DESIGN [fabrication] BUILD

by

Nicolas Glen Rader

B.S. Architecture
The Ohio State University, 2003

Submitted to the Department of Architecture in partial fulfillment of the requirements for the degree of

Master of Architecture
at the
Massachusetts Institute of Technology

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ROTC
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Submitted to the Department of Architecture on January 20, 2006 in partial fulfillment of the requirements for the degree of Master of Architecture at the Massachusetts Institute of Technology.

ABSTRACT

DESIGN [fabrication] BUILD proposes a new relationship among the architect, homeowner, and fabricator/assembler through the use of parametric software in order to create a truly customizable prefabricated home. This customization is possible through the combination of the software with CNC machinery and a material yet to be fully explored by architects, honeycomb composite panel. The result is a kit of parts that is efficient in terms of time and cost in design, production, and assembly, it is offered as an improvement from contracted stick built construction.

Thesis Advisor: Mark Goulthorpe
Title: Associate Professor of Architecture
"We are not architects. Nor have we ever studied architecture proper. We have, however, spent pretty much all of our lives living in some sort of house and have shaped those houses to better suit our needs, which we guess makes us architects along with everyone else who has made a decision about the place they call home."

|Courtenay Smith/Sean Topham |
|Inside Cover|
ACKNOWLEDGEMENTS

This is dedicated to First Boss, my grandfather Thomas Malanowski, who taught me not only how to build, but taught me patience, good work ethics, and love of family. Without him I would not be an architect.

Thank you to my parents and sisters, who have always stood behind me and encouraged me to go further. You always believed in me even when life was rough.

Finally, I am greatly indebted to Larry Sass. Thank you for taking me under your wing, you have given me so many incredible opportunities and continue to give selflessly. You are a true mentor and friend.
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DESIGN [fabrication] BUILD proposes a new relationship among the architect, homeowner, and fabricator/assembler through the use of parametric software in order to create a truly customizable prefabricated home. This customization is possible through the combination of the software with CNC machinery and a material yet to be fully explored by architects, honeycomb composite panel. The result is a kit of parts that is efficient in terms of time and cost in design, production, and assembly, it is offered as an improvement from contracted stick built construction.

Introduction
The idea of a customized home, pre-fabricated home or any combination thereof is not new. In fact, it can be argued that every home up until the industrialization of society was customized due to the necessity to build the home oneself or personally consult an architect or builder. With industrialization and pre-fabrication came cheaper and faster house alternatives where customization was replaced by choice. The first of these alternatives offered was the Aladdin Readi-Cut House created in 1906. Potential homeowners received a mail-order catalog with over 450 choices of homes to choose from, after selecting and ordering a house a kit of pre-cut numbered pieces was delivered to the site ready for assembly. Despite the numbering system, a large number of materials and pieces made up the kit of parts and still required a trained crew a substantial amount of time to assemble. Sears soon followed suit to Aladdin with their own mail order homes,
1 Aladdin Readi-Cut House
a product line that existed until 1940. In this method of home construction design time is virtually cut to zero, cost is reduced, and increases quality, but the ultimate sacrifice is the relationship of the homeowner to the architect or homeowner as design/builder is completely dissolved, the house is reduced to a tradable commodity.

As the trend of mail order homes came to an end in the late 1940's, contractors rose to the forefront of house construction where they remain today. They gained their market by reinstituting human relations in the home “design” construction process and promising customization not choice. Their main mode of operation is to purchase land and sell it to homeowners who choose which house they would like built from contractor defined styles of houses, not unlike the mail order houses. Customizability is declared by offering options for different sized rooms and choices of interior/exterior finishes, although the overall form and spatial quality remain confined within the predetermined styles. As a result, the community of houses is held together by impersonal repetition rather than the architecture providing for social interaction. To further problematize the role of the contractor, the majority do not prefabricate, therefore increasing the amount of time and decreasing the quality of construction once offered by mail order. The sheer number of materials and thus types of connections combined with poor craftsmanship, site conditions, and deadlines create a house that is impersonal and mediocre in quality,
Existing contracted homes in Cleveland, OH

New contracted construction in Cleveland, OH

2. "Customizable" finish and furnishing choices

3. Prefabricated system by Gary Venter Architect
As alluded to above, in a matter of a century the homeowner lost all contact with an architect and relinquished all personal wants and needs to a pre-defined set of designs. In 1995, the Philadelphia Inquirer stated that less than 2% of new homebuyers work with an architect. This disconnection has been exposed and exploited by suburban sprawl, consequently many architects have proposed solutions to regain design control and offer it back to potential homebuyers. Gaining inspiration from other industries that sell customizable products the majority of these solutions use the computer as the main vehicle for design exploration and distribution with CNC machinery realizing the promise of customization. In these proposals the architect, fabricator, and distributor work together to arrive at a piece of software that can be used by a potential buyer to design their space. Unfortunately, once the software is set in place the architect then removes himself/herself from the process and further contributes to the disconnection of homebuyer/designer. Resultantly, no solution has as yet been widely successful against contractor built stick construction, but it is important to provide a brief overview of some of these proposals so that this thesis can be weighed against them.

\[1\] Bell, p. 13
The overview begins with Nhew (NorthhouseEastWest) by OpenOffice, to which it must be admitted is not intended to be an adversary to typical home construction. The intention is for a space that is adaptable, transportable, and an extension of the body, but is a valid precedent in the way that it is designed and marketed. It is a simple dwelling of which the physical framework established by the architect is reflected in a digital framework on the internet where the materiality of the infill panels is chosen by the potential buyer. Despite the buyer's interaction with the software there is still no direct communication or formal decision being made between the architect and client, the form is static according to the architect's original intent.

This same disassociation of architect, buyer, and fabricator is symptomatic of Variomatic by Kas Oosterhuis, but in a potentially more damaging way. The architect has provided a base form that the client manipulates online by pulling and pushing points and splines. The form automatically and visually updates to reflect these changes, but it is questionable as to whether or not the individual will understand the spatial implications of their decisions. Material and space are now both at stake. Despite its ability to adapt in form (i.e. height, width, length) it is stuck in a highly specific typology that also comes into question when considering different site conditions and client desires. A positive note, however, is its use of CNC machinery which ultimately provides the variability without sacrificing time and money. The design file is directly linked to the fabricator which can produce and send the parts for the home without any paper drawings.

CNC machinery is also the crux of Manufactured Housing by Thurlow Small Atelier. The intent of this project is to rethink the way that mobile/trailer homes are designed. It works within the preexisting framework of a trailer and customizes the panels that infill the structure. Ultimately the same problem as Nhew exists, a customized appearance with monotonous space. The relationship of the architect/fabricator to the homebuyer is unclear, but it appears as if the panels would be premeditated by the architect and the buyer given a choice.

Finally, the last project to be mentioned is an ongoing research project by Professor Larry Sass of MIT tentatively titled P.A.T.C.H. (Parametric and Tooled Computational House) Architecture. The intent of this research is to provide an easily assembled house in disaster situations and in developing countries. This is unique in comparison with the other precedents because it involves a direct relationship between the architect and client. Together they design a faceted form for the house tailored specifically to the homebuyer, site, and culture, once this form is set a piece of software is applied to the form that creates digital fabrication files for the structure and skin of the home. These files can be directly used by a CNC mill to produce the kit of parts, which is shipped to location, and assembled by the owner. This is a truly customizable
4  Nhew| Open Office

5  Variomatic| Kas Oosterhuis

6  Manufactured Housing| Thurlow Small Atelier
system, however, there is a major weakness. The software is applied to the design rather than embedded within the system of design making it easy for the design to overstep the bounds of the physical system of construction. The architect and homebuyer are in fact reunited in this process, but now the fabricator is left to the wayside creating devastating potential onsite when a design is not construction worthy. Another innovation in this proposal is its use of a single material for the structure, therefore reducing the types of connections needed, and making assembly easier and quicker. Choice of finish material still remains but must be post applied.

In all of these precedents there is a great disconnect among the architect/homebuyer, homebuyer/fabricator, or the fabricator/architect causing a reversion to choice of design rather than customization of design or a potentially inviable product due to lack of understanding of construction. A great deal of pieces and types of connections still exist which can be costly, and difficult to assemble. Improvements are made from mail order houses and contractor built houses, but ultimately the potential in affecting the main stream housing market is minimal.
7  Shape Grammar by Larry Sass

P.A.T.C.H. Home Prototype

8  P.A.T.C.H. Cut Sheets
Proposal

My solution for a truly customizable prefabricated home begins with the complete re-integration of architect, homebuyer, and fabricator through a single piece of parametric software. A single file simultaneously acts as the design file and fabrication file, it is given direct input and provides direct output for all three participants, it is the glue of the relationship. This idea is not unique (i.e. the work of Frank Gehry), but all attempts to do so on a full scale structure have been unsuccessful. These attempts have tried to insert an existing mode of construction and materiality into the parametric realm which becomes too heavy computationally for commercially available computers. In order to offer a viable solution I have introduced a new method of fabrication and construction created specifically for use in a parametric model, involving the use of a 5-axis CNC mill and structural honeycomb panels. The entire design, fabrication, and construction process can involve as few as 6 or 7 people (architect, homebuyer, 2 fabricators, 3 assemblers), one material, and a month or two of time.

The question here is why is this specific or most beneficial to home construction? The simple answer is efficiency, flexibility, and future economy. The manufacturing, cutting, and assembling of material is essentially reduced to a single trade allowing more houses to be constructed in a smaller amount of time. The combination of parametric software with CNC equipment implies an
iterative process and customized repetition maximizing flexibility of design. Neither technology is time efficient or affordable without mass customization (flexibility) so it follows that they are suited for the goal of this thesis, truly customizable prefabricated homes. It should be noted that these technologies and the use of honeycomb panel in architecture today are expensive, therefore, this thesis is given under the assumption that cost will reduce over time.

To enter into the specifics of my proposed system of design and construction three things must first be described: architect/client/fabricator software interaction, honeycomb panel as material, and the site of a test case. Upon the completion of this description I will walk through the entire process of design, fabrication, and construction from beginning to end.

Reintegration through Parametric Software]
As stated earlier the parametric software is the glue to this entire thesis. It takes input from the three active design and construction participants and outputs a single viable product that is individualized for the homeowner. The fabricator provides the architect with material and CNC equipment constraints. For example, in order to have a structural connection no two corner pieces can meet at an angle less than $30^\circ$, the CNC mill cannot undercut edges more than 2" deep, or the material can only freely span 15' at a thickness of 3.5". The architect is then responsible for taking these constraints and applying them to a module in the parametric software building in joints for assembly and module aggregation. The module also has built in local controls for its height, width, length, and wall and roof slope, again, constrained by the input from the fabricator. Once established, the modules can be aggregated within the software to follow global controls and constraints that are set by the architect pertaining to client, site, and climate. Here the client enters into the picture working directly with the architect to modify these controls. Because the software being used is parametric this is an iterative process meaning several designs can be pursued quickly and refined and updated instantaneously. Direct output allows physical models to be printed or cut in a matter of hours in order to be better understood. Once a final design is decided on the file is ready for direct output for the fabricator because the constraints and joints are already built into the model.
Symbolic Diagram derived from the parametric model showing the relationship of the modules to each other and to the controls.
Material | Honeycomb Panel
The material I have chosen to work with is composite honeycomb panel which is already prominent in the aeronautics, automobile, and shipbuilding industries. It remains outside of the realm of architecture mostly due to its current cost, but is ideal for this project because it is lightweight, millable, has variable structural capacity, variable surface finish, inherent weatherproofing, and can be filled with insulation. It can be made out of a number of materials but is mostly made of aluminum, aramid fiber, or PVC. Honeycomb panel can replace siding, weatherproofing, plywood, insulation, gypsum board and a coat of paint in a typical wall of house construction. As seen in the accompanying figures typical connections for this material are mechanical with standardized implements. This restricts connections to orthogonal or planar angles which is unsatisfactory for this exploration. Manufacturers do note its ability to be machined with a 5-axis CNC mill when the edges are pre-filled with resin. The edges can then be glued together with a resin adhesive that unifies the panels. It is this ability that I exploit in this thesis. The joints that I propose are expanded upon in the following example of the implementation of my thesis.
Material Properties Chart

<table>
<thead>
<tr>
<th>Solid Material</th>
<th>Core Thickness</th>
<th>Core Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>7.0</td>
<td>37.0</td>
</tr>
<tr>
<td>1.0</td>
<td>3.5</td>
<td>9.2</td>
</tr>
<tr>
<td>1.0</td>
<td>1.03</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Honeycomb Samples

Typical Joint Details
Site| Cleveland, OH  
For illustration and test case purposes I chose a site and client with which to implement my system. This test case can be followed in the shaded illustration to the far right of the subsequent pages. The site chosen is on the west side of Cleveland, Ohio in a residential neighborhood interspersed with manufacturing companies having the ability to machine the panels for this exploration. The existing residents are slowly being forced out by high-end condominiums that are symptomatic of impersonal repetition. I therefore pose this test case as an improvement for the existing and future inhabitants. The clients for this case are assumed to be a young couple who are first-time homeowners with no children and only need a living space, dining space, kitchen, single bathroom, single bedroom, and have a desire for some exterior space.
Residential and manufacturing interspersed

New high-end condominiums onsite

Photographs shown on p. 11 are also onsite
Having all of this information in mind, I now offer my solution for truly mass customized prefabricated housing. I will walk through the creation of a piece of parametric software, its use in a design, the fabrication process, and finally the assembly process of a home.

Parametric Module
The only fabricator input I have taken into account is the size of the bed of a typical semi-truck that is able to navigate through residential streets, which is 9’x45’. Honeycomb panel can be manufactured in this dimension, however, is not logical for residential construction. Therefore, I have assumed that a panel can be as large as 9’x22’, 22’ being approximately the eave height (2 stories) or length of a home. These panels can be configured into an infinite number of modules for home design and construction but I have decided to begin with a simple portal frame made of two layers of panel. The layering will allow for programmatic separation, structure, and utility infrastructure. Taking the size of the panel into account this module is expandable up to 9’x22’x22’, but can be as small as 1’x7’x7’. Now that the size is defined and limited it can be parametrically controlled. The intention is for them to aggregate end to end. The joinery is also built in at this level, but for the sake of clarity has been left out until a later stage of this explanation.
Massing
With the most basic module established, as an architect I can now begin taking input from a potential homeowner. In this first stage the height and width of the module is discussed as well as the number of modules that are to be used onsite. The client’s desire for square footage, number of stories, height of ceiling, buildable area onsite, and proportion of area onsite are all factors in this input.

On the site in Cleveland there is a buildable area of 45’x55’ and the client is asking for a single story home approximately 1000sf with generous ceiling height. To satisfy this an aggregation of 6 modules of 9’x18’x18’ was agreed upon.
Site Deformation
With massing and aggregation agreed upon attention turns to global transforms which will affect the homes form. The first transform to deal with is orientation and path, which is critical in that it creates the relationship of the home and property to the community. In the top right diagram, a bar building has no relationship to its neighbors, the street, or its property. In the diagram below the home has been bent and reoriented to provide public (PU) and private (PR) space for the community and itself. If a neighborhood of these homes is designed they can be positioned and bent in any number of ways to create varying public and private spaces.

The test home has been bent like the homes in the bottommost line diagram to provide a small private garden in the rear of the site and an open public front yard.
Roof Deformation

The next global transform deals with the slope and curvature of the roof. The slope depends on the climate of the site for water run off, snow loads, and aerodynamics but also is a major component of aesthetics. The curvature transform gives the ability to increase/decrease ceiling heights along the length of the system. This transform can similarly be used on the floor of the home but the architect must take into account inhabitability of surface.

Although the client at hand prefers to have their house as a single open space the floor has been slightly pulled up and the ceiling down to create a sectional variation between interior public and private. Both extremes have a high ceiling, but the middle is compressed to indicate a division of space.
Thickened Surface

The layering of the module finally comes into play as the last of the global transforms. Up to this point the panels in the module have been assumed to be coincidental. By varying the distance between them structural integrity, programmatic division, functional space such as desks, shelves and counters, storage, and utility space are all gained. Here structural needs are the most important, but attention to the environment and client wants are also important factors. The interstitial space of the panels can act as cool/warm air buffers depending on the climate, and the angle of the exterior wall can maximize or minimize sun exposure.

The test case is shown as the bottommost line diagram in addition to the shaded rendering. As the architect I have decided to thicken the northern wall in order to provide a cold buffer from the mostly cool climate but have completely delaminated the wall in the south and tilted it in. This will maximize sun exposure and carry the warm air into the home. Because the north wall and the ceiling have thickened the innermost southern wall is released from structural responsibility. It can simply be a partition wall that transforms into the kitchen and the wall creating the bathroom.
Aperture

Openings in the surface of the home are the only major architectural feature controlled locally. In an aggregation of modules the edges connecting each to the next can be separated to allow for windows, ventilation, light, and entry. It should be noted that it is possible to simply machine traditional punched windows into the surfaces, however, this does not take full advantage of their system. Creating openings the full height of the panel between the modules allows more light, does not affect the structural integrity of the honeycomb, requires less machining time, and less assembly time.

The clients have expressed a desire for light in the morning and afternoon when they are home from their jobs so sun studies (shown on p. 43) have been done with the parametric model to maximize this light. The result is the south side of the home having openings between all but the last two of the modules which is the bathroom area. The orientation of the openings was planned so that the eastern light penetrates completely through the house. The north side has only two openings which allow afternoon/evening light to penetrate only to the public areas of the house. One opening in the system on the south and north side has been made large enough to be an entry into the public yard and private garden.
The last major component in the form of the system is the entry. Using concentric frames as modules leaves the problem of enclosure on either end. Two major inputs into this design decision are simply the amount of offset between the interior and exterior wall and client aesthetic desire. When a large offset exists between the walls the innermost set of walls can be pulled out to create a canopied entry. When there is little or no offset there are two main options. The first is simply to cap the end flush with the last module and then pull out the subsequent module to create an entry on the side. The other is to cap the end, but push it into the module slightly to highlight it as the point of entry.

The final iteration of the test case home uses the last of these three examples.
Completing the various stages of design it is essential to state that using parametric software creates an iterative process. At any stage and every stage of the design the architect, fabricator, and homebuyer are refining and changing the parametric model. Furthermore, the solution arrived at by the architect and homebuyer is only a single option in a world of infinite variation.

The use of parametric software leads to another major advantage, that of rapid prototyping. Because the design originates and exists in the digital realm it is often difficult for the client to understand the space created. The model in combination with a lasercutter or 3 dimensional printer can physically output several designs in a single day to help the homebuyer understand. The model can also be used in rendering software to better understand light conditions throughout the day and year.

The photographs of the physical model (opposite) do not depict the final test case model, but rather models done throughout the process of the thesis. They show refinement of a single model and also different design solutions. Photographs of the final design model can be found in the appendix.
Model Refinement

Different design options from a single parametric model
Lasercut Model
Sun Study

Digital Model Sun Study
June 21 Sun Study
Surface Finish
Materiality is the last design decision to be made before the model can be sent back to the fabricator for manufacturing and assembly. A benefit of the honeycomb panel is that virtually any surface finish: color, texture, material, opacity can be applied. The homebuyer can choose to have wood floors and painted walls as in a traditional home or snakeskin pattern walls with a fluorescent pink translucent floor.

Shown in these final renderings is a system of decks that have not been described alongside the design. Ultimately the exterior space such as decks, porches, and overhangs would be built into the parametric model, in this thesis however the exterior decking appears as an additive to the final design, an avenue left to be explored.
Fabrication Process

Once the design is complete and agreed upon between the architect and client the digital parametric model is sent back to the fabricator, where it originated from the given constraints of the material. Because these constraints and the construction joints are already built into the digital model this single file is ready for direct output to CNC machinery. In the first step of the manufacturing/fabrication process, the manufacturer’s computer will determine the most efficient size of honeycomb panel for the pieces to be cut from. With this information the proper thickness and area of honeycomb is glued to one sheet of material leaving the honeycomb open on one side where a resin gun fills the cells that become the edges of the panel. Once this resin is dry the top sheet of the panel is applied and the shape of the panel with the proper taper on the edges is milled by a 5-axis CNC mill. The shape being cut out the mill will take another series of passes to complete the joinery along the edges and cut out the necessary holes for utilities and wiring.
Assembly Process

With the last passes of the CNC mill the panel is complete and is light enough to be hand loaded onto a truck by two workers, realistically of course they would be stacked and loaded by forklift. It takes approximately 3-4 trucks to carry the entire house to the site, depending on size of house and truck. The foundation of the home has to be set before assembly and is done onsite during manufacturing of the panels. I have assumed that the foundation consists of linear footers to which the edges of each floor panel are mechanically fastened. With the arrival of the first truck assembly commences immediately with as little as two men and no additional machinery. At the completion of the floor structure it is necessary to have a lightweight crane on the back of a truck. This is necessary not because of the weight of each panel but rather size. With one man operating a crane it would take only two men to align the edges of a wall or roof panel and glue it into place. The insertion of glass into the system is assumed to be in a similar manner with slotted details and structural silicone in place of resin glue joints. This assembly process continues until the completion of the home. I estimate the entire assembly process exclusive of utilities will take as little as a week or even less.
In order to allow a fluid presentation of the process of design and construction an explanation of the joints between panels has been left out. The joint details shown opposite this page are the initial ideas from the start of this thesis. Each detail includes a number of standardized parts to make the joint flexible. However, this is antithetical to one of the main reasons for this thesis, efficiency. By introducing standardized parts into the joint the CNC mill is not being taken full advantage of, extra trades, parts, and time are brought into the project, and the resin filled edges of the honeycomb panel lose function. It is important to adhere strictly to the idea of bringing fabrication and assembly into a single trade. As a result the joints between the panels finally became a simple shiplap joint. The mill produces physically all details needed in the connection, no standardized parts are necessary. There are a few problems yet to be worked out, two of which are misaligned corners and undercutting.
Standardized Joints
The panels are quadrilateral to avoid sharp edges, decrease the number of connections compared to triangulated construction, and allow easier window insertion; however, when four thickened quadrilaterals meet at a vertex there is a misalignment (diagram left). This creates a jagged edge or a difficult double taper in the milling process. If this edge or taper is ignored a hole in the center of the joint can result, this is not a structural issue because the whole edge of the panel is glued, but is a weatherproofing issue.

Because of the curvature in this system of design undercutting must occur on approximately 33% of all panels. This is possible but is an added cost.
Conclusion

Since this thesis has not been literally tested it is difficult to state its success or failure. It has at least posed and drawn important questions to myself and others and received an amount of intrigue and comment. Therefore I will close with an exchange between myself and Professor Larry Sass, MIT, a note on leverage gained by the architect by using this system of design, and the steps needed before implementing this system.

Throughout this process Professor Sass commonly asked: What makes this architecture, what makes it unique, and why would people not want to tear it down in 20 years when CNC fabrication is the norm and the space can be updated? Being repeatedly frustrated by these crucial and important questions, I began to wonder about their pertinence to a systematized iterative architecture. The architectural uniqueness ultimately is the homebuyer’s input in the design process and resultant attachment to the space, in contrast to the current sentiment of house as tradable commodity. Architectural qualities such as light, texture, openness, and proportion are at the will of the client within a given set of parameters. For an architect to limit these parameters to a level of “goodness” as defined by himself/herself is to be as restrictive as a contractor offering choices of color and appliance. Therefore my final reply is: I wonder if it is okay to allow a client to create a “bad” space that will be torn down after their use of it is done. Would this still be architecture?

As alluded to above, this new process of design begins to blur the boundaries of architect, fabricator, and homebuyer. As the creator of the parametric system the architect is a facilitator among the parties involved, therefore, gaining power in the relationship even if some design control is lost. With the entire design and fabrication process held in a single piece of information, nothing can be done without it. Design fees may become less of a portion of the contract, but now the architect holds control over fabrication, structure, details, and assembly. A new fee and contract structure for the architect would have to be implemented for this system to be realized.

Finally, the next step in the implementation of this thesis is to focus on the pragmatics of it. Contacting honeycomb manufacturers for real material constraints and limitations is the first order of business, without this information any design work or software development done is irrelevant. Once this information is received it can be used to create joints and details to be physically tested for weatherproofing, durability, and structural capacity. When all of this is accomplished a full scale prototype must be built and tested allowing for the exploration of efficient manufacturing/fabricating processes. Only then would this new system of design and construction be valid for entry into the homebuyers market.
Appendix I

A collection of images, both in progress and final.

Opposing Page:
Design process using the same parametric model for different designs
North Elevation

North-West Corner
Final Design Model Photographs
East Elevation Corner

South-East Corner
Final Design Model Photographs
Long Section of Test Case
N.T.S. 63
Interior Material Studies
Internal Gutters

? Manufactured w/ incl. at 1/2
than ch? Or... handmade & closer than cut, then incl.

WALL SECTION

CESSARY GUTTERS?

EXT. DEF. OF SPACE

ALWAYS EXTEND OUTER ON DOWNSLOPE

P.S.C.W.
RUNNER GUTTER
DIFFERENT STANTION

ROOF SECTION

BnT ST.

RAILWAY/SLANT

PROBLEM?

GASKET TAG
(REAR FILLI STONE)
Transverse Section of Test Case
Scale: 1/4" = 1'-0"
Plan | Window Detail
Scale: 1-1/2" = 1'-0"
ILLUSTRATION CREDITS

1 Aladdin Readi-Cut House
   The Arts and Crafts Society. Online.
   http://www.arts-crafts.com/images/archive/aladdin2.jpg
   Original image from Aladdin Readi-Cut Homes
   Catalogue for 1920


3 Axon drawing of Studio 2
   Gary Venter Architect
   http://gva.net.au/studio2/?pg=6&s=schemeoverview

4 Nnew by Open Office as shown in Arief, p. 146

5 Variomatic by Kas Oosterhuis as shown in Arief, p. 140

6 Manufactured Housing by Thurlow Small Atelier as shown in Bahamon, p. 77

7 Image created by Professor Lawrence Sass and is used with his permission, MIT, 2006

8 Image created by Marcel Botha and is used with his permission, MIT, 2006

9 Material Properties Chart as shown in Hexcel Composites, p. 3

10 Honeycomb Samples
   Technical Resin Bonders Ltd. Online.
   http://www.trbonders.co.uk/products.html

   continued on p. 52
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Arieff, Allison; Burkhart Bryan. **PREFAB.** Layton, Utah: Gibbs Smith, Publisher, 2002.


continued on p. 53
11 Typical Joint Details as shown in Hexcel Composites, pp. 5-9

