Design Tools: Three dimensional modeling and parametric design software such as *Rhino* and *Solidworks* afford a 'file to factory' approach utilizing computer aided manufacturing such as the Maloya Laser cutting machinery that was used to cut the Porter House zinc panels

> In manufacturing industries, computer numerical control, direct numerical control, and industrial robots greatly increase manufacturing flexibility by controlling parts manufacture through software programming. Flexible manufacturing systems extend this by allowing all members of a family of parts to be manufactured at will and at random. Within a predetermined envelope of variety, there are no cost penalties for manufacturing any one part versus another, yielding a manufacturing system that can quickly respond to changes in demand. Computer aided design - computer aided manufacturing allows design modification and even new designs to be quickly developed with manufacturing requirements automatically generated from the design specifications.[31]

Shifts in Notational Systems

Shifts in notational systems have occurred as well, from scaled and dimensioned orthographic drawings to axonometric and nested template drawings with no scale or dimensions.[32] In the Eames house the notational systems consisted primarily of scaled and dimensioned orthographic drawings; specifically two dimensional plans, sections, and elevations. This notational system already begs the question of what happens in the third dimension? What happens when the building turns the corner? These systems cause segregation and stoppage at the ends of the elevation; they also lend themselves to building components and assemblies as discrete postage stamps, versus integrated envelopes or wrappers. They also require more interpretation and translation on the part of the builder or fabricator. This often leaves one to 'figure out' in the field how the components are to be assembled; which frequently compromises original design intentions.

SHoP makes particular use of exploded axonometric and unfolded nested template notational systems. Having both of these notations on one page, communicates, in tandem, the components and their assembly into a three dimensional system. They also inscribe on each nested template a number that is indexed into an Excel spreadsheet, and a diagram of its installation sequence. What is also interesting about this notational system is that it does not require scale or dimensions. It produces simple instructions for assembly, instead of abstract interpretations that occur through cross referencing between small and large scaled drawings [which are typically located on different sheets in the construction documents]. SHoP states:

> The optimization of an assembly-based technique requires revised drawing procedures that better facilitate the fabrication and construction processes.[33]

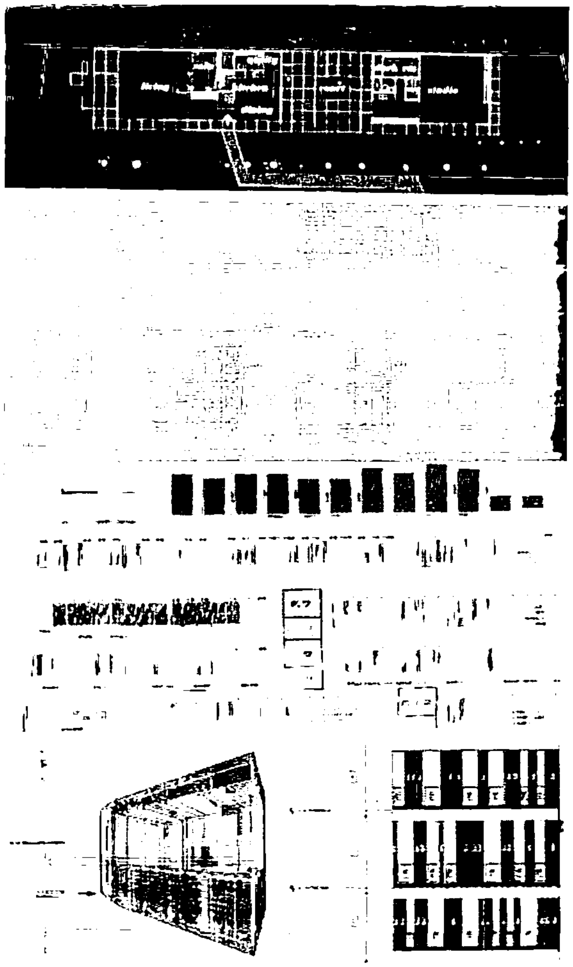

Figure 6

Top Images:
The Eames House notational systems were a two dimensional and cross referenced plans, sections, and elevations

Bottom Images:
The Porter house notational systems were nested template drawing indexed to excel spreadsheets for organization and updating any modification that may occur and axonometric drawing indexed to installation sequence diagram

Shifts in Organizational Structures and Construction Processes

This last paradigm shift bears less relation to shifts of manufacturing technologies, and yet the attitudes of integration versus discreteness are quite similar. Operating within an integrated and collaborative structure; the client, the architect, as well as the engineers, contractors, and fabricators, all play an integral role during the entire project. This approach saves time and money, and avoids many of the conflicts caused by the opaqueness of discretely phased and subcontracted organizational structures or construction processes. It is a fast-track approach that is simultaneously coordinated and demands that every player has a stake in the final outcome.

The Eames House, grew out of a collaboration between themselves, other modern architects, and John Entenza, the developer of the Case Study House Program. The Eames House was a case study, for examining the most progressive way to build or invest in architecture. Similarly, the Porter House was a collaborative effort between Shop Architects and development and construction management firm Jeffrey M. Brown Associates. SHoP approached Jeffrey Brown to develop the property, believing they shared similar urban and aesthetic visions.

The Eames objective of building an entire house with industrial off-the-shelf components is still astonishing, and such a project would not have been feasible if the Eames had not built relationships or a knowledge base from previous collaborations with industrial manufacturers.[34] Also their willingness to collaborate with an engineer was unheard of in house construction at that time. Engineer Edgardo Contini was brought into the Eames House project from the beginning to help them layout the steel framing plans.

In addition to the developer-architect collaboration, SHoP also utilized expert metal fabricators, Maloya Laser, and roofing contractors, Nick and L. Martone.[35] This ensured a level of expertise in handling the unusual use of roofing material to construct a façade system for the entire perimeter of the building. Furthermore, because the Porter House was a complex addition to an existing structure, engineers, Buro Happold were also brought in from the beginning to execute the mechanical and structural gymnastics of re-distributing new services and structural loads.[36]

Future Directions

The Eames House was a paradox, since it was intended to be universally mass produced, but at the same time had a strong desire to be customizable. The design's overall merit is still somewhat questionable, though perhaps only because it lacked the iteration, the principles of integration, or the technology to do so to meet its objectives.

Through the appropriation of new manufacturing and computational tools, processes, and technologies, architecture does have the potential to move towards mass customization; it is already being implemented in other projects by SHoP. This evidences that their zinc façade system is a repetitive yet differentiated system that can adapt to varied site conditions, budgets, programs, climates, etc. SHoP also streamlines and refines the zinc façade system in each project they design. The systems are still 'case studies' or 'prototypes' open to improvement and refinement.

If the Eames had continued with the Case Study House series, they too could have had the opportunity to refine and adapt their components and system, but perhaps their already proven success in object, furniture, exhibition design, and film prevented them from pursuing such an arduous task. Charles Eames loved object and furniture design for greater control and quicker results one could experience working at smaller scales. SHoP's system affords the design benefits at any scale.

Once again as Gideon states:

> Experiment had already proved that an organism was not entirely resolvable into its components; that it consisted of more than a simple sum of its parts. In the whole hierarchy of biological pattern, from the single cell to the complex human organism, there exist always centers directing the genesis of the various parts.[37]

This quote emphasises the crucial importance of the interconnections between the local and global. If architectural practices begin to think more about these worlds within worlds, specifically the simple rules underlying the emergence of complex systems, then perhaps we can design buildings that can adapt and 'slide in scale' as deftly as Shop's zinc façade system; there is no question we certainly have the tools, processes, and technologies to do so.

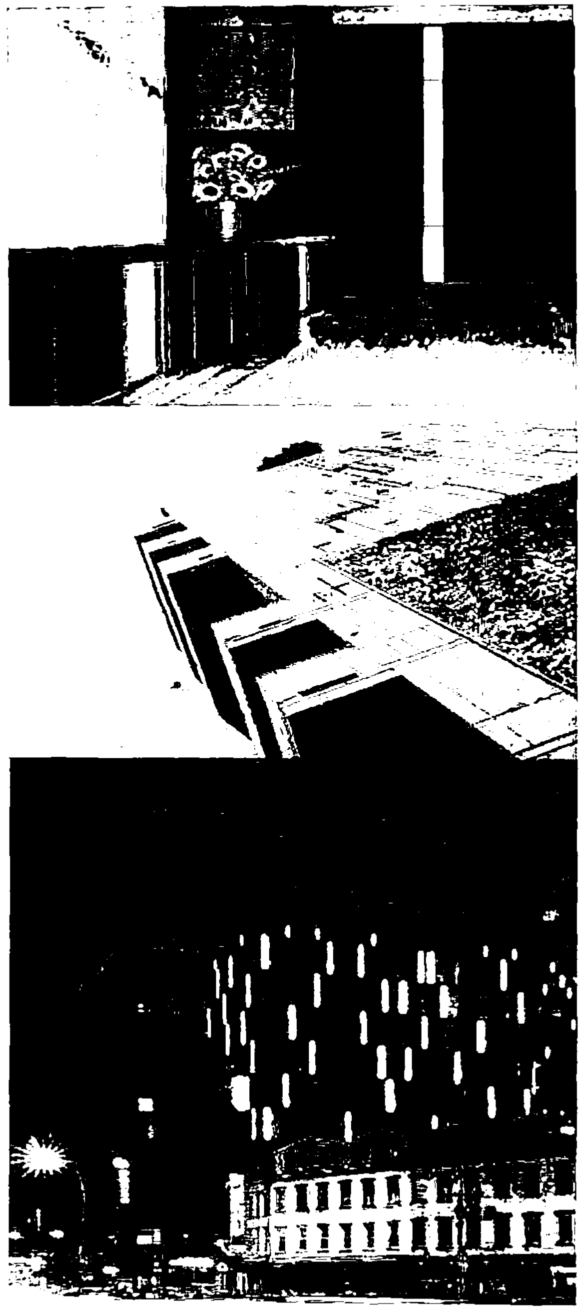

Figure 7

Top, Middle and Bottom Images:
Evidence of the scalar adaptations of the zinc façade system in the Porter House: from the scale of the objects in the interiors, to the scale of the façade in the building, to the scale of a iconic beacon light in the city

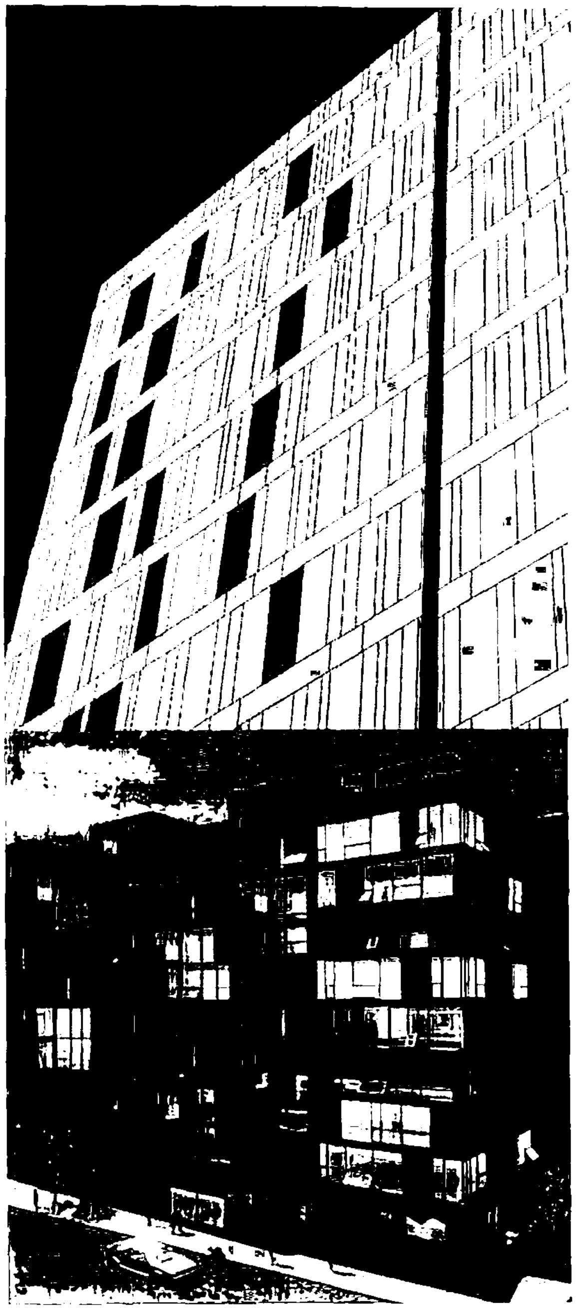

Figure 8

Top Image:
In a renovation of an existing office tower in Philadelphia, the zinc façade system was used her eto give the building a new skin.

Bottom Image:
SHoP is in the final design phases of another multifamily housing project, also in Philadelphia were they will once again utilize the zinc façade system. In this particular project they are investigating orienting the system horizontally versus vertically.

ENDNOTES

1. Reflecting upon the quote by Gideon, strictly mechanistic attitudes ultimately lead to, in most cases, discrete systems. If systems cannot be resolved simply by the components alone, but rather through the DNA or rules that comprise them, their interaction with other components, and ultimately their behaviors in a complex system, as he suggests, then this leads to, in most cases, more integrated systems. in *Mechanization Takes Command*. Gideon, Sigfreid, [Oxford: Oxford University Press, 1948]. p. 718.

2. "Scientific historian Thomas Kuhn defines paradigm as an accepted model or pattern that establishes an informational framework and set of rules by which its practitioners view the world." in *Mass Customization: The New Frontier in Business Competition*. Pine II, Joseph, Foreword by Stan Davis. [Boston: Harvard Business School Press, 1993], p. 24.

3. In this essay I will focus primarily the project's exterior envelopes, not their interiors, etc.

4. This investigation is based solely on evidence from text and images presented in books. Therefore these findings may not be as accurate if one were to the view the drawings, visit the project, or interview the architects in person in regards to the Eames House. In regards to the Porter House by SHoP, I visited the project, the office and interviewed the project manager.

5. Pine II, Joseph, Foreword by Stan Davis, *Mass Customization: The New Frontier in Business Competition* [Boston: Harvard Business School Press, 1993], pp. x-xii.

6. Ibid., pp. 10-14.

7. Ibid., pp. 11-12.

8. Ibid., pp. 14-32.

9. Ibid., p. 15

10. Ibid., p. 17

11. Ibid., pp.48-49.

12. *SolidWorks* is a parametric three dimensional modeling software, mainly utilized for product design. It is extremely precise so it integrates well with computer aided manufacturing machines.

13. [Although "availability" maybe called into question; because of the postwar climate there was a shortage of materials; and therefore a long lead time for the components to arrive.] in *An Eames*

Primer. Eames, Demetriuos. [New York: Universe Publishing, 2001]. p.136.

14. [Considerable additional cutting, welding and fitting of windows were performed by the Eames Office staff, especially Don Albinson.] in *Eames Design: The Work of Charles and Ray Eames*. Neuhart, James, Neuhart, Marilyn, and Eames, Ray. [New York: Harry N. Abrams Incorporated, 1989]. p. 111.

15. Ibid., p. 111.

16. Steele, James *Eames House: Architecture in Detail*. [Phaidon Press, 2002] p. 19.

17. Ibid., p. 19.

18. The Eames House was built in Pacific Palisades, California, where the climate does not encounter extreme changes; a somewhat 'fail safe' context in terms of universal application of their mass produced system.

19. Fibonacci series is "The resulting sequence is 1, 1, 2, 3, 5, 8, 13, 21, 34, 55,... (Fibonacci omitted the first term in *Liber abaci*); this sequence, in which each number is the sum of the two preceding numbers, has proved extremely fruitful and appears in many different areas of mathematics and science."

20. This technology of integration is similar to the technology in building components called SIPS or Structural Insulated Panels; or even the aluminum honeycomb composites used in airplane manufacturing technologies.

21. Neuhart, James, Neuhart, Marilyn, and Eames, Ray. *Eames Design: The Work of Charles and Ray Eames*. [New York: Harry N. Abrams Incorporated, 1989]. p. 111.

22. Even though the entire Eames House was in way, considered to be a prototype itself, I am speaking of prototypes utilized at a smaller scale before the actual building is built. Parts of the Eames House could have been studied through the use of the prototype.

23. *Rhino* is a 3-D modeling software, mainly used for product and automotive design, but is now being used by architects. It outputs and integrates very well with computer aided manufacturing.

24. *Excel* is data management software that is capable of managing huge amounts of information. Since the panelized system was comprised of many customized components; modifications and organization of these can become extremely complicated. By simply changing numbers in *Excel*, the *Excel* file can then be fed back into the parametric software *SolidWorks* and then recomputed to update all of the files; that are then sent to the fabricator's computer aided laser cutters.

25. "The laser cutter uses a beam of focused light to cut material. Low power laser cutters used typically for model-building can cut paper, card, thin wood and plastic. Higher-wattage lasers are used to cut significant thicknesses of steel. For the most part the laser-cutter can cut only two-dimensional forms out of sheet-stock for soft and hard materials. Used in combination with data efficiency software [such as Excel] for nesting and for the optimization of modules, the laser cutter can provide extremely efficient use of pre-prepared materials." in *New Technologies: New Architectures, PRAXIS: Journal of Writing and Building, Issue 6*. Reeser, Amanda and Shafer, Ashley, ed. [Cambridge, 2004], p. 122.

26. Shop Architects, ed. *Versioning: Evolutionary Techniques in Architecture, Architectural Design Issue*: [London: Wiley Publishing, 2001]. p.7.

27. Ibid. p. 6.

28. Ibid. p. 7.

29. Pine II, Joseph, Foreword by Stan Davis, *Mass Customization: The New Frontier in Business Competition* [Boston: Harvard Business School Press, 1993], p. 17.

30. Ibid., pp. 11-12.

31. Ibid., 48-49.

32. In the case of Shop, even though there are some dimensions on the drawings, this is simply for legal reasons, or reference, the drawings are still not to scale.

33. Shop Architects, ed. *Versioning: Evolutionary Techniques in Architecture, Architectural Design Issue*: [London: Wiley Publishing, 2001]. p. 92.

34. "The Eames-Saarinen entries, which included various kinds of living-room seating and several tables, caused a sensation due to their incorporation of two techniques of assembly. Their designs, which were based on the molding of wood into compound curves, and the cycle welding of rubber to wood, which were then being tested by one of America's leading automobile manufacturers, were so innovative, and came so close to the intent of the competition brief, that they won easily. The production of the series was thwarted by the war effort, yet the techniques involved formed the basis of Charles and Ray Eames furniture design throughout the following decade." In *Eames House*. Steele, James.

35. 'Working with Maloya Laser, a fabricator in Commack, New York, the team laid out the façade system using the 3-D modeling program *Solidworks*. To ensure the proper drainage, they consulted with seasoned roofing contractor Nick Martone of Glen Cove, New York - based L. Martone & Sons, who helped detail the lapped panels so they would function as their own flashing. in *Architecture,* June 2004, p. 80.

36. "The renovation and restoration of the warehouse and the interconnection of the two volumes was also a delicate business. The original structure had two cores opposite each other in the northeast and southwest corners. To provide structural support for the cantilever and to ensure that all of the units received natural light, the architects centralized the core, putting all mechanical equipment on the roof. It was also a challenge to provide the apartments with utility service: The 22-unit building contains eight different apartment layouts, the result of the building's varying profiles - the warehouse, the warehouse and addition together, and the addition alone. Rather than vertically extruding M/E/P systems as they would in a typical tower, the architects had to negotiate services through the three configurations." in *Architecture,* June 2004, p. 76.

37. Gideon, Sigfreid. *Mechanization Takes Command*. [Oxford: Oxford University Press, 1948]. p. 718.