Construction Critical: Technology and Experiment in Designer–Manufacturer Collaboration

Michael D. Gibson
Ball State University

Technology and Critical Approach

In recent decades, architects have adopted into regular practice two specific technologies that move the discipline of design closer to manufacturing and production management: Building Information Modeling methods and software, or B.I.M., and computer-based fabrication. These technologies are common to the prefabricated building industry, and present new, critical modes of collaboration and experimentation between architects and manufacturers using and learning from similar tools and methods.

Today, the potential for collaboration between designers and manufacturers emerges from technological common ground which did not exist in the era of mass-production. This common ground suggests that designers working with prefabrication as practice and theory can collaborate with manufacturing agencies based upon shared technologies of B.I.M. and computer-based fabrication. Technology may allow collaborative projects to emerge from *within* rather than outside the technical contexts of construction, thus presenting an opportunity to develop a *critical method* (after Tafuri[1]) related to prefabrication. Design in this context emerges as *construction critical*.

Two cases in collaboration illustrate experimentation in this technological common-ground. The regional context of this research – specifically Indiana – had formerly been prohibitive of this sort of work, as a result of the former, product-limited manufacturing model typical in the mobile home industry. Today's manufacturing model, in contrast, applies a range of new technologies for product management and manufacturing that provide the customization and efficiency demanded by the market. Coincidentally, these technologies provide opportunities for collaboration between industry and designers, where new methods can be implemented with greater effectiveness and far less risk.

Unlike the days of T-squares and vellum, designers today are engaged, simultaneously with manufacturers, in a revolution in information and production methods. In collaboration, prefab technology proves to be more than software and machinery, but also the set of implications which surround prefab technology's application, process, and objectives. Thus Building Information Modeling and computer-based fabrication are not merely "used" – they have particular meanings in the context of manufacturing and construction, and they have particular impacts on production and process.

Peter McCleary has written about "technology" as consisting of three levels (based on Heidegger's environmental philosophy) engaging "both reflection and action": "the mediation of technics (i.e., technical equipment) which are contextually arranged as techniques (i.e., technical processes); and that experience is conceptualized from the architect's reflection-in-action and then formalized as technology (i.e., technical theories)."[2]

The entire history of prefabrication technology in construction is weighted towards the first two manifestations of technology: technics and techniques. Here we can observe prefabrication as the whole collection of off-site construction methods, matching particular prefabricated approaches to the realization of various conveniences and efficiencies. However, the overall progress of prefabrication until the present lacks this element of "reflection-in-action": genuinely new methods in prefabrication are uncommon, and industrial production has realized a limited effect on the look and substance of manufactured buildings. Especially in the markets of single family residential and low-end commercial, prefabrication has amounted to little more than "another way to do get the same thing." The adoption of B.I.M. and computer-based fabrication to these industries reaches this end, and little more.

Two Cases in Collaborative Experiment

The following research and its attempt towards *construction critical* seeks this "reflection-in-action," taking the technologies of B.I.M. and computer-based manufacturing as a starting point, and contextualizing these technologies as processes within collaborative experiments, engaging "the makers" and aimed at real-world prototypes. This paper first presents a summary of research which emerged from observing the production methods and practices of two companies in the prefabricated building industry. Discussing research with leaders of these companies openly led to informal collaboration in both cases which informed two experimental prefabricated prototypes. The first prototype involves collaboration with Ferrell and Barker Construction Company of New Castle, Indiana while the second prototype involves collaboration with Truss Manufacturing Company in Westfield, Indiana (Fig. 1). The research has been conducted at Ball State University in Muncie, Indiana, and work on both prototypes is ongoing.

In the interest of pursuing collaborative, technology-based research in prefabricated building systems, specifically "light" wood construction (i.e., the use of conventional "two-by" framing), I developed the two research explorations which would examine two differing prefab building strategies using primarily a full-size construction prototype. Collaborators in both projects are smaller-scale prefab operations in the region, and both companies contributed to the construction of the prototype. In each case, the prefab systems developed resulted from direct observation of the manufacturer's working process – their combined use of technology, labor, and materials for design and production methods. Each prototype exhibits a component or system which is original to the research, but which could not have been conceived without the feedback provided in collaboration.

Fig. 1. Prefabricated panel operation of Ferrell and Barker (L) and computer controlled saw mill at Truss Manufacturing Company

The intent of each prototype as a prefab proposition involved strategies for increased material efficiency and the deployment of computer-based fabrication for light wood prefabrication, while exploring also the systemization of these components within B.I.M. and their relationship to conventional wood regulatory systems. These prototypes have become the basis for some very interesting conversations related to design and manufacturing which I hope to share as part of future project dissemination.

Collaboration with Ferrell and Barker Construction Company: New Castle, Indiana

Ferrell and Barker have sustained a medium-sized operation that produces prefabricating wall panels for construction projects in which they typically serve as general contractors. With a licensed architect on staff, they are a true "design-build" company in which they typically deliver the entire process of design and construction. Their methods for panel construction are based on decades of experience in the field, in which they have been able to incrementally collect knowledge on improving panel connections, controlling quality, and optimizing time constructing panels in the shop. Two separate B.I.M. software systems are used by Ferrell and Barker to develop wall panelization schemes for projects, manage construction timelines, and provide detailed and highly accurate cost estimating for projects. B.I.M. allows Ferrell and Barker a high degree of control over the resources they directly introduce to the project: framing lumber and the skilled labor retained for building panels in their shop.

At the time of construction, panel elevations and schedules are exported directly from the project's B.I.M. model, along with floor plans and other drawings in which panel framing and notations are further described. Yet despite the consistent and efficient use of B.I.M., in the end the various panel drawings become conventional construction and "shop" drawings. Panels are constructed as single units working from panel elevations and notes on paper. Various framing elements (plates, headers, etc.) are cut and penciled first, and then stud framing and full window and door openings, built using an in-house developed jig system, are added. Roofs and floors are not modularized, but precut and assembled on site.

The most critical part of Ferrell and Barker's construction practice seems to be the use of B.I.M. Yet the full potential of B.I.M. for creating panel schemes is unrealized, because the projects themselves are not yet designed in the B.I.M. system: rather, they are designed as two-dimensional CAD drawings without the panels or framing yet defined. Additionally, the conventions Ferrell and Barker use for panel construction have yet to be fully tested against their systems for estimating and project management: for example, they don't use estimating to "test" different panelizing scenarios against each other to determine, based on simulation, which is most cost effective.

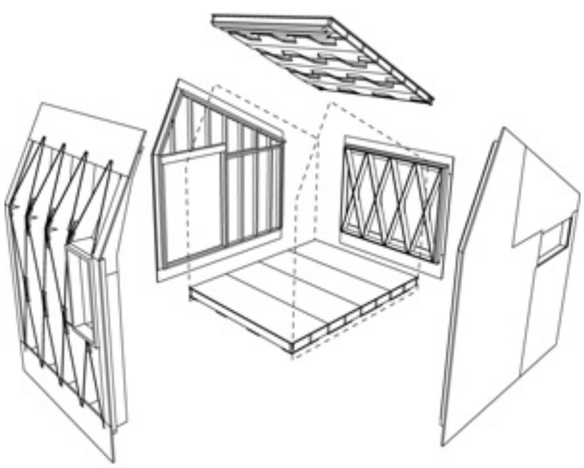

Fig. 2. Subassemblies in the "lattice-frame" mock-up: conventional side wall construction with CNC cut sheathing tiles, stressed-skin floor and roof panels, and plywood lattice panels

Lattice-frame Prototype[3]

Collaboration with Ferrell in Barker involved the construction of a prototype to study these issues: namely the deployment of CNC milling to develop parts and assembly systems, the development of differentiated wall panel systems (rather than the panelization of a "mono-system"), the use of floor and roof panels using a stressed-skin design, and the way in which these systems may relate to systemization in a B.I.M. model. Each of these developments related in some way to saving material and cost. The result of this collaboration was a full-size prototype with pieces milled on a 3-axis CNC router and joined into subassemblies in Ferrell and Barker's facility, without the use of paper drawings or plans. Sixteen completed subassemblies were transported to campus where they were joined and erected (Figs. 2 and 3).

Fig. 3. Completed lattice-frame mock-up, showing all systems demonstrated at full scale

"Light" framing systems such as wood are based on the convenience and redundancy of a "mono-system": that is, dimensional lumber for load-bearing parts of the system used in the same manner to construct non-structural interior partitions. In contrast, the prototype employs an "informed construction strategy" which uses an experimental lattice construction system for panels without vertical loading. The status of these lattices as *non-load bearing assemblies* can allow them to avoid regulation as walls in the building code, thus implying perhaps lower cost than field-finished, structurally regulated wall panels.

The system uses plywood, rather than dimensional lumber, to create a lattice composed of diagonal members. Members are connected with bolts and plywood plates. The sum of this system, beyond saving dimensional lumber, is a "lightful" panel that could perform like glazing or a daylighting panel when clad with either structurally reinforced plastic or cellular polycarbonate. Additional thermal resistance could be provided by translucent fiber within the lattice cells.

For the floor and roof spans, the prototype employs stressed skin floor modules prefabricated using structurally adhered plywood on the bottom with a pre-assembled subfloor on the top.[4] Short spans, in the range of ten to twelve feet, allow the use of smaller framing members: using engineered lumber, six inch deep members are permissible by code.[5] The stressed-skin diaphragm in the modules, in this case, provides stiffness for members used at maximum spans.

The benefits of a prefab system with short spans and maximizing the use of lattice walls over conventional panels can be assessed comparatively using B.I.M., with a model with conventional construction methods and equal floor area available for side by side comparison. A detailed experiment is pending, but preliminary assessment based on the conceptual design of a small house (Fig. 4) suggests that these methods can reduce linear feet of stud wall construction 50% or more, and reduce floor and roof framing from typical sizes (twelve- or ten-inch depth) to six-inch depths.

Ideally, the B.I.M. developed for this system would work with the panels themselves as parametrically controlled components that could be configured and manipulated *as assemblies* during design, although typical architectural B.I.M. systems (such as Revit) do not readily support the modeling of walls with real framing components or the division of walls into panels. Instead, the most useful B.I.M. would be based on a *system* of panel types that could be controlled, organized, assessed for performance and cost impact, and directly fabricated from a single B.I.M. model.

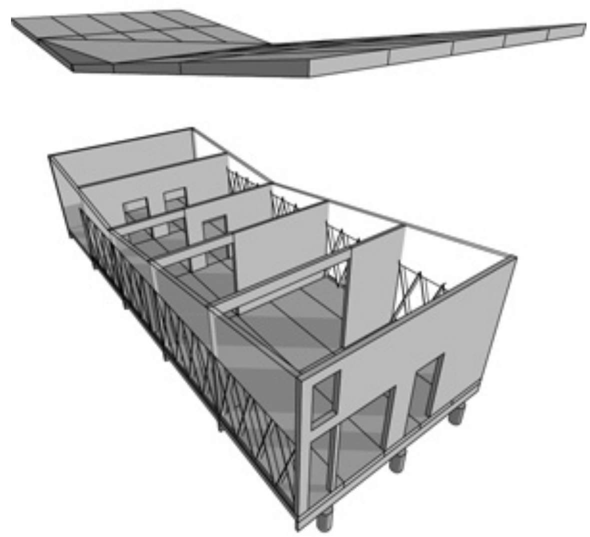

Fig. 4. Conceptual design for a small house: six interior walls comprise vertical load-bearing system, floor and roof spans are approximately ten feet, and remaining exterior walls use plywood lattices and light-weight panels

Collaboration with Truss Manufacturing Company: Westfield, Indiana

Truss Manufacturing Company is a medium-scale manufacturing operation that has been making pre-manufactured roof trusses for nearly 50 years and was one of the first manufactures in the region to adopt computerized design analysis to component cutting system at their facility. Software used in this process permits the creation and organization of individual roof trusses, members, and connections in a 3-dimensional computer model. In turn, the model operates as a B.I.M. that is used for structural reports analyzing both the overall system and each individual truss, as well as detailed estimates which include material consumption, waste, manufacturing time, and schedules. Computers in the office then send these truss "jobs" to a computer-controlled saw mill on the manufacturing floor which receives all of the truss components and quantities as a "batch." This batch, with other pending batches, is organized into a queue, which optimizes material usage. Optimization of manufacturing provides a competitive edge: competitive bids are delivered using higher quality materials and quicker delivery than many competitors.

Yet Truss Manufacturing Company's technology-rich process is compromised by their role in projects. Three-dimensional modeling and analysis are difficult to support in the context of bid jobs, and their CAD operators frequently identify geometric mistakes and other discrepancies in the mid- and upper-market tract housing in which they are typically contracted. Builders and architects for these projects provide only paper drawings – imported 3D models have not been used yet in the system. And lastly, the structural optimization of these roof systems hinges on particular parameters for walls and foundation below the roof: factors of the job which Truss Manufacturing does not control.

Shot-frame Prototype[6]

Work on a competition entry for a super-low-cost single family home was the initial basis for collaboration with Truss Manufacturing Company. The competition entry proposed the use of their digital B.I.M. to fabrication manufacturing process to create a repeating-section structural frame: a "shot-frame" based on the typology of the "shotgun" and other repeating-section framing systems. Similar to a prefabricated pole building, this frame comprised a continuous structural section from floor, to wall, to roof. The premise of appropriating this technology for the *entire* frame of the house was simple: if Truss Manufacturing's process could keep the cost of truss batches for complex, roof-intensive suburban housing into the range of a few thousand dollars, this technology could provide substantial controls for materials, costs, and labor for the *entire* framing system while permitting complexity and variation (Fig. 5). Truss Manufacturing Company, during the spring of 2009, will be assisting with the design and prefabrication of a full-size mock-up of this system.

The set of building sections as an integrated "unit" presents several advantages. First, as a system of defined pieces, the sections can provide a clear account of material and labor consumption, as well as fit together with tightly controlled tolerances. Secondly, the capability of simulating the structural behavior of these defined pieces can allow the structural certification of the system on a per-project basis, circumventing the regulatory codes related to the use of conventional framing members.

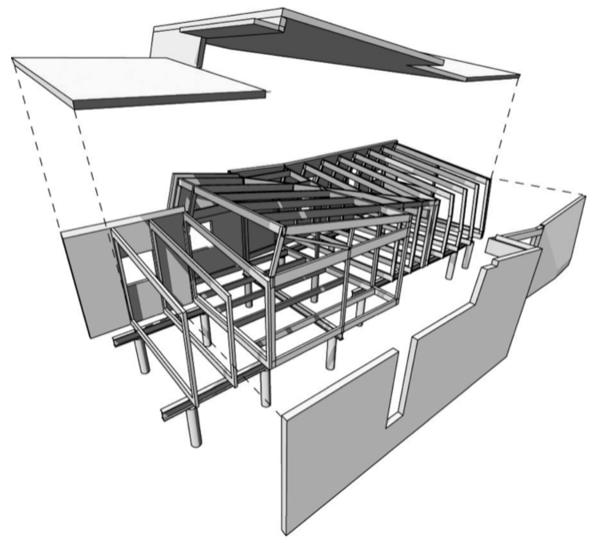

Fig. 5. Early concept for shot-frame system, utilizing prefabricated building sections and S.I.P. panels

This is already the practice in the custom truss industry, since building codes have provisions for only standard truss and rafter configurations: while moving this practice to light framing at the scale of the building might be impossible, a structural scheme organized around defined units makes analysis more direct.

The proposed system to be studied would "double up" section frames made of two-inch lumber and nest additional, heavier gauge steel connecting plates between them to create a unit twice as "thick" as a conventional truss. Sections, as a result, could be spaced in larger increments in a fashion similar to pole construction, perhaps achieving four-foot intervals. A consequence of both the spacing and structural design is that walls and purlin substructure between section frames can be further lightened and optimized, while maintaining the structural primacy of the system of sections.

Rather than work with parametric wall assemblies, the parametric armature of the associated B.I.M. model for this system would be based on the frame-sections. Each would prescribe a "stitch" in the model by which the envelope (walls, floors, roofs, etc.) would respond. Similar to the case of working with panels, architectural B.I.M. software has extremely limited capability in working with framing, especially framing which must be truly operative (affecting other components) in the hierarchy of the model. The systems at Truss Manufacturing Company are set up to provide this modeling capability, however, and it is conceivable to emulate the functions of their software by setting up a customized B.I.M. with a virtual "armature" that could be parametrically adjusted for any given project.

Points for Collaboration: Reflection in Action

Collaboration through research with these companies supports the assertion that collaboration today, in the context of new technologies for design and manufacturing, carries with it entirely different possibilities than those which the modernist prefab pioneers working towards *mass production*.

For architects like Walter Gropius, factory-built architecture required substantial outside investment, a large manufacturer willing to retool and take on risk in order to produce his product, and realize the large-volume purchasing needed to support manufacturing – among other issues. Today's market paradigm is entirely different, focused on a different set of theoretical and practical ideals. This idea is characterized in Kieran and Timberlake's book Refabricating Architecture: architecture, in reflecting emerging trends in manufacturing, must follow the ideal of "mass-customization" introduced by Dell Computer and other companies.[7]

While most of the examples of prefabrication available to us are ordinary, mundane buildings and systems, the push for mass-customization has provided the climate for prefabrication operations of a variety of sizes and specializations to emerge: both Ferrell and Barker and Truss Manufacturing Company are consequences of this market force towards mass-customization. These companies are neither "factories" nor high-cost specialty producers. Rather, they specialize in the lower market segment, in helping clients realize inexpensive buildings with even lower cost. With many in the full-service building market, these manufacturers are numerous and available to architects and designers who can work through the processes of technology, rather than from the rubric of traditional architect-builder relationships. And while Kieran and Timberlake imply that changes in prefab will be led by large contractors in the spirit of the "OEMs of the automotive world"[8], a technology-active collaborative model can be cultivated at a much smaller scale with designer/builder/manufacturer partnerships.

Technological Processes Instead of Products: Informed Construction Strategies

Current technologies engaging architectural design and construction have closed the processes of concept development, experimentation, and execution into a direct, interrelated process. This presents a radical difference from the technological world of the early twentieth century in the practices of the early prefab pioneers, when collaboration amounted to a long term partnership requiring the shared burden of substantial resources.

Collaborative experimentation today, as a result of technology, requires far fewer resources and can move from concept to prototype to market rapidly. Informed construction strategies are the immediate consequence of this speed of realization: construction concepts via B.I.M. can be simulated virtually and prototypes built directly from computer models, with the designer-manufacturer teams afforded the possibility of directly observing results. A technology-driven process, rather than the factory built product, characterizes practices specializing in prefab design today in which industry is a collaborating participant. This approach to process is reflected in the work of present-day practitioners, who have been able to use technology toward developing specialization in prefabricated design and execution. In particular, Anderson and Anderson architects have built their design-build practice model around "incremental transition from site-based craft and assembly to offsite componentization of building elements" rather than focus on the development of proprietary systems or products.[9] Their approach is not unlike the "box of building units…"[10] predicted by Le Corbusier, in which the architect engages *assembly* rather than *the assembly line.*[11] Anderson and Anderson's innovation in prefab methods is seeded in the understanding of how these construction systems work and how to apply advanced modeling technology and computer-based fabrication techniques towards experimentation with these systems. It can be argued that this sort of practice is based on *informed construction*: where innovative design, through access to technology and prototyping, is based directly on construction, material, and manufacturing imperatives.

In the context of collaboration, this ability to engage construction critically can allow architects and designers to address assembly and componentization directly as well. Scope in prefabricated design may move beyond "looks" and towards the actual regrouping and repackaging of building components, and the technologies used to manage and manufacture within this process. Kieran and Timberlake refer to as the implication of the "process engineer"[12] in design: rethinking of process which understands the imperatives of assembly and manufacturing *rather* than the informational hierarchy of traditional construction standards (i.e., the CSI system).

B.I.M. is particularly relevant to the notion of assembly and componentization in prefab, since its object-modeling software structure ties information directly to components in the computer model. However, the B.I.M. software used widely by architects (namely Revit from Autodesk and ArchiCAD from Graphisoft) categorizes building elements into rather prescriptive categories, based loosely around the CSI system and using discreetly defined walls, floors, and roofs as the basic ordering system for the model. Elements without clear places in this hierarchy are compromised, and these programs have no provision for basic structure like studs and joists. As a consequence, subassemblies that might relate to prefabrication strategies (such as wall *panels*) are not out-of-the-box possibilities. While Kieran and Timberlake call architects to use technology to focus on "…how we do things, not merely what they look like,"[13] architectural B.I.M. is simply not designed to allow an architect to consider a project from constructional imperatives. On the other hand, architects can gain hugely through collaboration with prefab manufacturers and builders in learning what B.I.M. *should* be doing: for example, the already noted observations of Ferrell and Barker and Truss Manufacturing Company, in which B.I.M. models are used intensively for complete building analysis and are informed directly by fabrication and assembly.

Open Technology Channels:
Analysis and Comparative Performance

Today in the area of design and prefabrication there now exists legitimate interest in understanding building analysis and performance. The prototypes described earlier are premised on the capabilities of B.I.M. for tracking materials and costs. Yet in ordinary practice, the capability of B.I.M. to relate construction methods to costs is revolutionary in that, for example, it can be quickly compared how even subtle modifications to a construction system can affect its overall performance and cost. In addition to practical "tweaking," this process of analysis and comparative performance can also legitimize more radical experimentation within prefabricated research. The hypothesized benefits of new methods, systems, and applications can be compared against those existing.

The concurrent use of these technologies by designers and manufactures provides the potential for "open technology channels" in which architects and manufacturers can work openly to improve construction methods, identify variables in design and construction which impact performance and cost, and fold this knowledge back into the process of conceptual development. Such open technology channels will allow prefabricated building to provide increased value to clients while simultaneously expanding the possibilities for design and meaningful (albeit low-risk) experiment: a pattern which Kieran and Timberlake have noted in manufacturing developments of other industries[14].

Prototypes Instead of Projects:
Systemization Through Building Information Models and Computer-Based Fabrication

Perhaps the most commonly cited critique of mass production is its lack of adaptability to the context of site and user: especially in the industrial process of the past, the ability for manufactured products to be varied and "tailored" was limited. In the context of building, prefabrication had to be systematized – in basic form, the factory-made kit fills this purpose. Yet kits required a substantial amount of factory tooling and manufacturing logistics, and kits, as products, must be sold at sustained volumes to maintain profitability: even with 100,000 sales from 1908 to 1940, Sears' kit-based homes did not prove to be a sustainable enterprises as buyers, who could purchase in a package nearly all the materials to build these houses (including pre-cut lumber and even paint), became apprehensive about their responsibilities in preparing site and hiring labor.[15] Today, mass customization, in place of mass production, is the new model for systemization and even manufactured homes, rather standardized in their structure and building methods, have achieved a high degree of variation through their systems of production.

In the context of design practices working with modern prefabrication, technology can make "systematic" design and manufacturing more specific to a given site or user condition. This is cited by Anderson and Anderson, who explain the use of computer-based design and fabrication as providing important "individualities" for each project,[16] which extend to social, environmental, and client-driven criteria. An assessment of their work presents a remarkable range of prefab *systems*, each differing in material and assembly criteria. It is evident that this practice has been able to specialize in the process of making *prototypes instead of projects*.

The prototype differs from the project, perhaps, in that it is a sort of one-off, a direct production from a concept. A project, on the other hand, is a process based on the experiences of other projects, with clear outcomes etc. In Anderson and Anderson's work, many of the projects are presented as "prototypes" when in fact they are projects executed as real, commissioned buildings. It may be asked – when do these projects cease as prototypes and become projects? Traditionally in prefab, the project may have been specialized, executed out of production experience, exactitude, and predictability.

Today's technology for design and fabrication provides production methods that can make any project a prototype, where project-specific information can be seamlessly managed with direct-from-model fabrication.

This presents an entirely different outlook for B.I.M. and computer-based fabrication: these technologies, rather than support the systemization of individual projects or approaches, can support systemization towards continuous variation and experiment.

In the iterative process of research, all projects executed through these technological methods are prototypes, since each can serve as iterations in a larger experiment. In the context of B.I.M., the idea of the prototype relates not just to the parametric properties of the B.I.M. model, but the ability of B.I.M. to work as an information and prefabrication armature for multiple projects. Collaboration in such a context becomes much looser; collaboration may engage these armatures in the development of *systems* for the development of further prototypes, rather than devote resources solely towards projects.

Conclusion

New modes of collaboration and experimentation have little resemblance to the previous attempts by architects working in the first half of the twentieth century to produce mass-manufactured architecture: technology shapes design and building in entirely new ways, rather than simply produces products.

These new ways are characterized by the parallel influence of technology in design and manufacturing within a collaborative process, the ability to readily analyze and interpret projects through technology, and the outcome of projects not as distant ends in building, but as prototypes in which systems for design and production can be meaningfully developed and improved. In order to move forward with research and discourse in prefabricated architecture, it is imperative to look beyond the "failure" of pioneering designers in the mass-production era and focus on the opportunities for collaboration possible in our own era of mass-customization and information technology. It is clear that many of the barriers that hampered Gropius and others in the mass-production days of prefab no longer exist. In contrast, today's design and construction environment is populated with smaller, technology-driven manufactures who exist side by side with smaller, technology-driven design firms, where opportunities outnumber obstacles for collaboration.

Notes

1 Tafuri, Manfredo. "L'Architecture dans le Boudoir: The Language of Criticism and the Criticism of Language." in Architecture Theory Since 1968, K. Michael Hays ed. MIT Press: Cambridge, MA. 2000. p. 149.

2 McCleary, Peter. "Some Characteristics of a New Concept of Technology." in Stein, Jay M. and Kent F. Spreckelmeyer eds. Classic Readings in Architecture. McGraw-Hill: New York, 1999. p. 170.

[3] Credits for Lattice-Frame Prototype: All funding for the project came from a fellowship with the Institute for Digital Fabrication (a unit of the Center for Media Design) at Ball State University. The CNC routing was completed on a Thermwood 3-axis CNC mill. Ferrell and Barker Construction company donated to the project the use of their indoor panel construction facility, approximately 65 wall studs, and transportation of the project at completion. The following Ball State University College of Architecture and Planning students were involved in the project: Kevin McCurdy (M.Arch candidate) in all phases of the project; Dustin Headley (M.Arch candidate), Jared Burt (undergrad), Eric Brockmeyer (M.Arch candidate), and Mark Vanden Akker (undergrad) worked during installation of the prototype.

4 The floor and roof systems are related to a modular floor system proposed by Burkhalter and Sumi Architects and used in the Swiss forestry facilities in Turbenthal and Rheinau (1993 and 1994). Similar methods for created stressed-skin systems have been improvised for created modular roofs with trusses, as well as longer-span floor systems.

[5] The American Wood Council. Span Tables for Joists and Rafters, 2005 edition. American Forest and Paper Association; Washington DC, 2005.

[6] Credits for Shot-Frame Prototype: Funding for the project will be provided through a Ball State Creative Arts Faculty Grant. The logistics of the project are still under development.

[7] Kieran, Stephen and James Timberlake. Refabricating Architecture. McGraw Hill; New York, 2004. p. 133.

[8] Kieran, Stephen *ibid.,* p.43

9 Anderson, Mark and Peter Anderson. Prefab Prototypes: Site Specific Design for Offsite Construction. Princeton Architectural Press; New York, 2007. p.11.

10 Le Corbusier and Pierre Jeanneret. “Five Points Towards a New Architecture.” in Conrads, Ulrich. Programs and Manifestos on 20th Century Architecture. in MIT Press; Cambridge, Mass. 1964. pp. 100-101.

[11] Kieran and Timberlake have demonstrated this approach to working with *assemblies* in their design for prefabricated subcomponents, namely a bathroom vanity that reduces 200 field connections to a single connection. Kieran, Stephen *ibid.* p. 100.

[12] Kieran, Stephen *ibid.* pp. 39-41.

[13] Kieran, Stephen *ibid.* p. 23.

[14] Kieran, Stephen *ibid.* p. 9.

[15] Stevenson, Katherine Cole and H. Ward Jandl. Houses by Mail: A Guide to Houses from Sears, Roebuck, and Company. The Preservation Press; Washington, D.C., 1986. pp. 19-29.

16 Anderson, Mark *ibid*. p. 11.