Chapter 4
An Open-Source Model of Collaboration and Customization in Architecture

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4.1 Architecture, Customs, Industry, and Customization

Customization is a central theme in architecture. Architecture and building construction are typically singular undertakings expressing individuality both in terms of character and customs. Based on tradition, social context, site specificity, and human relations, the production of architecture is defined by one-off prototypes seeking creative uniqueness tailored to users' specific needs. On a primary level, the idea of custom architecture is connected to characterizing one's boundaries and outlining a framework for social interaction.

Mass customization in architecture relates less with primary needs as it does to the commercialized methods of production generated by the industrial revolution. This type of made-to-order personalization designates adaptable and flexible models of production. This adaptability encompasses the capacity to oblige individuals' desires in a mass manufacturing process. Within the field of architecture, mass customization relates predominantly to industrialized building systems as these systems imply a business model of mass production.

Industrialized building systems, prefabrication of architecture or off-site fabrication of sub-assemblies, are not new strategies. Some have described prefabrication as the oldest new idea in architecture [1]. This prefabrication model in architecture is based on the experiments of many generations of builders. From Roman military engineers to medieval master guilds and to Great Britain's early industrialists, all prepared components off-site (precut stones, precut or notched wooden beams, iron beams) to facilitate on-site construction.

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The building industry today is highly industrialized. Architects and builders pick and assemble continuously produced components (doors, windows, beams, finishes, etc.), repeating a highly inefficient design and construction process for each building. This high level of custom building implies waste at almost every level of a building's production but affirms a perceived uniqueness. Our examination of the industry intended to elucidate connections and potentials between mass customization and industrialized building systems with the intention of elevating architecture in terms of efficiency, quality, and personalization.

The desire for an industrialized building process that optimizes construction efficiency, costs, and mass production has spanned eras, customs, cultures, and even public policies [2]. The history of architecture and prefabricated construction recounts this sometimes confluent but often divergent tale. The early twentieth-century economic crises, social turmoil, and industrial development shaped icons of prefabricated architecture. Projects such as Lustron[1] in the United States, AIROH (Aircraft Industries Research Organisation on Housing)[2] in Great Britain, government-owned and government-operated precast concrete panel plants[3] in the USSR, and Sekisui Heim M1 by Sekisui Chemical in Japan[4] all convey the modernist twentieth-century fantasy of factory-produced architecture [3]. Often supported by the transfer of military knowledge and processes to civilian industries, many manufactured architecture experiments were also supported by mega-housing programs in their respective countries [3].

Architectural projects spawned by new industrial materials and methods sustained the founding principles of modernity. From Konrad Wachsmann to Jean Prouvé and Buckminster Fuller [3], the goal of an industrialized, quality, and low-cost architecture for the many was a recurrent obsession for the modern architect.

Since modernity's union of architecture and industry, both fields (architecture and prefabricated construction) have outlined divergent trajectories. Architecture established an idealized representation of prefabrication, while the prefabricated construction industry has largely remained in a mass production paradigm[5] [2]; early debatable construction methods and repetitive design contributed to the negative connotation that the industry is still trying to relinquish. The evolution from "mobile home" to "modular houses" and to "manufactured homes" suggests a long but stigmatized history.

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[1] www.lustron.org

[2] For a project description, see Carbone, C. (2014)—*Prefabrication experiments (10) Aircraft Industries Research Organisation for Housing—the A.I.R.O.H. house* retrieved from http://prefabricate.blogspot.ca

[3] Carbone, C. (2014)—*Prefabrication experiments (22) Precast concrete* (*pieces*, *panels and boxes*) *in postwar U.S.S.R.* retrieved from http://prefabricate.blogspot.ca

[4] For a project description, see Carbone, C. (2015)—*Prefabrication experiments (62) Sekisui Chemical*'*s Sekisui Heim M1* retrieved from http://prefabricate.blogspot.ca

[5] "since the 1950s architects have retreated from this position, distancing themselves from the factory…factory produced has become a style," Davies C., *The Prefabricated Home*, Reaktion Books, 2005, p51

Mass customization in architecture, although not identified as such, has been the core dispute in the tumultuous relationship between architecture and industrialized building systems. Sigfried Gideon[6] [4], when analyzing the work of Walter Gropius on the relationship between architecture and industry, spoke of the superficial uniqueness of everyday architecture and how the need for this uniqueness hindered the development of industrially produced systems for architecture.

A little over 100 years after Gropius' manifesto on industrialized building systems[7] [5] for housing, architecture and industrialization are converging once more, this time with regards to new information technology and its potential to induce mass customization strategies within architecture. Big data is changing the way architects collaborate [6] and is generating a new paradigm of collaboration and customization within the industry. The theory that data management will encourage prefabrication was highlighted by producers and architects surveyed in the McGraw-Hill's report, *Prefabrication and Modularization*: *Increasing Productivity in the Construction Industry* [7]. Notwithstanding this trend, we suggest that a lack of inventiveness and ancient connotations still stifle innovation potential in this industry sector.

The development of information management software augmented by territorial, demographic, and environmental issues is leading a transformation of our design criteria and lends itself to new production and construction methods. Informed data management is central to this revolution in design and construction methods. However construction as a whole remains relatively distant from these contemporary tools' overall potential. A revolution in design, construction, and management methods articulated to data management will induce a shift toward information-based collaboration provoking an environment conducive to an open exchange of ideas. Autodesk Seek[8] seems to point in the direction of information sharing but not specifically for industrialized building systems.

Our study, financed in part by the Société d'Habitation du Québec, set out to map and characterize the prefabricated building industry in North America, particularly

[6] "Gropius' and Wachsmann's Packaged House system, with its carefully worked out designs of standardized building components, is in the direct line of future development, especially in its concentration upon the production of easily transportable and easily assembled multi-purpose unit parts and not upon the production of complete standardized house types. Nevertheless it had no financial success. Why is this ? …. These difficulties, in the last resort, lie within the present attitude of the house purchaser. No matter how identical in plan and appearance his house may be to all its neighbors in its suburban setting, the man building his own home still likes to believe that he is getting an individual, personal, handmade product." Giedion, S., *Walter Gropius*, *Work and Team Work*, Reinhold, 1954, New York, p76

[7] Gropius submitted his "program zur Gründung einer allgemeine Hausbaugellscahaft auf künsterlich einheitlicher grundlage", m.b.H. (Program for the Founding of a General Housing-Construction Company Following Artistically Uniform Principles) to Rathenau of AEG in April, 1910"; see Herbert G., *The dream of the factory-made house*: *Walter Gropius and Konrad Wachsmann*, MIT press, 1984, Cambridge, p33.

[8] http://seek.autodesk.com/search.htm

existing systems and their customization strategies to examine the potential for cross-pollination between prefab producers.

4.1.1 Customizable Architecture and Its Relationship to Industrialized Building Systems

Modular building, industrialized building systems, manufactured housing, prefabricated architecture, and the mobile home all share the genetics of early twentieth-century Fordism as applied to building construction. The advantages of a climate-controlled environment, standardization, waste reduction, labor efficiency, and bulk material procurement all contributed to the development of the desire for a factory-produced architecture. Advocated as a necessary change in housing production to serve the rapid urbanization that accompanied industrialization, the mass production of architecture in a factory echoed the mass production of other commodities. The convergence of industrial production, architecture, and urbanization was particularly fertile for the design of industrially minded customizable architectural prototypes [3].

The open plan (*plan libre*), proposed by Le Corbusier in 1909 under the name DOM-INO (domicile—innovation), was a structural system emblematic of the union of architecture and industrial production[9] [8]. The free or open plan combined new materials and methods, and reinforced concrete, toward an open post and slab structure that allowed planning flexibility and customization. A grid of small posts or columns defined space horizontally and vertically. This grid replaced preindustrial load-bearing walls and allowed for freedom in planning and three-dimensional organizations. The column/slab system is used today in the construction of most commercial buildings for flexible arrangements. This open plan "plan libre" was a revolution in architecture.

In addition to Le Corbusier's DOM-INO, many architects explored industrialized building systems for housing and pursued tactics for flexibility and adaptability. The Weissenhof neighborhood project orchestrated by Mies van der Rohe at the request of the city of Stuttgart, Germany, in 1927 encompassed 21 proposals by 16 architects. This exhibition of modern placemaking included proposals from Bruno Taut, Le Corbusier, and Walter Gropius and portrayed a potential for the industrialization of architecture.

In America, California more specifically, the Case Study House Program fused industry, architects, and the quest for an industrial but individualized architecture. Implemented by *Arts &Architecture* magazine with the support of its editor John Entenza, the Case Study House Program was based on modern values of innovation, scalability, reproducibility, affordability, and personalization. Thirteen out of

[9] "*Architecture ou révolution.*, *he touches on the idea of revolution*, *both technical and political. By the former*, *he clearly meant the industrial revolution*, *already achieved through the mass production of automobiles*; *by the latter*, *he presumably intended revolutionary socialism fermenting beneath the surface of society and due primarily*, *in his view*, *to the fact that the working class was ill-housed*." Frampton K, *Le Corbusier*, Thames and Hudson, 2001, New York, p31

the 36 residential prototypes were built on the conviction that architecture could be both mass produced and fitted to owners' personalities. In 1949, fed by European avant-garde influences and the transfer of knowledge acquired in military service, Charles Eames designed the Case Study House 8 and collaborated on the Case Study House 9 [9]. Eames explored an open frame structure, a clear span space, structured by a steel skeleton leaving considerable flexibility to potential occupants and users. This variability similar to what Le Corbusier had developed was based on ready-made industrialized components.

In continuing, developing, studying, and probing modern architecture's strategies, N.J. Habraken published *Supports: An Alternative to Mass Housing* in 1972 [10]. This progressive publication was the foundation of the "open building" theory [11], which aims to increase personalization, adaptability, and flexibility of architecture over time. Habraken proposed the separation of common infrastructure (supports) and personal systems (infill) to inform customizable building planning based on a shared substructure. Kendall and Teicher [11] reiterated and continue to sustain these ideas within the "open building" theoretical framework.

The establishment of "open building theory" was influenced by collaborative and customizable building systems that were examined or explored during the twentieth century as patterns for client-based personalization in design and production. Timber Structures Inc.'s Mobilcore provides one such example combining the strengths of on- and off-site construction within a larger made-to-measure framework. Published in the April 15, 1946 edition of *Life* magazine, the 8 × 24 ft. (2.4 × 7.2 m) Mobilcore[10] included all fixtures and appliances. The box-unit service core was divided into bath, mechanical room, and kitchen. For US$2700 (approximately 40 % of a total house price of the era), one could purchase a unit, have it delivered on-site, and then build a custom-made house around it. The organizational variability was articulated to a stable nucleus that optimized factory production for the complex parts of a building.

This type of box-unit construction for mass customization can also be seen in an even more systemic level in Sekisui Chemical's[11] first experiment into the housing market. Sekisui Chemical produced its first modular light steel frame box-unit in 1971: the Sekisui Heim M1.[12] The box-unit's commercial success contributed to lowering its construction costs and increased production capacity and illustrated the then attainable factory-produced adaptable house. The basic module unit was a rectangular prism composed of light-gauge steel-framed edges, which included walls, floors, ceiling, and service cabinets. Multiple cabinet organizations were available and this user-defined element exemplified the beginnings of mass customization strategies within the industry. Each box-unit could be juxtaposed or stacked with complete box-units or a 2/3 fragment of a unit. The stitching of adjacent units was simplified by the juxtaposition of structural edge members.

[10] *Life* magazine April 15, 1946—*Wyatt will use all kinds of building to get the job done*, p34

[11] http://www.sekisuichemical.com/about/division/housing/index.html#h_01

[12] http://www.sekisuiheimm1.com/index_english.html#

The system's variability, in plan and in section, challenged the mass production paradigm that defined most industrialized construction systems. The 2.4 m×4.8 m box-units were based on a familiar 2:1 tatami mat proportion. Each house included a distinct tatami room relating to traditional Japanese housing. This combination of industrialization, variability, and tradition established a new era for prefabricated architecture.

4.2 Industrial Cross-Pollination Toward Innovation

The customizable prefabrication that seemed evident to Timber Structures Inc. or to Sekisui Chemical appears to be permeating into the building industry today. Combining the flexibility of frame construction with factory-produced cores or modules creates a formidable, open customizable industrialized building system.

Kieran and Timberlake's Loblolly house[13] or Alastair Parvin's Wiki-house[14] make a case for an open-source approach to the mass customization of architecture. The theories imbedded within these prototypical projects support our pursuit for a comprehensive strategy for open collaboration toward quality and sustainable architecture.

The manufactured building industry developed from the application of new technologies to the ongoing urbanization of cities. Demographic and economic changes caused by the industrial society pressured government, which placed the burden directly on private industry to solve the growing housing crises. The postindustrial nuclear house and its privatization were the main constituents of the rapid suburbanization of North America, which established the single-family home constructed on-site by a wood frame builder as the nucleus of North American housing and building culture. The manufactured housing industry could not compete with the prevalence of the on-site builder and, as noted by Gideon [4], the superficial customization offered by traditional homebuilder; the purchaser's aspired uniqueness was however offset by an overwhelming homogeneity.

Today's social heterogeneity combined with environmental priorities, progressive design tools, and information management software is federating a fertile environment for the greater use of prefabricated building systems and their customization. Our research focused on customization as it relates to mapping potential collaboration and links between prefab manufacturers. Our research strategy aimed to organize this potential and start working to offer the means and tools for interactive online interaction. These tools would create an environment for choosing, composing, and assembling components and sub-assemblies for buildings, an "open" language for architecture.

[13] "Loblolly House"—American Institute of Architects case study retreived from http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab081572.pdf

[14] http://www.wikihouse.cc

4.2.1 *Research Strategy and Its Evolution*

In an evolving attempt to engage an open-source type collaboration in architecture and to reflect on the industry's potential, we established two complementary data structures: a catalogue of building systems and an annotated list of companies as a basis for a larger industry analysis and as knowledge incubators. We envision these tools as the starting point of an online reference point for prefabrication strategies and their crossbreeding (see Fig. 4.1 for a list fragment and Fig. 4.2 for a sample catalogue page).

Our growing annotated list of 800 companies was undertaken in 2014 and continues to be compiled by cross-referencing literature, trade associations, modular building groups, and a comprehensive keyword search on the internet. This annotated list along with proposed catalogue of case studies is the catalyst for a growing research project that shares information about the industry and more importantly strives to involve manufactures and stakeholders in an agenda of collaborative construction of knowledge.

The list of producers also allowed us to triangulate existing data and to generate a point of view in terms of how the industry works and how it could evolve. The share quantity of "box-unit or module" type producers depicts an industry still dependent on one type of prefabrication. This modular sector represented 72 % of our list. The assembled data also presented the archaic "pattern-book of house types" as the significant model for customization within the industry.

CANADA

COLOMBIE-BRITANNIQUE

ENTREPRISE	Adresse	Ville	Code Postal	AFFILIATION	TYPE	SUR SITE	MODULES	MATÉRIAUX	PERSONNALISATION	SITE WEB
Minaean International Corporation	1055 W Georgia St	Vancouver	V6E 3P3	X	Résidentiel (multi-familiale), kit de	Assemblage	Sectionnel	Métal, panneaux	Système de panneaux adaptable, maison résidentiel, multi-familiale, mass	http://www.minaean.com/
Moduline	1175 Railway St,	Penticton	V2A 5X5	Champion Homes	Résidentiel+Commercial		Sectionnel + Mobile	Bois	Choix limité à des plans pré-définis. Possibilité de modifications de ceux-ci selon	http://www.moduline.ca
Chaparral Industries	3075 Sexsmith	Kelowna			Résidentiel (modulaire,	Installation et Assemblage	Sectionnel + Mobile	Bois	Non définie	www.chaparralhomes.com
Shelter Modular	3294 262 St	Aldergrove	V4W 2X2		Résidentiel temporaire (workforce	Non définie	Sectionnel + Mobile	Bois et métal (conteneurs	Possibilité de créer son propre plan.	www.sheltermodular.com
Britco	1825 Tower Rd	Agassiz	V0M 1A2		Résidentiel collectif		Sectionnel			www.britco.com
Freeport Industries	3522 Red Cloud Way	Westbank	V4T 2G9		Résidentiel (Individuel et collectif),	Assemblage	Sectionnel	Bois	Non définie	www.freeportindustries.ca
Harmony Homes	833 Finns Rd	Kelowna	V1X 5B8	Indiana MHA (MHI	Résidentiel (Multi-familial)	Assemblage	Sectionnel	Bois	Projet custom	http://www.harmonyhomes.net/
Northern Trailer	3355 Sugarloaf	Kamloops	V2C 6B7		Résidences de travail (camp)		Sectionnel			http://www.horizonnorth.ca/
Cratex Container Sales	7664 80 St	Delta	V4G 1C1		Industriel et commercial		Sectionnel Conteneur	Conteneurs		http://www.cratexcontainer.com/
Atco Structures & Logistics	982 Boundary	Prince George	V2N 5T2		Logement de travailleur (camp) et		Sectionnel			http://www.atcosl.com/fr-ca/
Outbuildings	2128 Front St.	North Vancouver	V7H 1A5		Résidentiel (tiny) et agricole		Sectionnel	Bois		http://www.outbuildings.ca/
A-Mobile Mini		Vancouver			Commercial et industriel		Sectionnel + Mobile	Métal		https://www.mobilemini.com/
Eagles Homes	1292 Trans Canada	Salmon Arm	V1E 2T3		Résidentiel et promoteur résidentiel -		Sectionnel + Mobile	Bois	Système sectionnel	www.eaglehomes.ca/
Amco Modular Homes	7401 Industrial	Lantzville	V0R 2H0	Moduline	Résidentiel		Sectionnel + Mobile	Bois		http://www.amcohomes.ca/
Best Buy Homes	1433 Velocity St	Kelowna	V1V 3C2		Résidentiel		Sectionnel + Mobile	Bois		http://www.bestbuyhousing.com/default.asp?LocationSelection=10
Bob Paterson Homes inc.	1200 South Mackenzie	Williams Lake	v2g 3y1				Structural			http://www.bobpatersonhomes.com/
BROOKSWOOD HOMES LTD	3229 - 200th	Langley	V3A 4W4				Sectionnel			http://www.brookswoodhomes.com/
Chaparral Industries Inc.	3075 Sexsmith	Kelowna,	V1X 7T1		résidentiel, coimmercial,		Sectionnel			http://www.chaparralhomes.com/
Columbia River Homes	195 West Airport	Castlegar	V1N 4M5			Offre l'assemblage	Sectionnel			http://www.columbiariverhomes.ca/
Countryside Home Sales	2425 Cranbrook	Cranbrook	V1C 3T3	Winfield Home Systems, a	Résdientiel (neuf ou réutilisé)	Offre le transport	Sectionnel		Offre commercial : paiement mensuel pour acheter.	http://www.countrysidehomesales.ca/
Countryside Manufactured Homes Ltd.	401 Cree Dr	Kamloops	V2H 1G7		Résidentiel		Sectionnel + Mobile			http://csmh.ca/

Fig. 4.1 Excerpt from the list, to see the complete list go to https://drive.google.com/file/d/0B5Te_qsSnKzpWG9KTjdMS0EzZWc/view?usp-sharing

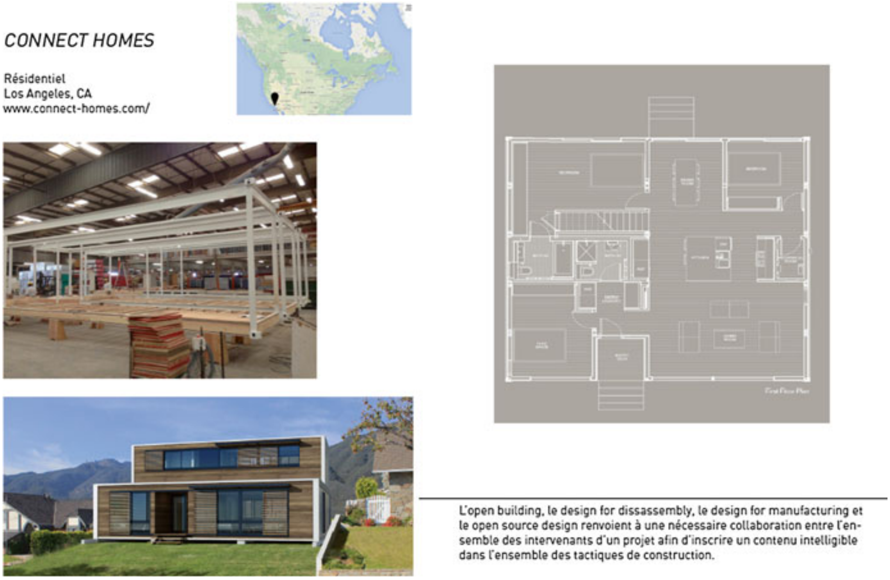

Fig. 4.2 Sample systems catalogue page—images are screen shots from Connect Homes' web site: sample page from report available at https://drive.google.com/file/d/0B5Te_qsSnKzpWG9K-TjdMS0EzZWc/view?usp=sharing (*Source*: Author)

The prefab directory was organized by location: the United States and Canada (province or state and precise address and contact information), by production approaches (modules, panels, components/kits, hybrids) [12] and by customization strategies. Other complementary characteristics such as materials or construction details helped measure dissimilar systems within the same prefabrication model. For example, a module could be framed in wood, steel, or concrete. The data fields are also evolving as we inform our characterization process, as there is no currently accepted theoretical model for grouping industrialized building methods; there are many [13].

Our methodological positions for the data's organization, type (modules, panels and pieces), content (sub-assemblies), and context (United States and Canada) were framed by our objective to elevate our local industry with regard to its undervalued potential and its current production. This localized point of view was also supported by a complementary objective of addressing a market where industrialized building has not taken a foothold.

This specificity is important as Asia, Europe, and Australia have a different industrialized building legacy. The North American market carries a vision of prefabrication and its potential customization influenced by the American dream of the single-family dwelling. In order to stimulate a paradigm shift toward open collaboration and customization, the traditional box-unit modular prefabrication model in the United States and Canada will have to be rerouted toward other building types and strategies. Our preliminary work has allowed us to compare our research with other industry characterizations and has revealed a great potential for innovation within a somewhat conceptually suppressed industry.

4.2.2 Current Approaches to Mass Customization

Our classification positioned modular (room, sections, or house boxes) at 72 %, panel (walls or floors) construction at 21 %, and kit (pieces or components) construction at 13 %. We observed a substantial overlap between modular and panel construction both in terms of business model and market share. The modular segment at 72 % showcased a limited potential for customization as each module is either juxtaposed or stacked. This does not impede customization practices at more internal levels of production such as finishes, interior systems, materials, and fabrication methods (cutting and assembling). The modular and panel segment is largely based on similar construction and customization strategies. A number of manufacturers have begun integrating building information modeling (BIM) [14] and have established a potential for a new type of custom prefab. BIM is changing the way architects and industry collaborate and is creating a fertile environment in which design and production could merge. This is the case of Premier Building Systems[15] from Washington, USA, which articulate their sales pitch to a capacity to tailor fit the home within a system of standard structural insulated panels. This innovation is occurring at a sluggish pace and mostly by experimental projects that are not being mass produced.

The lack of innovation is largely forged by archaic views of building construction and mass production. Our simple cataloguing system of boxes, panels, and pieces, although not the industry standard, illustrated this lack of innovation as most companies share similar business models. The list's secondary objective was to foster a potential cross-utilization of systems: boxes for service cores, panels for building envelope, and pieces for open and adaptable frames. These potential relationships between manufactures and builders could stimulate the industry allowing stakeholders to understand how systems work, their agility, and how they can be employed together toward quality and singular architecture.

The work of Kieran Timberlake for Loblolly house,[16] the work of Bensonwood Homes for corewall,[17] or Project Frog's[18] language of components point out the conclusive capability of industrialized building components to accelerate innovation and cooperation. A collaborative model based on an informed pedigree of interrelated systems could initiate a new era for prefabricated building systems.

Although we did not find large-scale examples of this type of "open" customization, we did find examples of information technology and computer modeling technology driving mass customization. This pattern will continue to drive architecture and industrial collaboration [7]. The outdated conceptual limits between design, fabrication, and construction are collapsing under powerful information management tools for construction [14]. We found that the companies that are

[15] http://www.premiersips.com

[16] "Loblolly House"—American Institute of Architects case study retrieved from http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab081572.pdf

[17] http://www.openprototype.com/press/corewall.pdf

[18] http://projectfrog.com

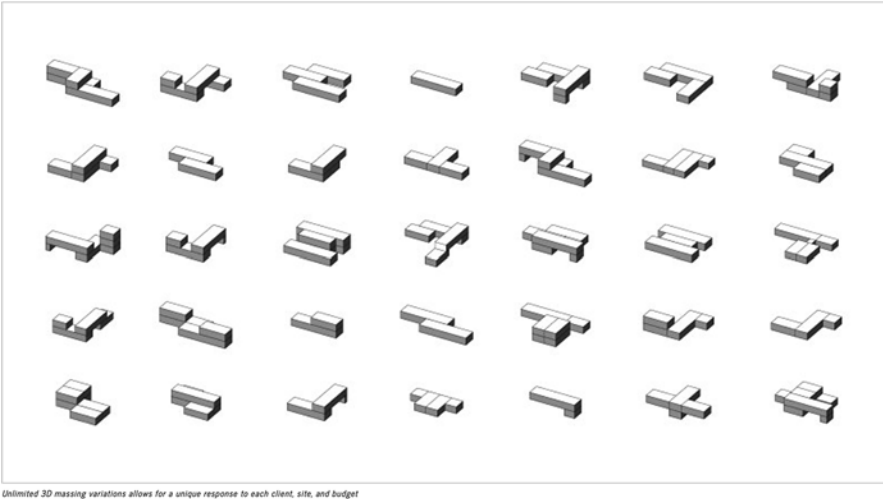

Fig. 4.3 Screen shot of modular configurations from Resolution: 4 Architecture's web site (*Source*: http://re4a.com/the-modern-modular/)

employing technology toward mass customization strategies are at the forefront of innovation, but are fairly marginal in relation to the industry as a whole. It is important to note again that this model applies to what we found within the North American market; Japan, Scandinavia, and Australia would most certainly have given us a totally different data structure as their industrialized building industries have advanced within a different social and contextual framework.

In conjunction with the flexibility and responsiveness of systems to meet various contemporary realities, the housing market is moving toward a customization pattern. The proliferation of lifestyle types is increasing demand for choice and is shifting the marketplace. The diversity of multiple family structures, behavioral individualization, and aging population structures underline the need for new design criteria with variability as its benchmark. The following examples highlight some of the efforts to implement customization in the housing industry either by architects or manufactures. The focus was on design strategies, as well as tools for customization.

(a) The case of Resolution: 4 Architecture: *The Modern Modular*[19] (see Fig. 4.3)
Developed in 2006 by a New York firm, Resolution: 4 Architects, this approach showcases standardization of prefabricated box modules and their potential aggregation. Variable in both vertical and horizontal juxtapositions, the box-unit configurations vary in H, I, L, T, and Z shapes. Each volume is completed off-site and then stitched to other volumes on-site. This adaptable and modular design process responds to an assortment of choices and lifestyles.

[19] http://re4a.com/the-modern-modular/

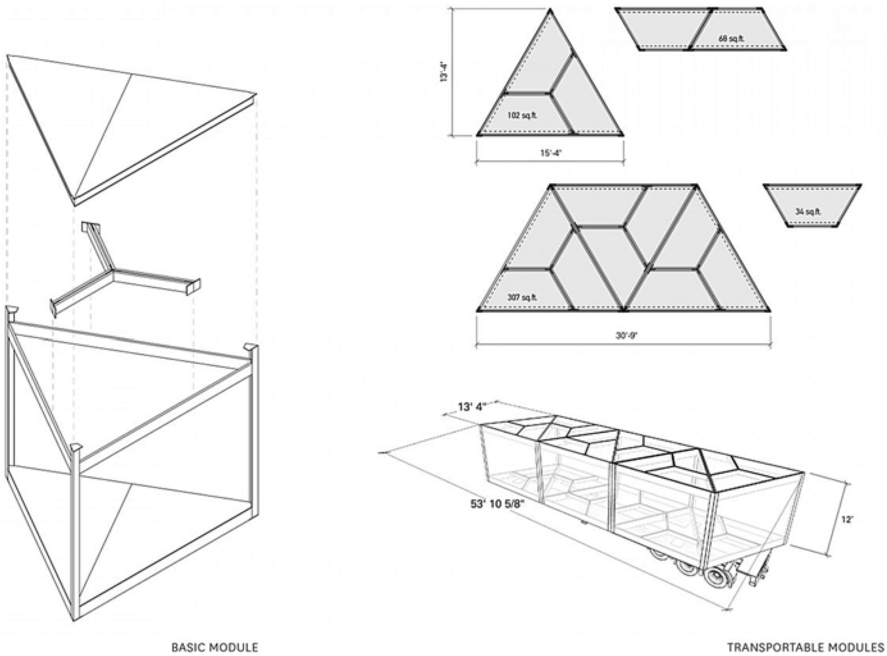

Fig. 4.4 Screen shot of the HOMB basic planning unit from Method Homes' web site (*Source*: http://skylabarchitecture.com/work/taft-residence/#slide1)

Similar to Sekisui Heim M1 in Japan, the volumetric variability is conceived as a response to individual requirements. Each unit is defined by its use: (bathroom, kitchen, office), lifestyle (home office) or living areas. This method of exploring architectural uniqueness within a system of standard components interprets a mass customization based on variable juxtapositions of a kit of space types and functions.

(b) The case of Method Homes: HOMB Modular Prefab[20] (see Fig. 4.4)

The "HOMB," an inhabitable honeycomb, was co-developed by Skylab Architects and Portland Oregon's Method Homes. The system is founded on the adaptability, strength, and compositional agility of triangles. Articulated to architecture's geometric heritage, the system reveals the unlimited flexibility of geometric compositions. Similar to Swiss architect Justus Dahinden's Trigon 65,[21] putting 100 ft two triangles together in multiple geometries or architectural compositions generates infinitely adjustable plans. Allowing users to choose window sizes, finishes, and materials further enhances the made-to-measure capacity of this geometric planning grid.

[20] http://skylabarchitecture.com/work/taft-residence/#slide1

[21] For a project description, see Carbone, C. (2014)—*Prefabrication experiments (40) TRIGON 65* retrieved from http://prefabricate.blogspot.ca

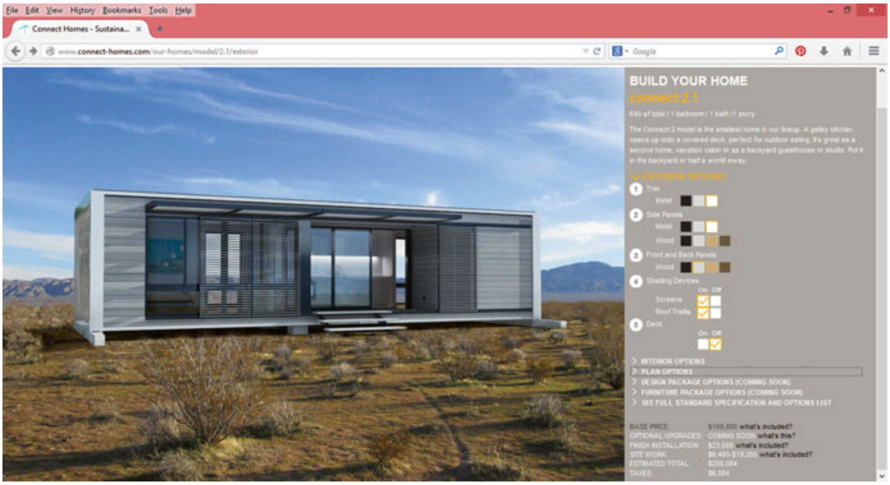

Fig. 4.5 Screen shot of configurator from Connect Homes' web site (*Source*: http://www.connect-homes.com)

This collaboration between architects and manufactures reveals a mass customization system characterized by its ordered variability for planning. HOMB modular prefab also includes choices for augmenting energy efficiency and reducing the buildings environmental footprint.

(c) The case of Connect Homes[22] (see Fig. 4.5)

Founded by two architects, Jared Levy and Scott Gordon, recognized for their contribution to Marmol Radziner Architects, this patent-pending modular system relates a simple modern aesthetic to sustainable design values. Ninety percent of the process is articulated to off-site production. Each design achieves a baseline sliver LEED (Leadership in Energy and Environment Design) and further design parameters achieve "gold" or "platinum" certification levels and even "net zero" energy use.

Aiming for an advanced level of personalization, the company has proposed a web interface where potential buyers can choose a predefined model and refine it with multiple options. The interface allows the user to choose spatial configuration, finishes, energy systems, and a myriad of elements to add to the basic design and tailor the design to preset individualized options. Analogous to the automobile industry, each selected option adds and modifies the design's cost in real time. This web interface typifies mass customization based on an option-controlled standardization.

(d) The case of Project Frog[23] (see Fig. 4.6)

Project Frog exemplifies the use of technology in generating their own "open-ended" architectural language of components. The variability of industrialized

[22] http://www.connect-homes.com/

[23] http://projectfrog.com/performance/technology/

Fig. 4.6 Screen shot of Project Frog's Kit-of-Parts from the company web site (*Source*: http://projectfrog.com/performance/systemized)

components conjures images of Ikea's business model for furniture or the general panel house designed by Wachsmann and Gropius [5]. Connecting uniqueness, standardization, and production efficiency, Project Frog is based on the manufacturing of high-performance technically advanced standard components predetermined for systemic adaptability and agility. This system employs consistent assemblies toward a diversity of building types and organizations.

An information management system and the encoded components enable a wealth of interaction possibilities. Parametric information modeling monitors material criteria, life cycle criteria, energy-saving criteria, and building performance. This precise and integrated design leads to a "lean" [15] production process that reduces waste at all levels of design and manufacturing. This mass customization based on computer modeling from design to production imbeds performance monitoring and control at all stages of the project's production.

(e) The case of Honka Canada[24] (see Fig. 4.7)

Honka has been producing timber houses from massive planks or logs since 1958. Informed by Finnish building culture and its link to timber and forestry, the company's production articulates traditional wood-working knowledge with contemporary design and fabrication tools and elucidates a state of the art streamlined relationship between conceptual design and manufacturing.

Each house is a unique design and an assembly of digitally controlled cut pine logs. Astute profiles provide stability, strength, and weather tightness. Each computer model represents a specific project and is transferred to digital fabrication once the design is approved. Machinery translates the design. This mass customization manufacturing method can reduce waste and epitomizes a just-in-time prefab tailored to a specific user.

[24] http://east.honka.ca/en/why-log-home

Fig. 4.7 Honka Canada's digitally cut log profiles—screen shots from web site (*Source*: http://east.honka.ca/en/node/219)

4.2.3 *An Untapped Potential*

The preceding examples demonstrate an unexploited potential. Current customization applies to different levels either to increase choice or to achieve made-to-order designs. Customization is not limited to the design. Contemporary design and manufacturing tools enable an efficient flow of information containing the parameters to modify, tweak, and intervene at different stages of production.

These mass customization strategies and levels of customization are permeating and will continue to transform the industry. The flexible aggregation of standardized components, geometric modular adaptability, programmed design variables, encoded components, and digital fabrication are a few strategies we have observed.

In each case technology is establishing a potential to redefine industrialized building systems toward architectural singularity.

The five previous examples also represent an informed collaboration between architectural design and industry enriching innovation and products. This collaboration could challenge the systemic lack of interaction between architecture and the prefab housing industry. Working from two diverse, distinct, and complementary perspectives, these two fields must be connected. A knowledge incubator could be a point of connection between these diverse stakeholders, as a confluence of factors seems to point to prefabrication as an important strategy for efficient and streamlined resource management. Still, only a small percentage of single-family housing starts to employ prefabrication, about 12 % in Canada, and even a more marginal amount employ technologically advanced customization strategies, with many still only using the age-old "plan pattern-book" for customization. A large proportion of companies are just producing houses in a factory as they would on-site.

Our study has led us to imagine and conceive of a knowledge incubator, a collaborative online tool that could hypothetically increase both industry/architecture connections and prefab use within the building sector. We are currently establishing an online "wiki-prefab" platform that would engage producers, stakeholders, and technology toward a network of potential hybrids and toward a library of potential ready to use informed components for architectural design. This library of components is not a new idea. Autodesk "Seek" already employs online networking for collaborating and sharing building information. Our proposal, similar in strategy, addresses not only the need for informed components for architectural modeling but also for the value of combining industrial production and architectural design.

We believe this industrial cross-pollination is an ingredient for accelerating change.

4.3 Sixty-Four Years Later, Accelerating Change

In his 1951 *The Prefabrication of Houses* [16], Burnham noted that in the turbulent era of the early twentieth-century America, even with the encouraged growth, prefabricated building systems never truly permeated American building culture. Though highly subsidized, factory production of houses never achieved its potential to provide a lower-cost and higher-quality alternative to traditionally built housing. The extremely competitive, low-cost, low-overhead, and entrenched building culture reinforced on-site wood frame construction and relegated the factory-built house to a market share that stabilized at no more than one out of eight or ten dwellings produced.

Sixty-four years after the work of the Albert Farwell Bemis Foundation, our corresponding and evolving project draws on similar values of a better product (sustainable, efficient) for a larger part of the population. Our analysis shows that the prefabricated building industry has developed in a parallel, somewhat divergent model to the housing industry and even more so to the practice of architecture.

This divergence already recognized at the beginning of industrialization increased during the twentieth century and has impeded a fertile cross-contamination between architecture and industrialized building systems.

Today, factory-produced building systems are evolving into sustainable, resource-responsible, and customizable options for housing but still only garner a fraction of production in North America.

Digital fabrication, automation, mass customization, and lean construction are becoming typical in factories around the world and can contribute to a renewed, durable, and ecological building culture. Within the contemporary convergence of a renewed production process, an appetite for sustainable housing options, and a demographic shift toward heterogeneity, the manufactured housing industry can be an important player in establishing creative building and housing concepts to serve the market's ever-evolving lifestyles and family structures.

Prefabrication and Modularization: *Increasing Productivity in the Construction Industry* [7] discusses the different conditions of increased competitiveness for prefabricated construction systems. Articulated to a variety of topics, such as the lack of skilled labor, waste reduction, increased productivity, and reduced construction time, a larger environmental awareness is driving increased attention to off-site fabrication. The contemporary building culture defined by an integrated design process and digital conceptualization is also more conducive to factory fabrication. Furthermore resource-optimized factory production is also accepted as a valid and superior alternative to complex and resource-intensive on-site building. Harnessing this potential of factory-based construction hinges on a new creativity.

Our current research established the need to share knowledge within the architectural profession and throughout the building industry to both recharge prefab's potential and erase age-old connotations. Ancient mass production models no longer limit architecture's long-lasting objective of creative uniqueness. Today's tools inform a creative process that allows us to understand that the perceived uniqueness of the architectural process is being overtaken by uniqueness imbedded in variable processes that leverage technology toward holistic approaches.

Encouraged by our preliminary mapping of the North American prefab industry, our aim of breeding knowledge exchange within the industry has led us to define and imagine an online collaborative "wiki" as an open-source model for collaboration and customization in architecture. We are currently collaborating with and calling upon trade associations, academics, and manufacturers to establish a test version of this information management tool to assess our premise. We suggest that we are at the cusp of a new and "open" era for the oldest new idea in architecture.

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