
DYNAMIC MODULARITY:

A New Approach to Off-Site Construction

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Signature Page

DYNAMIC MODULARITY: A NEW APPROACH TO OFF-SITE CONSTRUCTION

A Design Thesis Submitted to the Department of Architecture &
Landscape Architecture of North Dakota State University

By

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In Partial Fulfillment of the Requirements for the
Degree of Master of Architecture

Primary Thesis Advisor

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Thesis Abstract

The goal of this thesis project is to examine the several possible ways that a single-family residence can be built using various forms of off-site construction in order to determine which methods are the most suitable. There are already many methods of off-site construction, most of which can be classified into a few groups. Those methods include prefabricated construction, modular construction, as well as three-dimensional volumetric construction. Today's construction-related work force is facing a shortage of skilled laborers which is in turn, resulting in tighter budgets and tighter work schedules. The methods explored in this thesis will aim to resolve these conflicts in an efficient, cost-effective manner.

Thesis Narrative

Historically, construction of a single-family residence has occurred at the final location of the house itself. This traditional form of construction is one that most people are familiar with and in fact, is likely the only method that comes to many peoples' minds when asked. On-site construction is a complicated process and faces many challenges throughout the duration of a project's build. Factors such as adverse weather conditions, material waste, and number of laborers play into how long the construction process will last, as well as how efficiently the building will operate. For example, Stacy Fitzgerald, author of *4 Undeniable Benefits of Offsite Construction*, says "with traditional wood framing, experts recommend wood moisture content of no more than 15 to 19 percent. Higher than that and you're setting the stage for moisture-related problems like wood rot and mold, so protecting wood framing is critical, which can be tough with on-site construction outdoors." Combine these conditions with the fact that the field is facing a shortage of skilled laborers, and it becomes apparent that there's likely going to be a change in the way we construct a large number of homes within the near future.

Today's economy is bringing a large demand of construction-related workers into the workforce. However, contractors and developers are struggling to fill those open positions. Converting from on-site to off-site construction can help bridge the gap between both the lack and the demand of skilled laborers that exists presently. With the methods of off-site construction, fewer workers are needed. According to Blue Future Partners, "The global construction sector actually holds the record of

having the lowest productivity gains of any industry in the past two decades, stalling in countries like Japan and Germany and even falling in Italy and France. Whereas for manufacturing, the value-added per hour has increased by only 1% for the construction sector." Off-site construction pulls the workers off of scaffolding and out of the dangerous conditions that go along with on-site construction. It instead allows workers to be in a controlled environment, such as a factory, with good lighting and safer conditions. Not only does a controlled environment allow for safer conditions, but it also allows for the opportunity for laborers to become more precise with the work they do. In fact, "offsite construction can take up to 40 to 60% of labor off the job site, opening up cost and time saving opportunities for contractors and developers looking to speed up their project schedules", according to Mary Tyler March, author of *5 Trends Shaping the Future of Offsite Construction*. This is because the off-site method allows for prefabricated units to be routinely built which results in a very high level of worker specialization and output.

Along with the higher quality of building framing and finishes that off-site construction produces comes a large amount of waste reduction and time-related savings. According to Angela Lee and Gerard Wood, authors of *Introducing 3D Volumetric, Modular Construction*, "waste can be reduced by up to 80%", and "deliveries to the site are reduced by up to 70%." Savings in cost also take place in areas such as site insurance, security, waste disposal, and temporary on-site offices. Higher structural durability also means a higher

Thesis Narrative

energy efficiency when operating heating and cooling systems within the building. With more careful oversight happening in the building process, it's easier to avoid unintended holes within the building's framing and cladding – which is often to blame for air tightness and long-term durability. With the construction process becoming stream-lined and taking place much quicker, clients are able to avoid paying several months' worth of interest payments on loans and only paying contractors for a relatively short time on the site.

By designing, manufacturing, and constructing larger components of buildings, we can more successfully coordinate labor, create higher quality of buildings, and do so in a safer, more efficient, and cost-effective manner. This thesis project will attempt to develop new methods and technologies to fabricate, transport, and construct buildings. As the industry struggles with making the shift to the modular approach of construction, how can architecture play a role in creating more efficient and effective methods of off-site construction?



Figure 1

Project Typology

While methods of off-site construction can apply to a vast number of typologies, they greatly differ in scale of modularity. The lengths to which how small or large a modular unit is produced, ultimately depends on the size of the building being constructed. The term prefabrication refers to any form of construction taking place beforehand, in a place other than the actual site where it will be setup in its final location. The term modularity refers to the prefabrication of a final form in several modules that will also be assembled in a location that differs from where they were initially built. Volumetric construction, on the other hand, involves constructing as much of a building off-site as possible before transporting it to the site for assembly. The latter method often goes as far as to fit modules with internal or external finishes before

leaving the factory or place of prefabrication. Since these modular units are often transported by truck to the site for assembly, the size of the modules themselves have limitations. In the most complete form, an entire house can be constructed in a factory and transported to the site. However, this method becomes counter-productive as houses become too large to be fully transported by means of roadways. For this reason, this thesis project will analyze the typology of a single-family residence as it is possible to prefabricate and transport the building in its full possible range from a very small module to a completed house. Perhaps there is a scale of modularity relative to the final size of a prefabricated building that results in the most efficient use of labor, materials, and transportation.



Figure 2

Typological Research

Njordrum Modular Housing

Brief Information:

Location: Varies by Project
Architects involved: Njordrum by Wienberg Architects
Year of Completion: Varies by Project
Size: Varies by Project



Figure 3

Background Knowledge:

Njordrum is the term given to the Danish-designed modular houses created by Wienberg Architects in Højbjerg, Denmark. The mission of the Njordrum is to draw the qualities of nature into the home and vice versa. They focus on creating interior spaces that have access to natural lighting, high ceilings, and a good contact to the outdoors in order to create houses that are measured by the architecture rather than the floor area. With the concept of downsizing in mind along with the use of Scandinavian aesthetics, Njordrum aims to bring together architecture, nature, light, and people. The modules are composed to function as individual units with the possibility of joining to other modules in a flexible approach. This creates an opportunity for countless configurations. To Njordrum, sustainability is common sense. They find it important to think about a home's sustainability throughout its entire

life cycle and make choices that will make the most sense in the long run. The aesthetic of their designs can be summed up as the creation of spaces that form a conscious context of both form and function. This means putting the best materials together in a way that reflects the perfection of nature.

Relevant Material:

The size of the houses vary in the number of modules selected. Each module is 45 square meters and the houses are shown to be executed with one to four units with a maximum floor area of 180 square meters. It seems the Njordrum modules are completely constructed with interior and exterior finishes in place. This leaves the attaching of the units together to be the only assembly that takes place on site (unless it is a single module arrangement). Each module has a portion of it that is a built-in exterior deck/porch. The remaining indoor

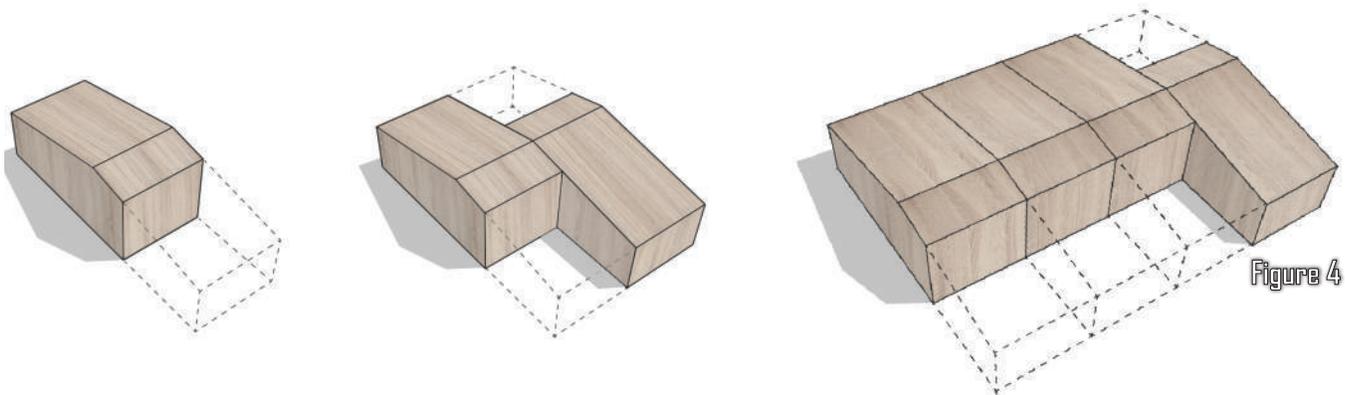


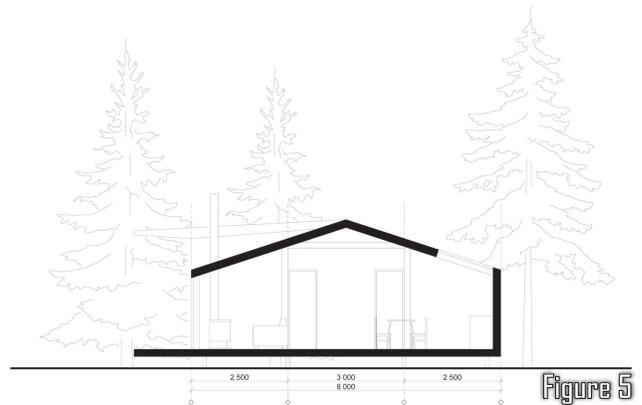
Figure 4

Typological Research

space varies on the overall arrangement. A single-module unit contains a layout that is similar to a studio apartment. A two-module unit contains a module that is similar to the single-module unit along with another unit that is almost entirely open space in order to create larger common areas such as living room and dining room. Once we get up to a three-module house, the floor plans of the modules become something different entirely from the previous arrangements - this also applies to the four-module unit as well. This means that there would be more than just four types of modules, but rather as many as ten or more. These modules are constructed mostly out of wood because of its high availability and lasting qualities. The foundation is made up of a point foundation system which requires much less use of materials and also allows the units to be relocated with ease.

Conclusion:

The type of modular approach that the Njordrum units take is very unique. Each module consists of an exterior envelope that is the same shape and size as the others, with the only distinction being what the contents are on the insides. By



doing so, the modules become a set of pieces that can be attached to each other like literal building blocks. This approach also contributes to the possibility of a very high degree of volumetric construction which in turn, translates to an even smaller amount of assembly required at the final building site. The modular design behind the Njordrum houses leads to a very large extent of specialized labor involved with the construction process that takes place away from the site. This is one of the main underlying goals within the prefabricated building industry as well as one of the main tasks that I will attempt to accomplish within my own designs.



Typological Research

Axiom Desert House

Brief Information:

Location: Palm Springs, California
Architects involved: Dwell with Turkel Design
Year of Completion: 2019
Size: 2,110 Square Feet

Figure 7

Background Knowledge:

The Axiom Desert House (Axiom 2110) is a built example of a series of 11 different predesigned, prefabricated houses called the Axiom Series. The series of prefab homes were created after Dwell partnered with Turkel Design of Boston, Massachusetts. Dwell is a magazine publication and online media platform that specializes in promoting inspiring design to architects, designers, and enthusiasts. The partnership of Dwell and Turkel Design believes in the importance of creating prefabricated homes that combine sleek, modern designs while avoiding today's common characteristics of the long, rectangular prefab homes that have the sole purpose of easy transportation. The Axiom Series homes reap the benefits common to off-site building techniques including extremely airtight building envelopes, high insulation levels as well as their own passive heating and cooling techniques. Home buyers that are interested in an Axiom house also have the option of reviewing the features of their home online before it's shipped to the site. This allows for a high level of predictability in material quality, attention to detail, and overall control of the price.

Relevant Material:

The Axiom Desert home is actually the private residence of Joel and Meelena Turkel and

was displayed as a Featured Home for the Palm Springs Modernism Week in February of 2019. The Axiom Desert house executes a certain set of characteristics that really help it fit into the context of Palm Springs, California. It features a lot of elements that gives it a strong sense of very gradual transition from inside to outside living that is much more subtle than most houses. This is a very important aspect of the houses in the area since the climate is very inviting to those who prefer to enjoy the warm weather. The layout of the house takes on an "L" shape with its entirety on a single level. It is a 3 bedroom/3 bathroom house that has all the essential rooms along with an office and a built-in carport.



Figure 8

Typological Research

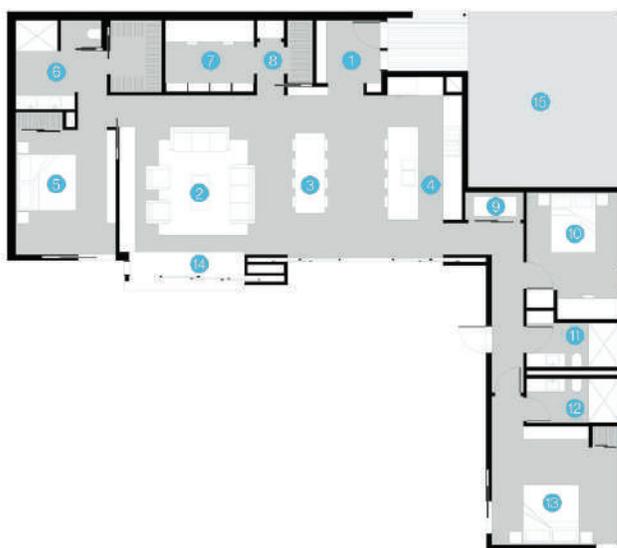
The Axiom Desert House along with the entire series of Axiom homes provide a great example of how prefabricated homes can be executed in a way that provides a high level of variability and options compared to today's standard of homes that are built off site. Dwell doesn't publicly provide much detail on how their homes are modularized because that is perhaps the best aspect of their designs. The homes appear seamless and lead very little implication of how they could possibly be built before the final assembly on the site - giving them the illusion that the homes aren't prefabricated at all. Dwell and Turkel Design have, in my mind, created a new level of deception of the degree of modularity involved that all prefab design firms should pursue.

Conclusion:

This case study leads a successful investigation into not only one example of off-site construction, but ten other similar examples as well. The Axiom homes include passive heating and



cooling techniques, high levels of insulation, and an extremely airtight building envelope. Their designs minimize site disturbance during installation and are flexible enough to fit strict zoning codes. However, the modular designed houses' best kept secret is perhaps, the process involved in order to appear to have such a small degree of prefabrication. This is a highly desirable characteristic amongst consumers as well as a quality I aspire to hold my designs to.



Main Level

1	Entry	8'x8'
2	Living	19'x18'
3	Dining	10'x18'
4	Kitchen	11'x20'
5	Master Bedroom	11'x16'
6	Ensuite	12'x9'
7	Office	10'x7'
8	Storage	6'x7'
9	Laundry	7'x3'
10	Bedroom	11'x14'
11	Bath	11'x5'
12	Bath	11'x5'
13	Junior Bedroom	14'x14'
14	Living Platform	14'x4'
15	Carport	20'x20'

Figure 10

Typological Research

DubiDom Modular House

Brief Information:

Location: Moscow, Russia
Architects involved: B10-architects/Ivan Ovchinnikov
Year of Completion: 2016
Size: 915 Square Feet

Figure 11

Background Knowledge:

The house itself is situated on the shore of a lake, Lake Pirogovo to be exact. The site is a very woodsy type of environment with a lot of birch trees and evergreens which plays into the rustic appearance of the house. The house is a modern, patio style home with everything on a single level. The rustic cabin-like feel of the house seems to do a very good job of fitting into the region. The majority of the surrounding houses and buildings on the lake resemble a similar nearly Scandinavian-like architectural style. The Pirogovsky reservoir area comes off as a very similar region as the northern Minnesota lakes area as well as the lifestyle that follows. The house is designed in a fashion that would allow it to fit in very well with many of the houses seen on lakes in the Midwest.

Relevant Material:

This house was created as an individual project since the standard models were not found

to be suitable for the site itself. The clients for the project had actually had a compact DubiDom house of 40 square meters previously made for them, but found themselves wanting a larger one made to accommodate their entire family after experiencing a successful operation of the smaller house over the duration the cold winter months. The house was built at the DubiDom factory located in Kazan before traveling nearly 1000 kilometers to its installation site. The units were built with the interior trim, utilities, furniture, and equipment already installed. Once at the site, the house was assembled and connected to a water supply, septic tank, and electricity. This house is a 3 bedroom/2 bathroom residence that has the more private spaces grouped at one end and opens up to the common areas at the other end. It features a large living room with a kitchen off to the side. The exterior is surrounded by deck space on three sides. The

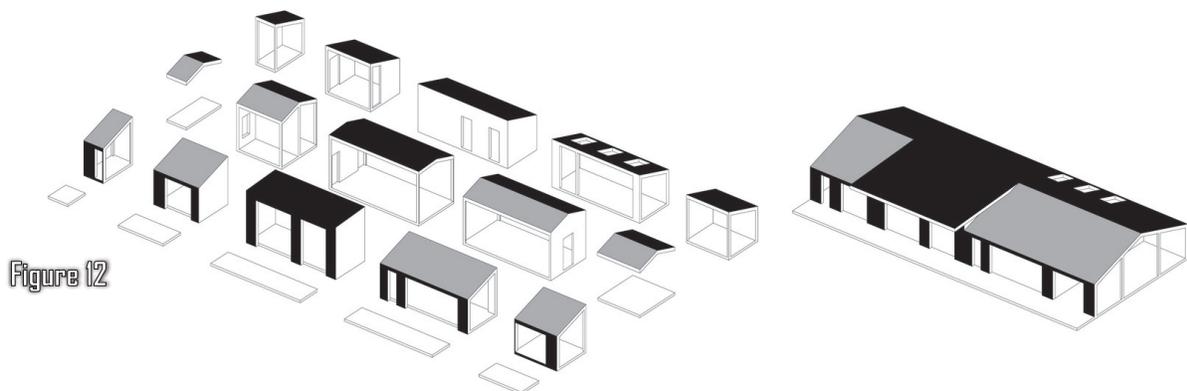


Figure 12

Typological Research

majority of the technical and utility rooms are located along the rear façade with the main entrance and living room looking out the front of the house, towards the water. The overall goal was to produce a house far away from the city, in the shortest time frame possible while executing a high quality of design at a low budget. In order to do so, environmentally friendly materials were used such as recycled barn wood and readily available pine for the building frame as well as the interior cladding. The entire interior design was done by Anastasia Sokolova who happens to be the owner of the house.

The DublDom house is a good example of how the design of a home with a familiar appearance can be split into distinct modules. The individual modules are, for the most part, different from each other. However, they still accomplish the goals involved with off-site construction. Since this particular home was specifically designed for a new set of clients, it became a new kind of technology. This would be a good tactic for a design firm specializing in prefabrication to expand and develop their options of modular homes for future clients.



Figure 13

Conclusion:

The firm behind the design of this case study generally specializes in prefabrication. Their clients often choose existing modular-designed homes that have been previously developed. In this instance however, the house was entirely designed for the specific clients themselves. Since the design for this house wasn't intended for mass production or duplication, this is the only instance of this house (to my knowledge). This is a pretty rare case for a modular-designed building, but it still provides a great example of how a single-family residence can be separated into distinct modules.



Figure 14

Major Project Elements

The kit of parts for a single-family residence can also be described as a set of characteristics one should consider when designing a home. All types of buildings are often regulated in many ways; mostly related to codes and zoning laws. However, when possible, single-family residences should exhibit these characteristics:

Entry

- The entryway to a residence should be located at or near the front of the house itself since it plays a big part of the initial impression a person has of a house.
- When unexpected guests arrive, the entry takes on a similar function as a waiting room and should be inviting as well as private from the rest of the house to a certain degree.
- When possible, a secondary entry/exit should be provided at the rear or opposite side of the house as well.

Living Room Space

- Should be a common meeting space of the house in which family members can interact as well as entertain friends and guests.
- Should provide a conversation area with ample amount of seating.
- Seating should be directed towards a view, a fireplace, a TV, or perhaps a combination of these options.
- In the case that there is opportunity for a large living room, more seating should be provided than anticipated in order to avoid making the conversation area uncomfortably distant.
- The living room is often the largest room in a house.

Kitchen Space

- Should be placed near or at the corner of the building so that there is a lot of ventilation and sunlight as well as a means of entrance/exit to the outside.
- The kitchen should provide plenty of space for preparing and cooking food as well as sufficient storage space for pots, pans, dishes, utensils, etc.
- When there is ample space, a pantry that connects to the kitchen is highly recommended.

Dining Area

- Should be placed near the living room as the dining area can also be used for special occasions, but more importantly, should be situated so that it has direct access to the kitchen.
- Is often used for many other activities besides dining and should be able to accommodate.

Bedrooms

- Should be located near the sides or edges of the house so that they provide ample lighting and ventilation as well as privacy.
- Should be placed so that natural light is provided during morning hours but avoid lights from potential traffic at night.
- Room area should be dimensioned in order to provide comfortable clearances around a bed and necessary furniture.
- Should provide room for a dresser or wardrobe especially if there is no closet space provided.
- A client might require space for a desk within a bedroom, especially if there is no office room within the house.
- There could potentially be a guest room as well in which all of these rules should apply while

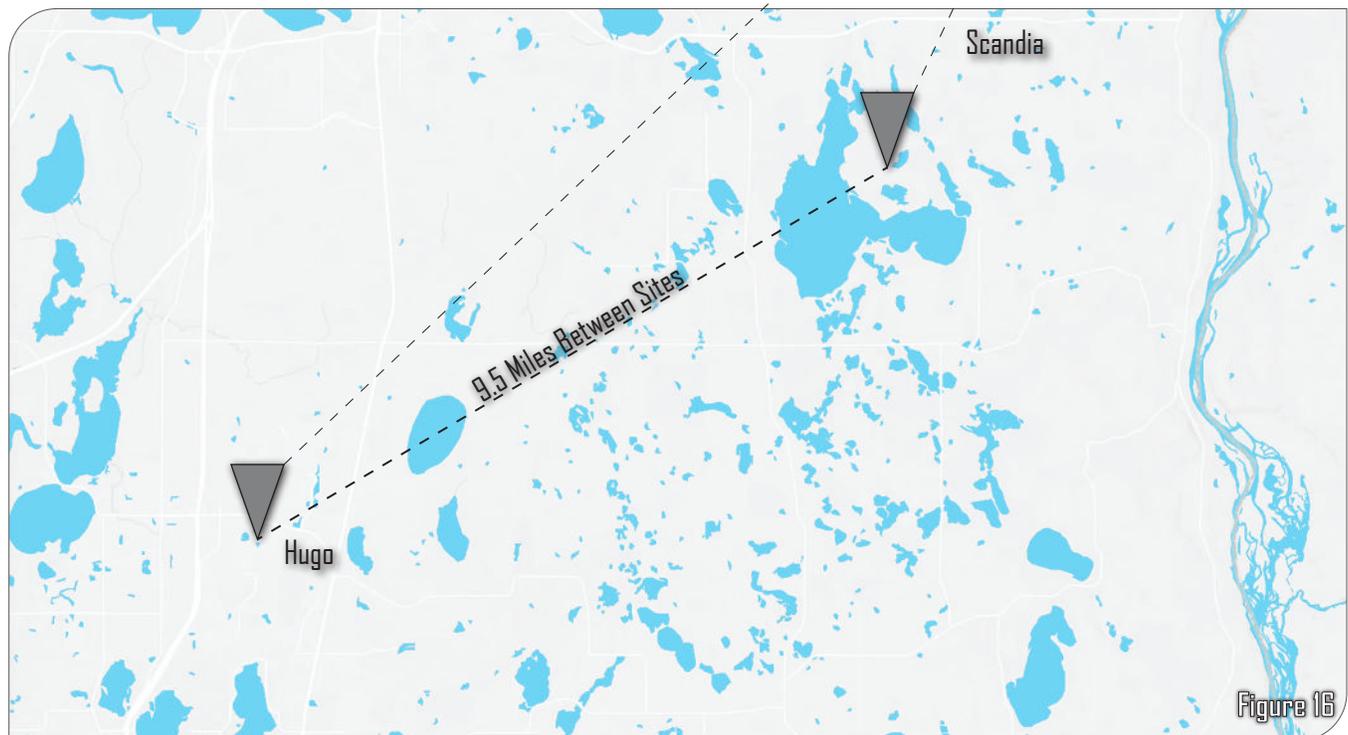
User/Client Description

This type of prefabricated building would primarily be designed to be used by a family of any size – hence the term “single-family residential.” Actual design of modular portions of the home would have the potential to be crafted so that there is a large variety of layouts and arrangements possible. A prefabricated house could be designed for an occupancy of one person or it could be designed for several people based solely off of the number of bedrooms and bathrooms, for example. By designing modules with common connecting locations, a building can be formulated through a plug-and-play type of process. Aside from new home builders, potential clients could also be individuals who are interested in doing additions to an existing home or those who would like to replace an older home with a new one.

Site Information

Possible locations should be a couple different sites that vary in topography or land types yet are all within the same city or relatively small region. By choosing a couple of sites that follow these principles, this thesis project will be able to demonstrate the adaptability of off-site construction with spatial arrangement in response to topography as well as the ability to deliver modules to the given sites.

The chosen site(s) should be readily available and accessible plots for the assembly of a single-family residence. Since the main ideas behind off-site construction and prefabrication are to create buildings cheaper, faster, and better; it would not be very wise to implement off-site construction for a site that doesn't follow the same



Site Information

principles. This means no sites should be chosen that would require excessive demolition of existing buildings, parking lots, vegetation, or large structures in order to prepare the given site. While a potential client could still make the choice to go against this logic for whatever reason, I intend to choose a more manageable site in order to exemplify the ideas behind the industry of off-site construction.

With this in mind, I am proposing the selection of two sites - one being within the city of Hugo, Minnesota, and the other on the outskirts of Scandia, Minnesota. The Hugo site is on a very flat plot of land in a fairly new housing development. On the other hand, the Scandia site is situated on a sloping plot of land that borders the edge of a large pond in

the country. I have chosen these specific sites based on their individual locations, topographies, and contextual surroundings. These locations have been chosen partially because of their relative distance from each other as well. The two sites are just barely under ten miles apart from one another. By doing this, the sites will have nearly identical climate data leaving the only distinctions between them being intended differences.

Rural Site Location:
19331 Meadowridge Trl N,
Scandia, MN 55073
Lot Size: 1 Acre



Figure 17

Site Information



Urban Site Location:
4520 Cosette Ln N,
Hugo, MN 55038
Lot Size: 9,844 Ft²

Project Emphasis

Efficient Use of Material

Construction process should be able to conserve materials and produce much less waste than a conventional on-site build.

Faster Than Conventional Build Time

Overall construction process, site delivery, and site assembly should take place in a duration that is significantly less than conventional methods.

Takes Place without Interruptions from Weather

Construction process should take place within a controlled environment that would allow modules to be built without the disruptions of adverse weather conditions.

Safer Conditions for Construction Workers

The environment of the construction process should provide laborers with plenty of lighting as well as increased safety standards similar to that of a factory.

Lower Carbon Footprint

Delivery of modules to the site should result in a reduced amount of trips made to the final location than conventional methods.

Goals for the Thesis Project

My goals for this thesis project can be grouped in a few different categories. While I clearly intend to make an academic statement with this research, I would also like to pursue personal and professional goals along the way as well.

Academically, I intend to:

Research. Spend my final moments of my academic career taking advantage of the information and resources available to me.

Innovate. Develop new methods and technologies of off-site prefabrication.

Educate. Diminish any negative connotations and views that revolve around the industry of prefabricated homes.

Professionally, I would like to:

Create. Design new instances of successful architecture for a wide variety of people.

Refine. Strengthen my research skills and my ability to apply information to new areas.

Display. Demonstrate my skills and perhaps new-found abilities of importance to the architectural community.

Personally, I would like to:

Expand. Increase my current knowledge pertaining to the field of architecture as well as the scope of today's society.

Network. Create new connections with people in order to produce more opportunities for myself.

Flourish. Make the most of whatever may come my way and be able to enjoy what I do.



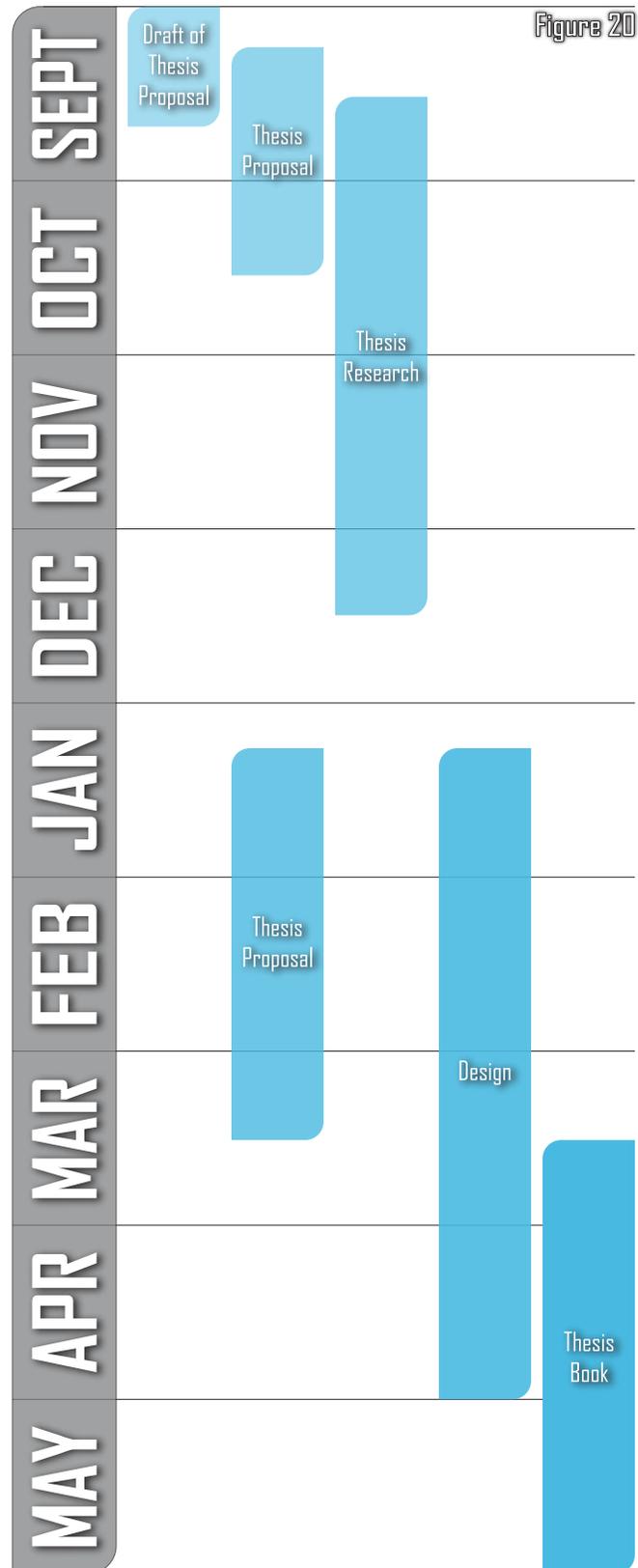
Figure 19

Plan for Preceding

Research Direction. Research will be conducted in several areas in order to support the premise that the field of architecture can play a large role in creating more effective methods of off-site construction. There will be investigations taking place behind the typology of a single-family residence which will help establish a set of criteria in which future designs will be held to. The development of this criteria will be verified through the process of analyzing the historical context involved with both single-family residences and off-site construction. This research approach will accurately develop the programmatic requirements necessary to further direct the thesis research.

Design Methodology. Various design methodologies will be employed including a mixed method of qualitative and quantitative analysis, graphic analysis, digital analysis, as well as the possibility of an interview subject. Data will be gathered by whatever means available during several stages throughout the research process. The research findings will then be analyzed and presented.

Documentation of Design. Initially, all research applicable to the design solution will be documented. However, as the design further develops, some areas of research may become unimportant and therefore may not be crucial to be documented any longer. As for the process of the actual design solution, documentation is likely to be held in a different manner. As design develops, key stages will be documented along with whatever pieces of knowledge that might have influenced certain changes or outcomes.



Theoretical Premise/Unifying Idea

Philosophical Framework:

By using combined strategies of research and analyzing both qualitative and quantitative data about today's building industry, many problems involving inefficient use of time and materials can be identified. These problems within the construction process often translate to complications of how and when projects are completed. Many alternative methods of construction have been identified that have the potential to improve or solve these challenges entirely. These findings will establish a process that will allow buildings, such as single-family residences, to be built while achieving a higher level of satisfaction and efficiency.

Theoretical Framework:

In theory, the typology of a single-family residence is one of widely varying sizes and characteristics. This research aims to identify the necessary parts of a house as well as their ideal size and arrangement. By determining and classifying a standard group of what makes up a successful design of a single-family residence, we can develop and coordinate a more efficient process of construction. Through the design and creation of larger components of preconstructed buildings, we can create a higher quality of buildings and achieve better coordination of labor in a more efficient, and cost-effective manner. By identifying the most important "building blocks" of a house, we can determine how to develop modular units that have the potential to streamline the construction process. The size of these housing modules are often determined based on how large they can be made while retaining the ability to be efficiently

transported. Since the size of a single-family residence likely varies based on the program requirements of the family living there, the level of modularity for a prefab home would be in direct correlation. Another factor that would directly influence the size of preconstructed modules is the location of the building's final assembly, as well as the path taken to transport them there. In most cases, modules will be built to the largest size possible that a semi-truck flatbed trailer will allow to transport. However, if a building needs to be transported to a site from the initial build location on a restrictive corridor such as through a narrow road or underneath a low clearance bridge, the module will likely need to be constructed smaller than some would consider ideal. All of these factors need to be taken into consideration before the design can begin. When these factors do not create limitations on the size of modularity, it entirely comes down to the desired size of the overall completed house. In the case of a "tiny house", the entire house could possibly be built in a controlled environment before being transported in one piece, whereas a very large house would need to be split up into several modules.

Strategies:

This project will rely heavily on typological case study research in order to walk through how others have approached this method in the past as well as the reasons behind why certain outcomes are more successful than others.

Tactics:

Selected case studies will be used to explore various spatial arrangements and configu-

Theoretical Premise/Unifying Idea

rations of single-family residences and similar prefabricated buildings as well as how the parts (rooms) of a whole (the house) connect to one another. Three-dimensional modeling will also be used to help further visualize and study the communication between the units that make up a single-family residence. Through the creation of diagrams and informative graphics, I will then be able to portray my findings in a way that speaks to a wide audience.



Figure 21

Literature Review

A History of Prefabrication by Alfred Bruce and Harold Sandbank

A History of Prefabrication is a book about the development of the prefab industry within the United States following the post-Depression era. The book is comprised of six installments that were previously published as articles in *The Architectural Forum*, a magazine that has since ceased publication. In fact, one of the aspects that makes this so interesting (to me) is the depth of information it provides from such an early time in the mass development of prefabrication. This lends itself to the fact that the authors, Alfred Bruce and Harold Sandbank gathered and published the articles in the form of a cohesive book in the year of 1944.

This book offers a contrasting insight into the history of prefabrication compared to more relevant sources mainly due to its age. Many of today's books mention little of the history prefabrication if any at all. Those that do usually only hit a few of the high notes while skimming through the rest. This book (being accessed 75 years after publication) offers a much more in-depth developmental history of the industry. The authors suggest that prefabrication in America may have been said to began when the wooden frame house was developed and progressed through the invention and industrialization of builder's tools. The wood frame house was a structure that had evolved to use products of prescheduled machine production while being assembled on the final site, however. This evolution of the way we constructed house, according to Alfred Bruce and Harold Sandbank, "... left our

construction practice in the position of taking only partial advantage of the benefits of mass production that had produced low-cost products for a large part of our national requirements." The main source of pressure that kept the prefabrication movement alive from then on laid within the problem of producing homes within the reach of average incomes within the mass market. The movement stayed at a standstill until the Great Depression. The prefabrication movement, as the authors put it, "sprang to life after the collapse of the stock market in 1929 and after the deflation a year earlier of the boom in traditional building which had just swept the country. A market-hungry nation suddenly became aware that in the field of low-cost housing, it had neglected one of its greatest potential markets." This arose to a fresh outlook of the industry that many experts hadn't considered before. Many organizations and professionals began to research and promote the development of modular systems in order to simplify construction through the use of standard repetitive members. For example, Bemis Industries Inc., a non-profit organization involved with research and experimentation in the housing industry began to describe what they desired in an ideal building material. The organization was researching a material that would perform as a triple function – providing structure, insulation, and wall surfaces all as a single material. This was perhaps a point of view that hadn't been pursued by any previous organizations and definitely a product of the stimulus to change the building industry. Another push to change the industry came from the U.S. government itself. The Federal housing agen-

Literature Review

cies, through their purchase in less than two years of almost 75,000 prefabricated dwelling units for war workers, had brought the prefabrication movement out of the stage of an experiment and into the stage of actual mass production. The Government had become the prefabricator's best, and virtually, only customer at the time. However, the war housing dwellings were held to production standards so low, that these poor qualities became highly associated with the notion of prefabricated houses, that have somewhat carried over to the present-day view on the industry.

A History of Prefabrication also goes into the evolution and experimentation of the different methods and materials that followed as well. For example, the idea of the "mast house" was a very early concept in this age of the modular movement in America. First proposed for the design of a skyscraper in Chicago by Frank Lloyd Wright, the mast house involved the idea of a building being suspended by a central core. This idea was further developed when Buckminster Fuller designed the Dymaxion House, a modularized home that was meant to be exclusively prefabricated. Fuller argued that houses should be created in a universal design so they can be used anywhere in any climate, rather than being built to meet certain climatic conditions – all characteristics of which the Dymaxion House exhibited. This is just one of the many examples explored within this book, many of which have been forgotten and/or could have applications in today's world. On the other hand, some of the content in this book seems to have aged poorly with the way today's society has evolved since then. However, A

History of Prefabrication does an excellent job of summarizing the specific developments of construction using the materials of concrete, steel, and wood – many of which still hold as relevant.

Overall, I believe this book presents a lot of useful knowledge in a way that many other sources lack. I was a little weary of this book when I first discovered it because I assumed it would be greatly outdated and irrelevant to the atmosphere of present-day prefabrication theories. With that being said, I proved myself wrong because this book was a much more literal step back in time than I could have anticipated. It has lended a much more detailed developmental history for me to build my thesis research and ideas on, as well as some trial and error instances that should perhaps be avoided.

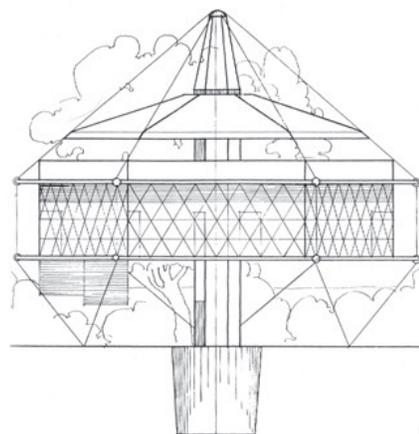


Figure 22

Literature Review

The New Building Block; A Report on the Factory-Produced Dwelling Module by Joseph Carreiro

The New Building Block can be summed up as a book that covers various methods of factory-produced prefabrication as an attempt to help solve the rising need of housing along with rising housing costs. The main author that is credited with writing the book is Joseph Carreiro, although there are several other people that have been credited with helping put together the content – those people can be found listed in the beginning of the book. Since it is somewhat unclear as to who has contributed what throughout the book, I will be referring to Joseph Carreiro as the author for a majority of the book's content. The New Building Block goes in depth to address a few topics such as the components or systems of a house, transportation methods for prefabricated modules, as well as several case studies and their respective analyses. A brief statement in the beginning of the book establishes a constructive mentality towards the factory-produced dwelling module that goes as follows: "The new prefabricated elements (whether a panel, a room, or a whole dwelling) should be thought of as new building blocks – of a new scale, produced in new ways, and offering new challenges in their assembly..." This statement is in fact what ultimately allured me into choosing this book as a source to include within my literature reviews because it speaks a message that I have been trying to convey.

One of the main topics of this book is about stressing the need to change the way we build

homes. Carreiro argues that it's important to consider every possible way in which new technologies can be applied in order to lower the cost of construction in today's desperate situation. Methods of modular construction often stay up to date with breakthroughs within the construction industry for this reason, which has allowed modular approaches to advance to a point where it can contribute significantly. The construction industry today can be said to be in a desperate state for numerous reasons. Skyrocketing costs of land, constantly rising interest rates, scarcity of mortgage money, and many other factors have resulted in the ever-increasing costs of construction as well as the shrinking pool of construction workers. The author proposes four major factors that will increase the need for new housing. Those factors can be said to be increases in newly formed households/families, removal of houses from the market as a result of damage or deconstruction, the need to provide adequate flexibility in the housing market, and the growing idea of the second home/weekend home market. As for actually creating modular house designs, Carreiro proposes the idea of breaking down the home into subsystems. Instead of thinking about the individual rooms, it's important to analyze the systems that take place within a home. For example, a bathroom could be considered an individual unit, but the bathroom along with its respective plumbing wall is a much more complete component. In a highly modularized home for instance, these systematic components could not only provide for cheaper, faster, and better construction, but they could also be entirely

Literature Review

replaced with little disruption to the rest of the house – much like an old and worn out appliance. When the industry of prefabrication has advance to be able to achieve such a high level of modularity, it will, as Carreiro puts it, “... be the biggest change in housing since man came out of the cave.”

Another huge factor of prefabrication that often becomes overlooked, is the transportation involved from the build location to the assembly location. In order to achieve safe and efficient transportation, a dwelling module must be rigid enough to be pulled over the highway, and often hoisted into place by a crane. In order to be transported on roads, dwelling modules are often restricted in size to be approximately 12 feet wide

by 60 feet long maximum. If modules are built out to these extents, they often produce a house with strange characteristics that differ in appearance and function of a traditionally built house. The author describes an uncomfortable effect of typical dwelling modules that results in a string of narrow rooms flanked by a corridor that produces the unusual feeling of looking down a tube. Therefore, we can understand the need to consider more options in spatial arrangement when designing modules to be able to fit within the 12-foot by 60-foot hauling restrictions. One way to bypass this restriction size is to use a helicopter to both transport and place the modules at the final site- this is often much more expensive than the alternative.



Figure 23

Literature Review

A more creative approach, however, involves nesting pieces into each other or creating units that can somehow fold for a more compact transport. This method addresses the concern of shipping empty space as well. All of these factors must be taken into consideration while in the design phase in order to be successful. After all, prefabricated homes often travel up to 300 miles (and even further in some cases) from the manufacturer, according to Joseph Carreiro.

The New Building Block really lives up to its title as it is one of the better reports that I've read on factory-produced dwelling modules. Aside from the content I have reviewed in the previous paragraphs, the book contains another section that entirely consists of case studies along with statements from the designers and individual analyses that have been done by the author. Out of the many case studies discussed in this book, there's a few that have attained certain characteristics that I intend to incorporate within my designs come next semester. For example, the Canister and Link Design by architect Robert Fawcett uses a corrugated stressed-skin steel along with unique connection points in order to create a lightweight system that allows for various arrangements – an aspect that will have much importance within my own designs for prefabricated dwelling modules. Along with that comes an in-depth knowledge that was discussed pertaining to module transportation which is something many other sources have been missing. Overall, I believe the contents of this book have the ability to impact and influence designers who have an interest in housing prefabrication.

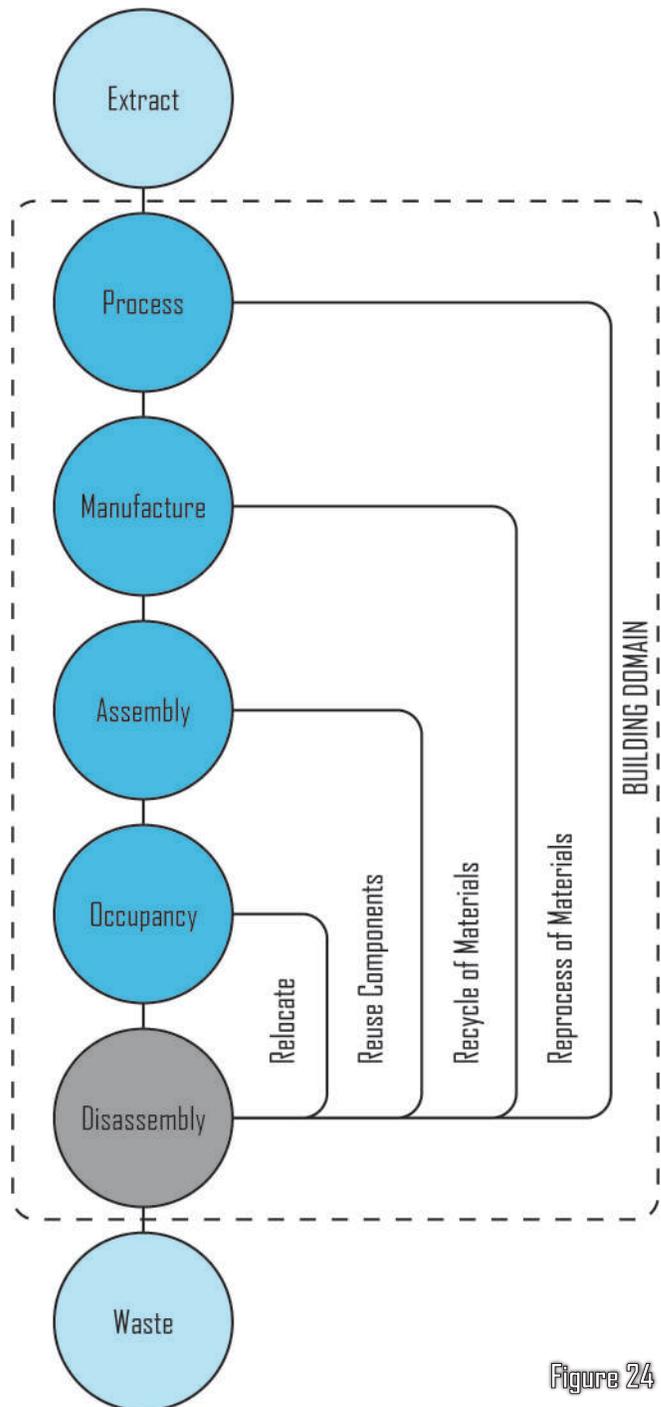


Figure 24

Prefab Architecture: A Guide to Modular Design and Construction by Ryan E. Smith

The final literature review is on yet another book. However, due to this book being quite lengthy as well as there being some repeated topics from the previous reviews, this literature review will not be addressing the entire book. This book has been written entirely by Ryan E. Smith except for the foreword which has been written by James Timberlake, FAIA, of KieranTimberlake – an architecture firm in Philadelphia. This book covers a large expanse of knowledge pertaining to prefabrication as well as the entire field of architecture. The contents of the book are broken down into four parts: the context, the application, case studies, and the conclusion. This review will be focusing on the second part, the application (pages 77-247), which can be further broken down into the principles, fundamentals, elements, assembly, and sustainability of prefab. Throughout the book, Smith goes into a lot of detail to explore the ideas behind prefabrication and into even more depth in order to examine the specifics of how prefabricated buildings can be – and are built today.

The current atmosphere of the United States' building industry is extremely demanding. According to Ryan Smith, the "construction expenditure in 2008 was estimated at \$1.3 trillion. This is double the next closest country, Japan, who spent \$600 billion." Considering the amount of money invested into building practices, there is relatively little advancement in technology within related areas of work. It's no surprise that, in 2008 follow-

ing the realization of this issue, that the National Institute of Standards and Technology (NIST) issued a request for the National Research Council (NRC) to appoint a committee of experts to provide areas of advice for advancing the productivity of the United States' construction industry. The NRC developed five recommendations which can be summarized as: the widespread use of Building Information Modeling or BIM software, improved jobsite efficiency, greater use of prefabrication, innovative demonstration of installations, as well as performance measurements. All of these recommendations are already involved within the industry to some degree. However, it seems the one recommendation that has struggled to gain interest over the past century is a greater use of prefabrication. All of the recommendations given by the National Research Council are of course related to one another. With the advancement of one area, follows the advancement in other areas due to the higher achieved effectiveness reaching out into other technologies. Prefabrication, however, has historically lacked the technological advancements seen in most other areas of construction. While there are many instances of prefabricated components being integrated in today's buildings, there has been much change towards developing truly prefabricated buildings.

The notion of prefabrication is perhaps most often associated with a reduction in building costs although it has the potential to create savings in time, material, and labor as well. However, just because a building utilizes methods of prefabrication, doesn't mean it accomplishes any of those

Literature Review

things. In order to be productive with prefab, there must be a high degree of planning. This means, when prefabrication has been carried out properly by addressing all of the involved principles, the concept of saving becomes common throughout many aspects of the build. One of the main methods for reducing the overall cost of a project is the reduction of material used. Since prefabrication takes place off-site, materials are held within a factory setting meaning larger quantities can be bought at a cheaper per unit price. With construction taking place in a controlled environment, it becomes easier to find places to use scrap materials that would otherwise be discarded on the site. "The materials are present no sooner or later than needed... in a manner that requires less on-site installation material, and results in reduced time and overhead." It's easy to see how one benefit of the construction taking place off of the site translates over to several other related benefits. Time savings in the duration of construction are arguably the most beneficial when it comes to prefab, however. Since most prefabricated projects don't utilize precast foundations, site work can be done at the same time as the building is being produced rather than the latter process taking place after the other. This is not to say however, that there aren't hidden costs within the prefab process. Areas that often include hidden fees are overhead relating to manufacturing staff, fabricator profits, transportation and assembly costs, as well as design fees. Despite all of these factors, the actual quality of prefabricated buildings comes down to the quality of design and production. As Smith puts it, "prefabrication is

not synonymous with standardization, and therefore is only as good from a design perspective as the demands placed upon it." This means it requires the abilities of all those involved to create something that is mutually beneficial.

The main elements of a prefabricated building could be said to be the modules. Modular architecture is often associated with the utopian ideals of modular homes that can be traced back to the 1960s which were often viewed as cheap and temporary. However, modular construction is still employed today, and in ways that are more standard than one might expect. To the degree in which prefabrication is executed, modules make up the largest of the finished elements. A module is a standardized unit of construction that is designed for ease of transportation and assembly, and is often more finished than most other components upon arrival at the site. These modules are usually built from steel frames, wood frames, or precast concrete. For small dwellings, modules are often built to meet the International Residential Code while larger multifamily dwellings are built to standards of the International Building Code. Of the three previously mentioned materials used to construct the majority of a module, concrete is the least used. This is because concrete modules become vastly heavier than the steel or wood framed counterparts, making transportation and assembly much more difficult. When concrete is used in prefabrication however, a "knock-down" method is typically used so that panels can be flat packed during transport and popped up into place later on. While wood is the most common material

Literature Review

used for framing modules, steel is primarily used in commercial forms of prefab. Steel-framed modules provide much more strength and precision than wood does at an even lighter weight as well. Perhaps the most extreme difference would be the heights that each of these materials allows modular construction methods to reach. A wooden modular approach will allow for a maximum height of three stories typically. Steel modules can be assembled up to 12 stories high, while a combination of steel and precast concrete can reach upwards of 20 stories or more. A more unique alternative to these methods that has recently become quite common is the use of shipping containers as modules for a prefabricated building. Ryan Smith claims that the “international trade deficit has made unused shipping containers potentially usable in architectural applications. As many as 125,000 abandoned

containers currently clog British Ports and nearly 700,000 in the United States exist due to our enormous import industry” (as of 2008). These unused shipping containers are ideal for the use of modules since they are designed with plenty of reinforcement so that they can be stacked several layers high. They’re also built from 14-gauge COR-TEN steel which is naturally corrosion resistant. However, one aspect of shipping containers being used as modules in architecture, is that their standard width is eight feet which makes for uncomfortable room sizes. The only way to get around this problem is to cut apart and reattach shipping containers to accommodate larger spaces which can be a lot of extra work. Perhaps in the near future there will be a more suitable material for creating a standardized building module.

The final topic of importance within this



Figure 25

Literature Review

section of the book deals with the final assembly taking place at the site. It has been addressed many times that there is a lot of planning that goes into the transportation of prefabricated elements, but the process needed to install the modules is often overlooked. As some form of crane is typically used to set modules onto truck trailers at the factory, a crane is also likely to be needed at the site to remove them and set them into place. The use of a crane for a typical prefabricated dwelling is very limited whereas a traditional dwelling doesn't involve the use of a crane, but rather smaller equipment gets the job done instead. Of the two main types of cranes, those being mobile cranes and fixed cranes, mobile cranes are more often used for obvious reasons. Mobile cranes such as crawler cranes are most commonly used at the site. However, when rough terrain is not a problem on the site, a truck mounted crane can be used which has the advantage of being able to be transported at highway speeds. Another major part of the on-site assembly is the foundation upon which the modules will sit. For modular construction, foundations can be piers, linear footings, or continuous footings. The selection of the foundation type depends entirely on the way the modules have been built. Site-cast foundations and slab-on-grade methods are often not as precise as the factory-built modules which has the potential to cause major alignment problems. This leads us to the topic of material joints and mate-line stitching. Seams can be hidden where modules are joined together by installing the finish materials over the joints. Interior as well as exterior materials that cover module mate-lines are often left unin-

stalled at the factory and sent to the site as ship-loose items where they can be installed later. However, at joining locations that are anticipated to have larger gaps that aren't desired to be hidden, a joint can take on the advantage of a sliding fit, an adjustable fit, a reveal, a butt joint, or just an ordinary edge. When it comes down to details like these, Smith states that "Architects dealing with off-site fabrication must think more like product designers."

The main takeaways I've found in this book deal with how and why prefabrication has the potential to play a big role in battling the struggles found in today's construction industry. With that being said, the United States "use(s) 26 percent more energy than 20 years ago, (while) buildings account for 39 percent of carbon dioxide emissions", according to Ryan Smith. Therefore, architects as well as the many other building-related professionals must assume a larger responsibility to help building owners understand the implications of the vast amount of design decisions involved. This book also addresses the problem of a building's life expectancy as well. Not only is it important to make very informed decisions for the buildings we design, but it's important for the clients and consumers to maintain efficient use of buildings and their components. When it comes down to it, the lifetime of a building is very much out of control of the architects and construction professionals. Instead, the end-product-users of the buildings we create need to be conscious of the energy and materials they use as well, and I think that's a very important thing to recognize.

Project Justification

The specific reasons behind my choice of a thesis research topic have a lot to do with my previous work experience and the interests that have carried over from those jobs. For example, in the past few years, I have worked in two factories, at a building material retailer, and at an architecture firm as of currently. While working as an architectural intern has helped me gain a lot of insight in the field, there's something else that the other jobs have helped open my eyes to. After all, I have been studying architecture for the past four years, so the learning process between school and my current job somewhat coincide of course. It's the jobs that had a less direct connection to the field of architecture that helped shape my curiosity about modular prefabrication and off-site construction. Perhaps my first glimpse of modularity was when I worked in the plastic molding and assembly department for 3M in New Ulm, Minnesota. Most of what I did at this job involved manufacturing pieces and items that were for the most part, identical from one to the next. Although it was a dull job with a tough rotating shift, it helped me learn a lot about industrialization of products and how to maximize the efficiency of the production of a variety of items.

My next job after this was as a delivery and yard worker at a company called Design Home Center. This company had a lot of things going on making it hard to label exactly what this company is. However, they could be described as a sort of lumber yard that also functions as a retail store along with salesman, drafters, interior designers, and a carpenter on site. My main duties at Design

Home Center were to deliver building materials to job sites. Any kind of product or material needed to complete anything from a small carpentry project all the way up to the full construction of a house was handled by me and my coworkers. Needless to say, I learned a lot about construction on a wide variety of projects and even more about a plethora of building materials. The job was often very labor-intensive, but I had the opportunity to talk to a lot of interesting characters on a daily basis – this was my favorite part. Perhaps the most beneficial part of this job was the frequent conversations I had with the contractors. Being in communication with them led me to help understand how to estimate certain amounts of building materials for projects. Even today, I often find myself relating relevant problems and tasks to my experience at Design Home Center in New Ulm.

The next job I held was another factory job. This position was for Integrity Windows in Fargo, North Dakota. Here, I was working on the assembly line once again. I was working part-time while attending school on a full-time schedule. Much of the lessons one learns while working in a factory, were lessons that I had previously began to understand while working for 3M. However, this job brought me new insight into the building industry – windows! I of course knew all about them, but windows were a technology I had always taken for granted beforehand without even realizing it. While working at Integrity Windows, I learned all about the proper terms for parts of windows. The particular factory building I worked in handled the production of casement, awning, and stationary windows of all

Project Justification

sizes. I also learned a lot about the details of how windows operate which was something I had completely overlooked before working here. Although working for Integrity Windows seemed like a step backwards in the direction of my goals at the time, I was able to meet some very down to earth people there as well as develop a new understanding of how to incorporate the use of many kinds of windows into my own designs and in my current position as an intern architect.

Those experiences pretty much take me up to where I stand today as a graduate student of architecture. As I mentioned earlier, working at an actual architecture firm has helped me learn a ton of knowledge about the building industry, but for the most part, the knowledge that led me to the interest of off-site construction was gathered at jobs before this. When contemplating the process that would be necessary to execute a prefabricated modular home, I am able to visualize what the laborers would need to do at every step along the way because I have been in their shoes. For these reasons along with my experience of highly efficient factory production, I feel a need to streamline the process of building construction by using newly developed methods in order to help solve problems that exist within the industry today.

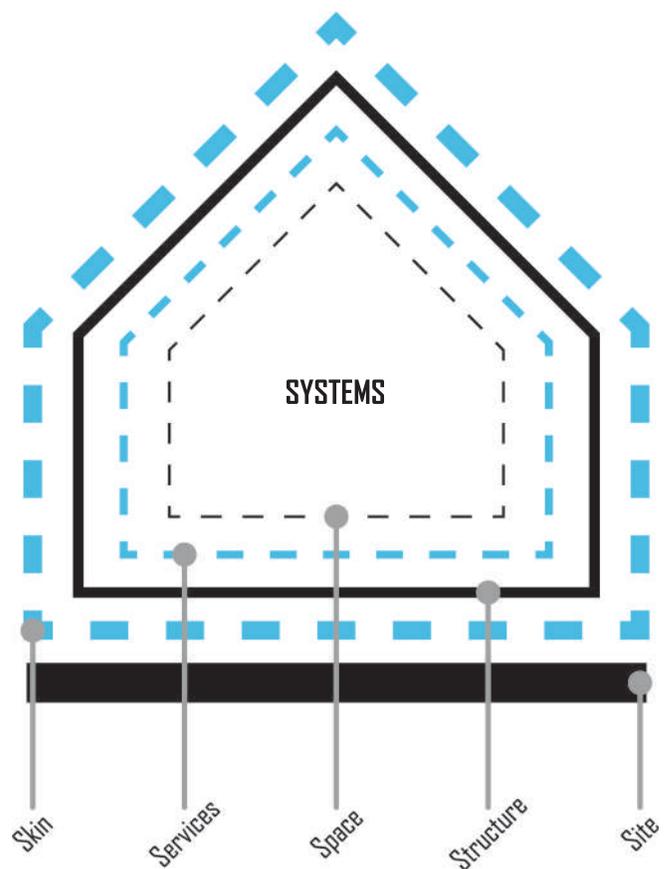


Figure 26

Historical, Social, and Cultural Context

Introduction:

The United States dominates ownership of the prefabrication housing market. However, this is primarily due to the amount of growth that has taken place in the country. The United Kingdom, Japan, and several Scandinavian countries control the majority of the innovations in prefabrication taking place worldwide. This can be said to be an effect of the social and cultural contexts that have helped shape the construction industries within these individual housing markets. For these reasons, we will be exploring the history of the development of prefabrication within these countries as well as the social and cultural aspects involved. Many buildings over time have taken advantage of the benefits of prefabrication for a number of reasons with those being to simply reduce the cost of a project, or to deliver in a shorter amount of time, as well as to employ new forms of innovation. As Ryan E. Smith puts it, in his publication, *History of Prefabrication: A Cultural Survey*, "Prefabrication relies upon social and cultural context: labor, factory ability, knowledge base, and especially market to determine what is developed. The greatest developments in prefabrication in the housing industry in the U.S. for example can be attributed to events that have spurred this on including the California Gold Rush, Tennessee Housing Authority, war time and post war housing, and most recently the energy and housing crisis of the late 20th and early 21st century. Just as America's solutions to prefabrication have come out of its immediate context, so have developments in other cultures. However, other cultures have been able to

establish a holding of prefabrication beyond immediate needs into the very desire, or building for a better." This argument, however, points directly to the problems in the U.S. that are related to housing construction. The industry today is overloaded with inefficiencies, waste, risks in safety and finances, as well as a serious lack of innovation. In order for innovation to occur, it must be socially driven and therefore, lessons from other successful cultures should be examined and adapted. Utilizing the previously developed systems of modular construction in the manufactured housing industry for the future of housing in the United States has a real potential to deliver more affordable and higher quality buildings. Building upon the existing history of construction ensures that newer technologies become an extension of the society that develops and supports it. By using what we can learn from the United Kingdom, Scandinavia, and Japan, as leaders in the industry of prefabrication, the United States may be able to enhance its capability for modular construction in order to deliver higher quality housing. As we continue through the 21st century, architects, engineers, and builders must ask themselves; where is the housing industry headed?

Historical Context:

The history of prefabrication in the Western hemisphere begins with Great Britain's effort to colonize the globe. Many of these settlements would require a rapid building strategy. The British, however, weren't very familiar with the materials that were available in different countries. In order to quickly build settlements, they decided to manufacture components in England and ship them to vari-

Historical, Social, and Cultural Context

ous locations around the world. The earliest recorded of such cases was in 1624 when houses were constructed in England and sent to what is presently known as Massachusetts. These simple shelters were timber framed for structure and also utilized timber for infilling the roof, floors and walls. There is also speculation that other means of infill material could have been canvas or a lighter system of weatherboarding. English colonial prefabrication building also extended as far as South Africa. In 1820 the British sent settlers to Eastern Cape Providence along with their own three-room wooden cottages. These structures, known as the Manning Portable Colonial Cottages, were not as broadly prefabricated as our current understanding of

off-site construction. However, they did require a significant reduction in on-site labor to build the houses versus the previously traditional methods of building from scratch that took place at the site. These portable colonial cottages made their way to many other British settlements throughout the 19th Century as well. The impact of the prefabricated cottage on the British settled North America and the future United States is uncertain, however. Other methods of British timber architecture such as the balloon frame have been assumed to be the beginnings of the light timber frame in the United States also. Light frame timber construction resulted from two primary factors: an abundant supply of lumber in North America as well as a rapidly developing

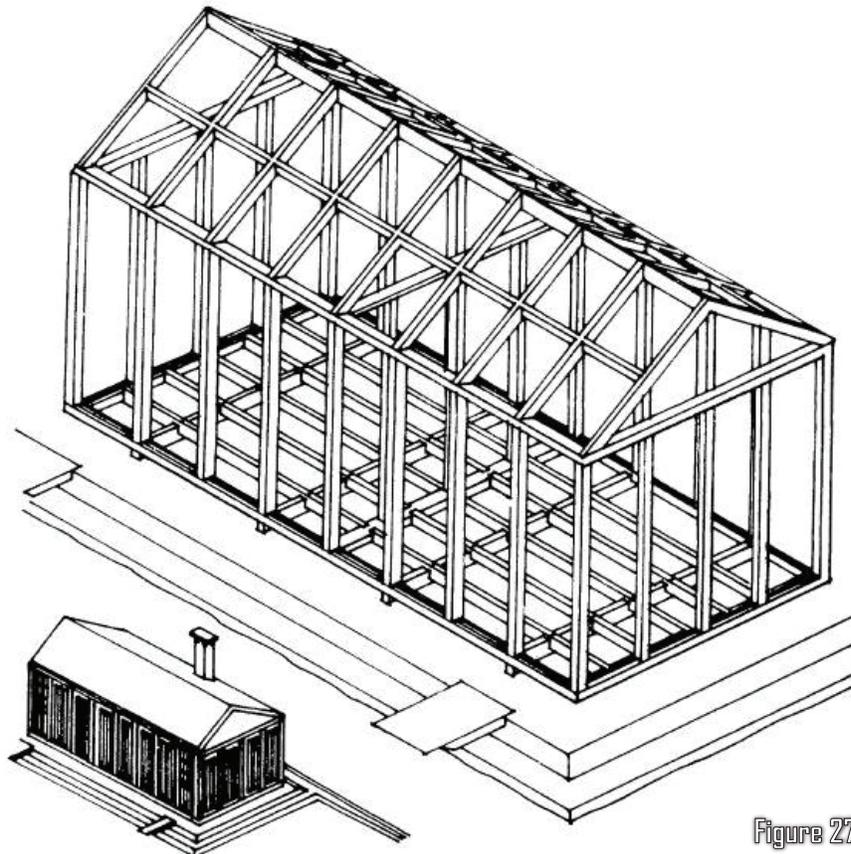


Figure 27

Historical, Social, and Cultural Context

industrial economy with mass-produced building materials.

Prefabrication in Scandinavia follows a similar pattern of development as many other nations. Their advancements have been around three major events with those being the industrial revolution, the mid-war and post-war housing crisis, as well as today's renewal of interest in utilizing CAD technology for custom produced architecture. The difference with Scandinavia (including Finland, Norway, and Sweden) is the use of wood in the majority of its housing construction. Aside from construction, wood is more frequently used in other means of Nordic architecture than in most other cultures. This is typical as it is estimated that about 37% of the land in Norway is covered with forests. The lessons to be learned from Scandinavian countries have to do with the cultures' ability to perfect the methods of production of this material in order to produce prefabricated construction products. Whether or not prefabrication takes hold is a decision of the market, industry and ultimately the people or consumers, however. Several factors have also aligned themselves within the housing market such as a balance of design, high production quality, and a practical overall price. Of the all Scandinavian countries, Sweden and Norway originally embraced prefabrication in full, but Finland has been noted for its recent advances in timber CNC-fabricated frames in building. The prefabricated housing industry in Scandinavia wasn't always as effective as it has been recently, although. It wasn't until the end of World War II when the housing demand was at its greatest it had ever been in not

only in Scandinavia, but around the world as well. It's estimated that at this time, nearly 70 companies were producing more than half of all housing in Scandinavia. In 1947, over 17,000 houses were prefabricated in Sweden alone, according to Smith. This is because during the late 1940s and early 1950s, prefabrication was finally conceptually understood by not only the building industry, but also society as a whole. This led to a variety of prototypes, new methods of production, as well as experiments in partition wall prefabrication that integrated electrical and plumbing systems. This led to prefabricated modules becoming larger in size, which in turn, guided prefabrication to become employed at a commercial building scale in standard building practices. By the 1960s, many radical experiments were being explored in prefabrication. In most cases, these experiments failed to the same degree that many of the U.S. experiments of the time did. Around 1980, prefabrication accounted for approximately 85% of all homes built within Scandinavian countries. Unlike the mid-century homes, these were not high aesthetic, architect designed homes, but instead more so a variety of styles and sizes to that could meet different needs of the market.

The vernacular method of construction in timber post and beam has been considered one of the earliest preindustrial advances in the principles of prefabrication. It has been examined through the means of British construction by way of the colonial cottage and in contemporary Finnish timber frame systems. Although built by craftsman through custom joinery, the methods of construction in

Historical, Social, and Cultural Context

Japan were historically mass-produced. This tradition of standardization in Japan has made their historic structures very durable. The use of such standards has not only been employed in housing, but also in public and government buildings. Master carpenters were the developers of the methods of off-site production of timber frames and infill panels which would later be assembled in full on-site. After the time of the post-war housing needs and the prototype period of the mid-century, Japan would go on to become the world's most successful prefabricated housing industry. Even though the United States owns roughly 26% of the global prefabrication housing market, Japan is the fastest growing prefabrication economy in the world. "In 2004, a total 1,160,083 houses were newly built in Japan. Among them, 159,224 houses were prefabricated. This translates into roughly one out of every 7 new homes in Japan in 2004 were built using factory-based methods," according to Smith. This number has undoubtedly increased since then. Japan, similar to Scandinavia, has made prefabrication a mainstream construction method. Japan also has a scarcity of land for which to build upon, but the need for housing continues to grow. Out of the approximately 49.5 million homes in Japan, only 2.2 million were built before World War II. About half of these wood-framed homes only have only a 33-year life span. The need for new, more efficient and durable homes is causing many Japanese consumers to buy an existing home, demolish it, and build new. Even with building from scratch, frustrations with poor construction and scheduling in the traditional approach have driven many consumers to explore

prefabrication as an option. What we essentially take away from Japan's history is that the United States needs to find its own culture of collaboration, process, and focus on people in order to advance the capacity to prefabricate housing effectively. From the perspective of Americans, The UK, Scandinavia, and Japan were more uniform cultures throughout the industrial revolution in which prefabrication was developed. These advances have continued to develop further with the tradition of innovative construction. Advances in the U.S. have not been as extensive as these other countries, but no less impacting on the prefabrication methods across the globe. For example, light frame construction has expanded to Japan and other areas of the world as a preferred method of building because of its flexibility, bringing it into the factory for mass production. Keeping in mind the problems associated with certain prefabricated and standardized buildings in the past, it is also useful to identify the strengths which emerged from that work, and which can be readily applied today.

Cultural Context:

With all of the innovations in housing prefabrication around the world, the United States continues to lag behind despite its high growth rate in housing. At first glance the numbers would indicate that this is not the case, as the U.S. owns the largest portion of all the prefabrication market around the world. However, this is primarily a factor of the immense manufactured housing industry, which constitutes about 24% of the U.S. residential market. In many ways, technology is social before it is technical. Technology is not something that

Historical, Social, and Cultural Context

determines the destiny of people, but instead is an expression of people. Society seems to have lost this basic understanding or perhaps in its pursuit to become more technologically advanced, never even considered the possibility. The misunderstanding that technology has the potential to inadvertently create negative impacts is especially prevalent in the building industry where the process of construction has not changed dramatically in many decades. Many of the technologies implemented by designers and builders are taken as they appear without being challenged to be used in new ways and innovation in new products is not demanded and therefore is underdeveloped. Design by the product manual is both an outdated model and promotes a lack of progress in the industry. Prefabrication is among these innovations in technology that has vastly lagged behind in the United States. Technology is an extension of social needs and wants, not a barrier. Prefabrication is also a technology that has emerged out of the necessity and desires of societies in various cultures. The United States is an exemption from this ideology, however. In the U.S. we could use a good amount of attitude change about the role technology can play in the way we create our environments. A newfound sense of optimism concerning technology should help us to create new technologies methods for the production of housing. In times of housing shortages throughout history, there has often been a growth in the need for prefabrication to be utilized to produce housing. Again, the production of these houses has most often been done in wood, using systematization to cut kit homes including framing

and enclosure. Scandinavia is a region that has perfected its system of wood harvesting and production during these time periods. By the 1930s, catalog houses became the most popular means of offering precut kit homes. This procedure was also used to develop precut public buildings such as churches and hotels. During times of war, Sweden was able to further develop this technology which resulted in the completion of wooden homes in record times for a war-famished Finland. This interest in wood prefabricated housing extended to all aspects of society including the design world.

Perhaps it is because of its exceptional history of automobile manufacturing that Japan's ability to adapt digital and material technology for other purposes such as building is very likely. In addition, Japanese culture, which focuses on collaboration and team building, is able to solve problems quickly and efficiently in order to produce better products. A keen focus on people and process that leads to products has been Japan's key to success. Because Japan excels in its process, it's likely that they will continue to lead innovations of prefab. Since prefabrication in housing has had its success in the mobile home in the United States, it is possible that there is a way to utilize the ideology of the manufactured home industry in order to deliver more durable housing. The manufactured industry continues to grow but is not favorable to the majority of citizens of the United States. This is because it is vastly misunderstood as being ugly and of poor quality, due to a history of poor examples. However, the mobile home has been one of the few successful forms of

Historical, Social, and Cultural Context

prefabrication in the U.S. because it simply doesn't try to more than what it already is, and its owners don't expect any more of it. Society has misinterpreted this housing type as competing with other housing options. Because of this, prefabrication has come under attack as a substandard method of construction for all housing. The lessons to be learned about prefabrication from manufactured housing are sometimes applicable toward other types of housing as well. It is just recently that mass-produced methods of housing production are being utilized to create many different types of manufactured housing at different degrees of construction quality and cost. It's unfortunate that a number of prefabricated buildings built in the past were judged to be of such poor quality that the method as a whole has continued to be largely rejected in the United States. In the United Kingdom, for example, a state-driven mass provision of social housing was organized after World War II that employed prefabrication. From the resident's perspective, standardizing the construction process of a building such as a single-family residence can satisfy a number of definitions of value. For example, a balance of lower build time, more ideal costs, and higher quality can be achieved with due attention also given to the whole life assessment of the building. The resulting early completion, user satisfaction, and ease of maintenance all indicate that standardization and prefabrication have great potential for the future of this market. It shouldn't be impossible to arrive at socially desirable, more sustainable, and technically sound solutions through prefabrication as it seems to be

within the U.S. today. An important distinction to be made is between the process and the product of construction. Technological advancements and different organizational structures allow concepts such as standardization and prefabrication to address many of the problems facing the house-building industry including the shortage of skilled laborers and the need for a greater client engagement. Unfortunately, there are various barriers to change in this respect, including a widespread negativity about past mistakes in our own culture. It seems that rather than building upon the techniques of modular housing of the past, the current attitude is towards mass-customization of buildings which greatly increases the number of choices offered to customers, while retaining the efficiencies of the production philosophy. While it isn't exactly an issue for clients to have such a vast amount of choices (in fact it could be argued to be more so the opposite), it has become a huge contradiction in the way architects and designers must successfully carry out their designs. In the perspective of this trend towards a client-focused house building strategy, it's important to understand market preferences, as well as perceptions of the meaning of a house or home by the given occupants. If prefabrication has the capability to enable greater design flexibility and customer involvement, then this may have an influence on feelings of security and comfort as a greater degree of control is given to occupants over their dwelling space. While this may not necessarily be the case, the potential for design flexibility and client involvement should be considered as the greatest non-monetary advantages of increasing

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prefabrication within the house building industry. Houses with greater amounts of prefabrication and modularization tend to be a concern of lenders and valuers, so it becomes important to create a sense of reassurance for residents and future consumers that these properties are perceived as durable and attractive. Therefore, simply stating that there is various degrees of prefabrication or modularized elements existing throughout all of housing construction misses the point about the cultural resistance we have been experiencing in the U.S. population.

Social Context:

In a time of many economic and environmental troubles, prefabrication holds the potential to aid in furthering a shift in the construction industry in not only the United States but in other countries as well. Prefabrication already succeeds in many cultures by offering affordable and durable housing options. These methods of prefabrication in architecture create a narrative of the desire for a better method of construction, an investigation of the production standards of the building industry, as well as a search for design and construction innovation. Therefore, a home can be seen as not just a house, but rather the setting in which social identities are defined and experienced. It is widely known throughout Scandinavian countries that prefabricated homes are better built through prefabrication than not. The housing market has also become so accustomed to prefabrication as its primary method of building production that lower initial costs are more obtainable through the use of prefabricated timber components. Simply put, the

construction industry within these Scandinavian countries cannot afford to build traditional on-site buildings and for them, prefabrication is a much more affordable and effective solution to this problem. Today, Scandinavian prefab housing continues to flourish in Norway, Sweden, and Finland. There continues to be an abundance of forestland as well as sustainable harvesting procedures that have been able to continue this responsible means of growth into the future. By using structural glulam members, buildings can be fabricated through the use of CNC precision cutting along with the joints for floors and roofs. Today's architects in Scandinavia are using these techniques in combination with traditional methods of timber framing in order to design modern aesthetic architecture. Their governments have been supporting of prefabrication in not only timber construction, but in precast concrete construction as well. Scandinavian governments, architects, and people see prefabrication as the method to provide affordable housing and public buildings to all. The difference in Scandinavia is that prefabrication seems to be benefitting all involved parties. By refining the way they build with lumber, Norway, Sweden, and Finland have been able to transition from traditionally crafted buildings into mass produced crafted buildings. The greatest difference, however, of Scandinavian prefabrication advancements when compared with the United States is found within the socially accepted process of prefabrication. This could potentially be attributed to the fact that these countries never experienced a widespread use of mobile homes that gave the method of production a bad

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reputation. Instead, the Nordic people have viewed prefabrication as a different, and more importantly, better method of building. This society has been able to take their cultural traditions of shipbuilding along with its plentiful resource of timber and explore the various possible methods of production and construction for housing. Much like the people of the United Kingdom, Scandinavians don't avoid prefabrication, but they rather see it as a way to produce affordable quality buildings.

Great Britain has been a leader and a big influence of prefabrication on western culture from very early on and continues to be so today. The Manning Portable Cottage used by early settlers focused primarily on systems of prefabricated timber frames along with infilling between the structure. They were described as consisting of grooved posts, floor plates, and triangulated trusses. The panels of the cottage fit between the grooved posts which were of standard sizes making them interchangeable. This system was designed to be mobile and easily shipped in order to further the colonial agenda of the British. From the United Kingdom we learn that prefabrication can often be found through a search for more proficient buildings. The developments of the portable cottage as well as the creation of corrugated iron point to Britain's desire to expand its influence on the world during the 19th century. Although the ethics behind their history of colonization are somewhat of concern, Great Britain was able to promote a culture of technological advancement through their own desire for expansion. Many buildings in the UK today are designed from a concept of harnessing technology to serve

humanity better and to be more sustainable. The use of manufacturing in order to produce architecture was not fully realized until the post-war era in Japan. It's assumed that several Japanese architects developed a number of prefabricated housing schemes, usually in timber and based off of the traditional ken grid, through the inspiration of the work of Le Corbusier and Walter Gropius. These houses were often small and simple, but of modernistic aesthetic. Japan, much like Scandinavia and the U.S. at the time, had its own series of catalog houses that marketed and prefabricated houses. Also being devastated by World War II, Japan built thousands of these small dwellings in order to meet the needs of their post-war housing shortage. Currently, most prefabricators in Japan use the modular method combined with an infilling approach.

The U.S. and many other countries could learn to use cultural traditions of construction along with new and old technologies with the intention of building upon the existing traditions in order to achieve architecture with a higher design and production quality. From Japan we learn perhaps the greatest lesson of all. This lesson being that the improvement of a process leads to advances in the construction industry. Prefabrication in Japan, like Scandinavia and Great Britain, excels not only due to a strong belief in the ideology and the precision of production, but primarily because of its people. Their culture is one of great collaboration, integration, and perseverance which also distinguishes their construction industry from any other in the world. With the upcoming changes in the United

Historical, Social, and Cultural Context

States' demographic along with an increase in the number of people likely to be working from home, a continued demand for increased flexibility and choice in housing is to be expected. The demand for better environmental performance, along with the potential adoption of new technologies in building techniques implies the need for an open mind when exploring various innovative approaches such as prefabrication.

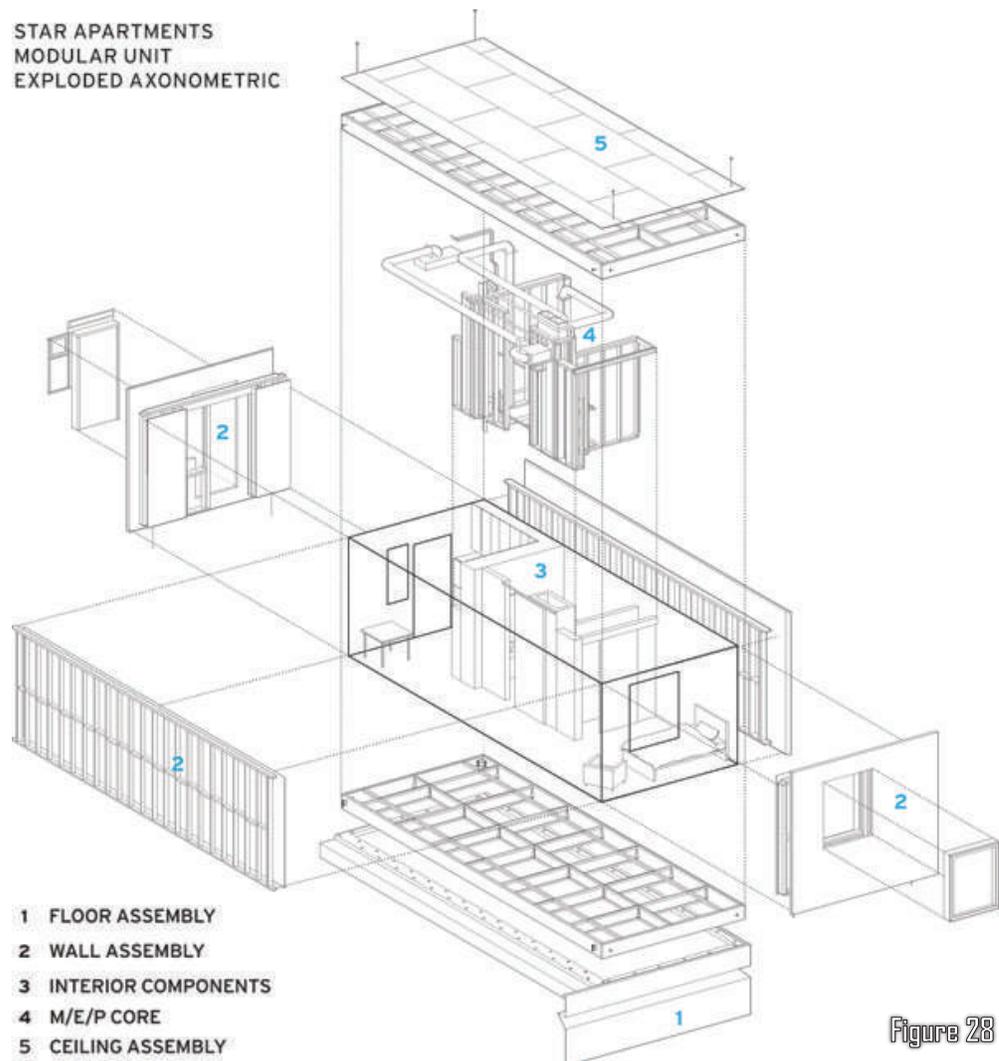


Figure 28

Site Analysis

Washington County, MN:

History:

Early development within the area of Washington County took place on the St. Croix River, which now partially forms the border between Minnesota and Wisconsin. The river provided a canal for the movement of early settlers along with logs and lumber which was key to the logging economy that flourished before the area's forests were mostly depleted. This area's first settlers arrived at present day Afton in 1837. This region was originally part of the Wisconsin Territory until the eastern part of that territory achieved statehood in 1848. The Stillwater Convention of August 26, 1848 proposed to Congress that a new territory be created with the name "Minnesota." Congress responded by creating the Minnesota Territory effective March 3rd of 1849. For this reason, Still-

water has labeled itself as the "Birthplace of Minnesota." Washington County was one of the nine counties created by legislature at this time, being named after George Washington with Stillwater named as the county seat.

Climate Data:

(According to bestplaces.net)

Climate Averages:

- Rainfall: 32.7 in Washington County, 38.1 in United States
- Snowfall: 49.4 in Washington County, 27.8 in United States
- Precipitation: 108.9 days Washington County, 106.2 days United States
- Sunny: 196 days Washington County, 205 days United States
- Average July High: 82.5 degrees Washington County, 85.8 degrees United States

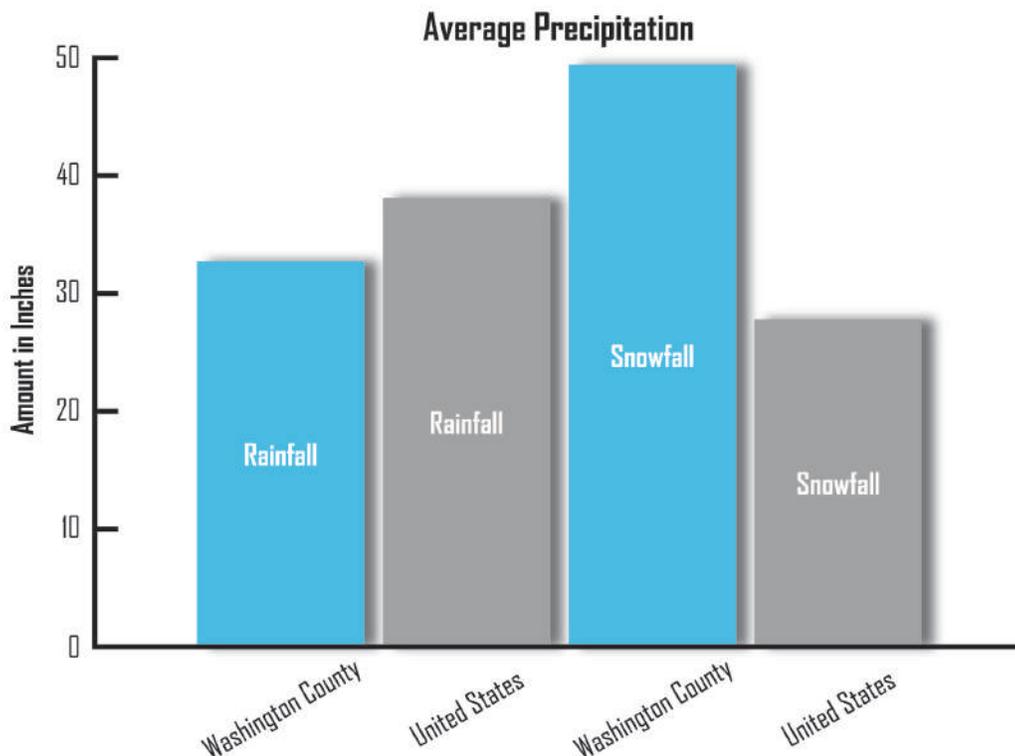


Figure 29

Site Analysis

- Average January Low: 5.3 degrees Washington County, 21.7 degrees United States

Demographics:

As of the census of 2010, there were 238,136 people, 87,446 households, and 64,299 families in the county. The population density was 620 people/square mile. There were 87,446 housing units at an average density of 228/square mile. The average household size was 2.67 and the average family size was 3.14. The county population contained 23.5% under the age of 18, 6.2% from 18 to 24, 32.90% from 25 to 44, 28.7% from 45 to 64, and 10.3% who were 65 years of age or older. The median age was 38 years. For every 100 females there were 98.02 males. The median income for a household in the county was \$79,735, and the median income for a family was \$92,497. About 5.2% of the population was below the poverty line.

Ethnic Makeup of Washington County, MN

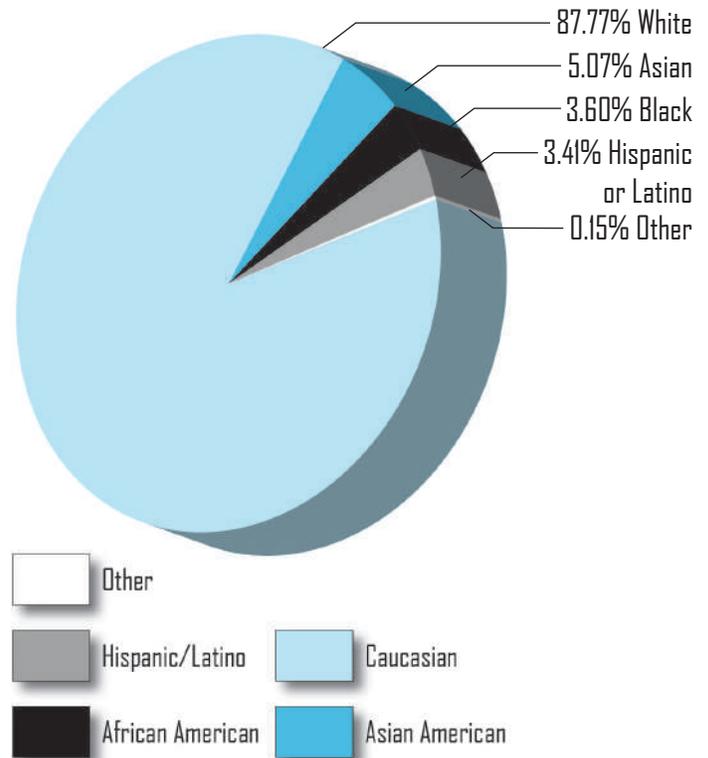


Figure 30

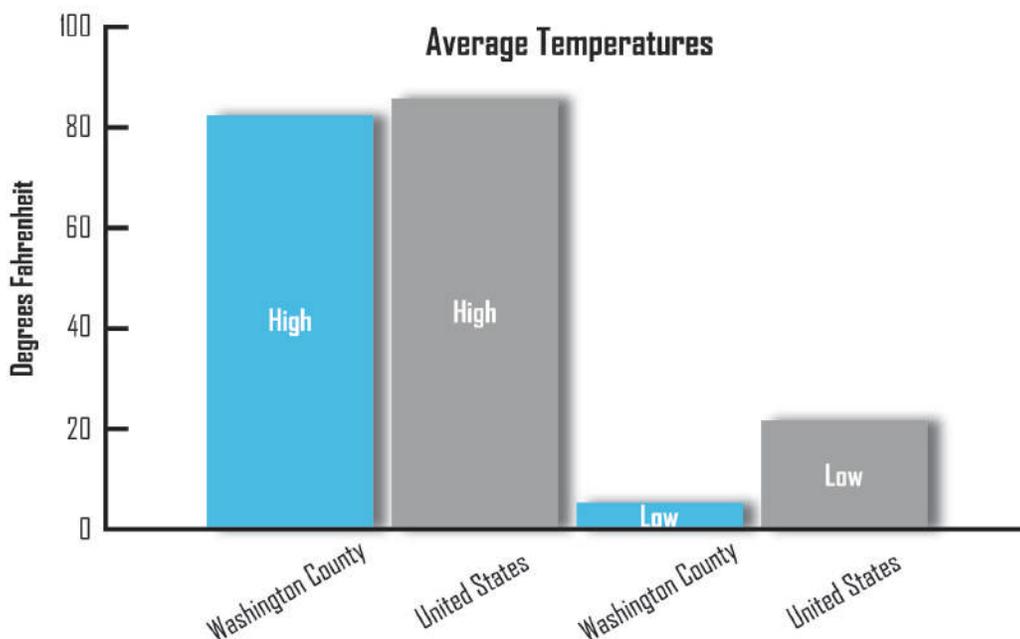


Figure 31

Site Analysis

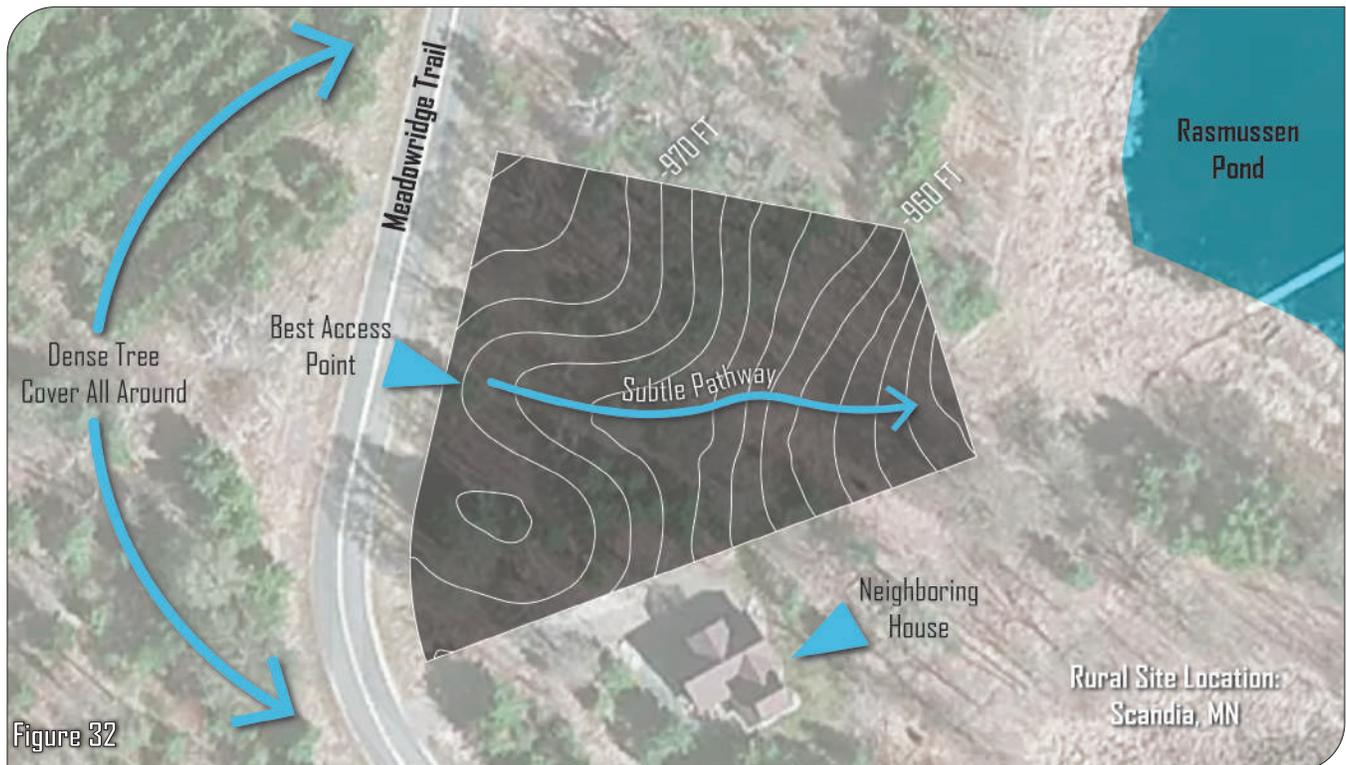
Scandia Site (New Scandia Township):

- Town Size & Population: 39.85 square miles with 4,159 people (estimation as of 2018)
- Site Address & Size: 19331 Meadowridge Trail N, Scandia, MN 55073 @ 1.01 Acres
- Zoning Code: The site is categorized as a "140 Res V Land" zone which must comply with a mostly generalized code for Washington County.
- Topography: The highest point of the site is about 976 feet above sea level and the lowest point is about 948 feet making the difference in elevation from the two points at about 28 feet.
- Notable Context: The site itself consists of a heavy tree cover of both coniferous and deciduous trees. Access to the site is best between the middle of the property lines off of Meadowridge Trail to the west. From here, the site slopes mostly downward to the shore of Rasmussen Pond which is very plen-

tiful with cattails. Of the neighboring sites, there are only two houses currently with one being to the south and another across the street to the west. The appearance of the houses within the neighborhood seem very traditional for the area and do not have any certain kind of distinguishing characteristics in form or materials.

- Roads & Circulation: Meadowridge Trail is the only road that the site has access to, being on the west side. The road is somewhat hilly and winding as it partially follows the pond shore.

- Views & Corridors: The trees on the site create a very secluded feeling with there being little view of surrounding houses or buildings. There exists a subtle corridor through the middle of the site between the road and the shoreline due to a slight break in the trees.



Site Analysis

Hugo Site (Oneka Township):

- Town Size & Population: 36.04 square miles with 15,008 people (estimation as of 2018)
- Site Address & Size: 4520 Cosette Ln N, Hugo, MN 55038 @ 0.23 Acres
- Zoning Code: The site is categorized as a "140 Res V Land" zone which must comply with a mostly generalized code for Washington County.
- Topography: The entire site is very flat with the average elevation being about 916 feet above sea level with a range of the highest and lowest points being a difference of less than two feet.
- Notable Context: The site is essentially a clean slate within a quiet, orderly neighborhood with young Ash trees bordering the south and east sides of the site. Across the street to the south, there is a park which consists mostly of a playground for the community's children. An immediate noticeable

characteristic of the nearby houses is the height of the steep rooftops. Most houses exhibit a series of gabled roofs that front towards the streets. Also, most houses are two stories tall with attached garages that have living space above them. The exterior cladding of the houses is of many different colors and styles.

- Roads & Circulation: The site is bordered by Cosette Lane to the east, Valjean Boulevard to the south, as well as a paved alley at the west side. There is also sidewalk along Cosette Lane and Valjean Boulevard.

- Views & Corridors: There are no noteworthy views from the site since the neighborhood is relatively flat and open. Views to the southeast would be best however, since the site is on the corner of an intersection making this direction more open than the others.

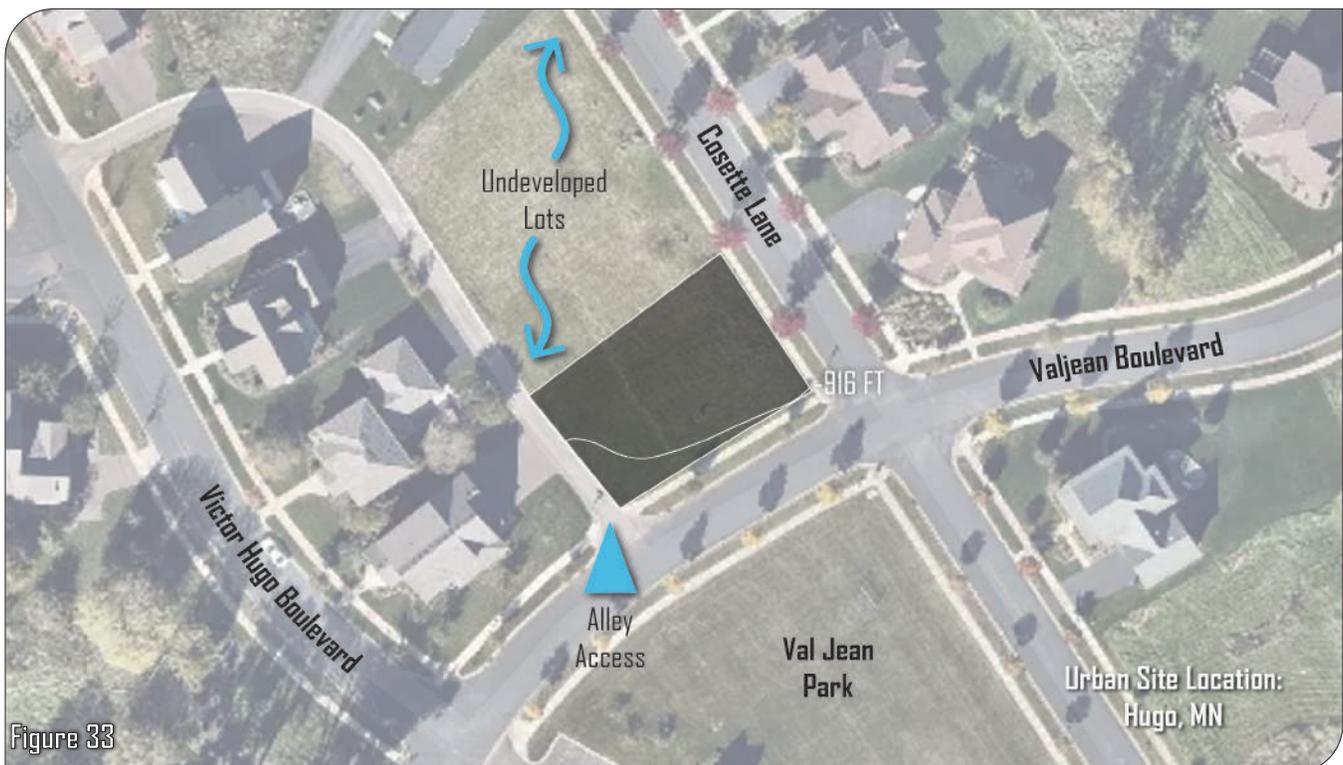


Figure 33

Performance Criteria

The final designs of the thesis project should achieve certain characteristics and criteria in order to successfully promote the benefits and advantages of building off-site through prefabrication.

1. Space Allocation

The two prefab house designs will vary in form and spatial arrangement due to their sites but will share similar spaces. These spaces and their relative sizes will be determined through the typical prevalence of certain rooms and the average floor area of American homes. This statistical data has been put together by the National Association of Home Builders (NAHB) and the Census Bureau's Survey of Construction (SOC) and has been organized by house sizes. A small home is described as being less than 2000 square feet, an average home is between 2000 and 3000 square feet, while a large home has been expressed as being larger than 3000 square feet. Of all the case studies that have been explored, prefabricated houses often have around 2000 square feet of floor area. This

means the resulting room sizes are likely to be based on either small or average houses within the United States.

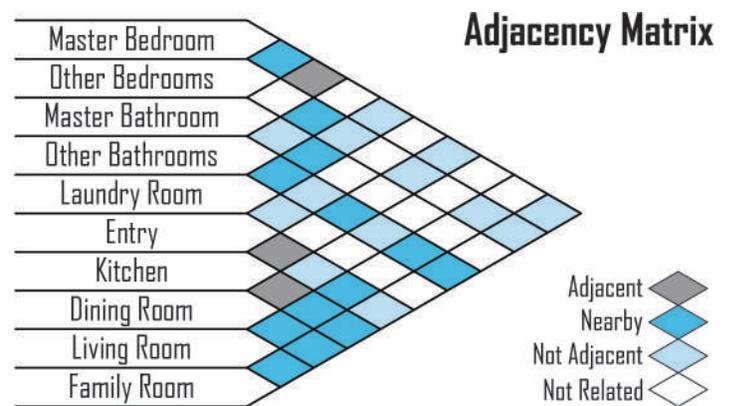


Figure 34

Average Space Allocations for Single-Family Residences						Figure 35
	Small Houses (<2,000 SF)		Average Houses (2,000-3,000 SF)		Large Houses (>3,000 SF)	
Master Bedroom	231 SF	14.2%	309 SF	12.0%	411 SF	10.9%
Other Bedrooms	237 SF	14.6%	432 SF	16.8%	677 SF	17.9%
Master Bathroom	104 SF	6.4%	154 SF	6.0%	209 SF	5.5%
Other Bathrooms	86 SF	5.3%	163 SF	6.3%	285 SF	7.5%
Laundry Room	63 SF	3.8%	96 SF	3.7%	134 SF	3.5%
Entry	47 SF	2.9%	88 SF	3.4%	128 SF	3.4%
Kitchen	195 SF	11.9%	300 SF	11.6%	420 SF	11.1%
Dining Room	126 SF	7.8%	192 SF	7.4%	266 SF	7.0%
Living Room	193 SF	11.8%	223 SF	8.6%	282 SF	7.5%
Family Room	181 SF	11.1%	296 SF	11.5%	426 SF	11.3%
Other Finished Space	167 SF	10.3%	326 SF	12.7%	541 SF	14.3%
Total	1,630 SF	100%	2,580 SF	100%	3,780 SF	100%

Performance Criteria

Space Interaction Net

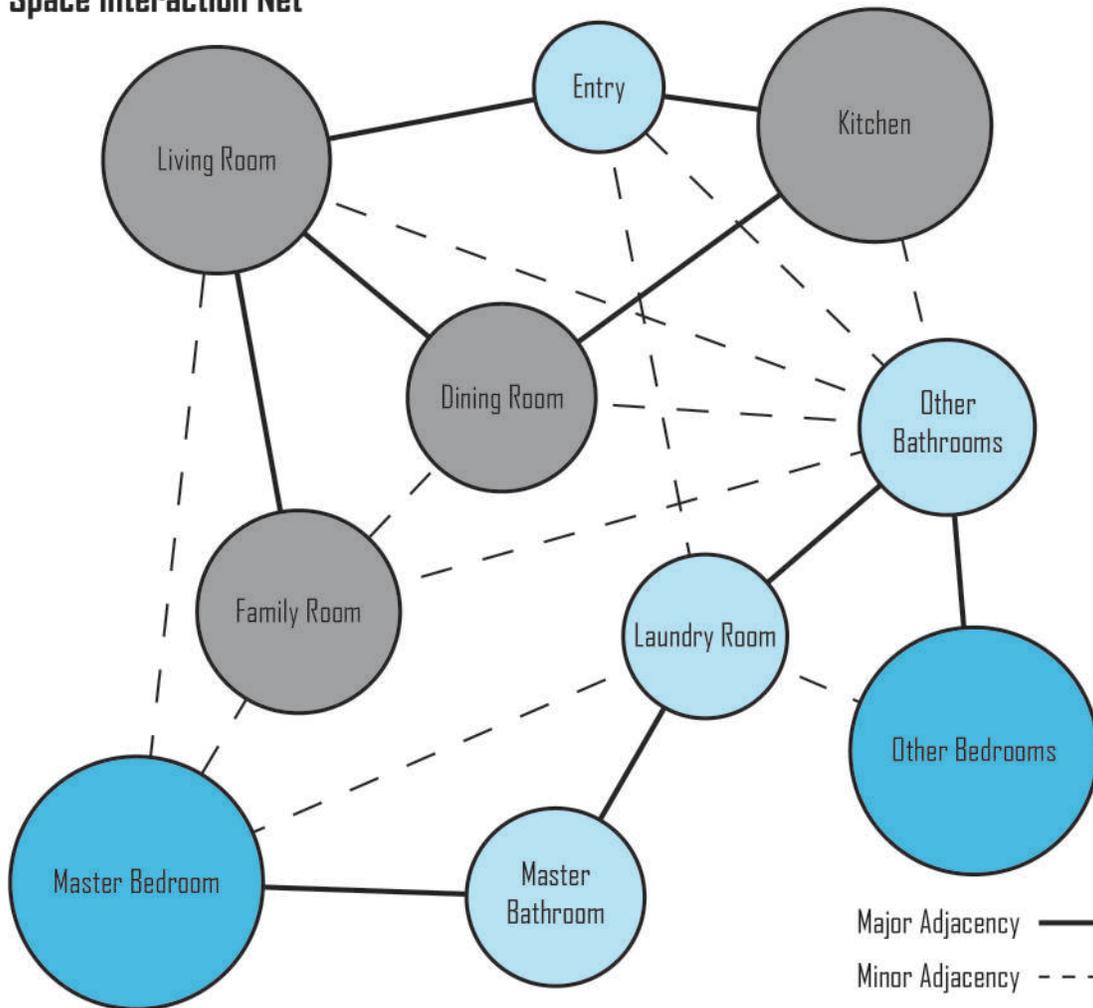


Figure 36

2. Cost Reduction

One of the main advantages of utilizing modularity and prefabrication is the savings in overall cost. Arguably the next most important aspect of prefabrication, would be the savings in the build and assembly time. Prefabrication requires that modules are built off-site, meaning that rather than being a linear process, preliminary site work and construction can happen simultaneously. This means that a faster completed project solely relies on the fact that construction is taking place else-

where. Therefore, we will assume there will be a shorter construction time frame and instead focus more so on the reductions in the construction cost. In order to do this, building cost resources such as the information found on costtobuild.net will be used to analyze the financial implications of the produced dwelling designs.

3. Material Conservation

Through the process of modularity, a building can be thought more as a system of individual

Performance Criteria

parts. In order to efficiently create building modules, material shape and size should have a direct influence on the actual construction process. This way, the assembly procedure of the modules can also become more streamlined in an attempt to ensure less materials go to waste during the build. This will be achieved by exploring suitable construction techniques and reviewing building material dimensions provided by the manufacturers. Actual performance of designing for material conservation will be analyzed by weighing the cost versus the size of the amount of material being wasted or potentially being reused.

Summary:

The overall goal of this thesis project is to explore the many existing methods of how single-family residences have been built in the past through various forms of off-site construction in order to develop and propose more advanced tactics. Today's construction-related work force is facing a shortage of skilled laborers which is in turn, resulting in tighter budgets and tighter work schedules. Prefabrication has the potential to help alleviate these conflicts experienced today within the building industry around the world. Successful development of prefabrication results in a number of benefits including a more efficient use of material, a faster than conventional build time, a reduced carbon footprint, safer conditions for workers, as well as a decreased potential for weather disruptions.

The modular construction process often exhibits a more efficient use of materials because through the use of a controlled construction

setting, such as a factory, workers are usually able to reuse materials and produce much less waste than a conventional on-site build. Since the majority of construction would now be happening in what is typically a factory-like environment, the atmosphere of the construction process is able to provide laborers with plenty of lighting as well as increased safety standards and supervision. This also results in the laborers being able to constantly build without the typical disruptions of adverse weather conditions, leading to even more productive use of time. Also, the delivery of the housing modules to the site most often results in a vastly reduced number of trips made to the final location, which leads to less combustion of fossil fuels and therefore, less carbon dioxide emissions. When all of these things have been achieved, the overall construction process, site delivery, and site assembly typically take place over a duration that is significantly less, at a final cost that is significantly cheaper than conventional on-site construction methods.

Design Process

Further Research:

An important area of research I did alongside of thesis had to do with something called shape grammar. Shape grammar, as well as shape computation, has been explored in a theoretical approach by various architecture and design related professionals as a means of analyzing the underlying relationships between shapes and how these relationships produce certain aesthetic outcomes. Shape grammar is used to create a language with two-dimensional and three-dimensional shapes while shape computation is a series of systems that generate geometric shapes. The foundation of shape grammar was developed and introduced by George Stiny and James Gips in the early 1970s and has had many implications in the arts and design world. Applying shape grammar to the field of design, more specifically design of the single-family residence, is a difficult task since design is largely a subjective matter. Typically, factors such as materials and the human scale play into the average person's judgment of a well-designed home. However, many design concepts have direct ties to mathematical concepts and hard facts. In reality, many designers and artists incorporate math into their works – although they might not even be doing so consciously. The challenge becomes the analysis of the process of design. George Stiny, author of *Shape: Talking about Seeing and Doing* poses the

question, "What kind of mathematics is design?" Better yet, "What kind of mathematics works when I don't know what I'm going to see and do next?" The tasks that were necessary to complete this research revolved around two broad areas: defining the basic group of parts for a single-family residence as well as developing a shape grammar that creates various spatial arrangements for said group of parts. The group of parts for a single-family residence can also be described as a set of characteristics one should consider when designing a home. When applied to architecture and space planning, shape grammar can be used to explain a designer's process. A typical process of a simple shape grammar system can be generalized into a few basic steps:

- [Creating and Modifying a Shape.](#)
- [Organizing the Grammar.](#)
- [Exploring the Produced Shape Computations.](#)

Material Selection:

This type of thought towards shape grammar greatly influenced and began to setup the geometry of a modular system in my mind. I began to see the need for a system that would be able to efficiently create the potential for many kinds of computations or arrangements. Throughout this design process, I also began to search for a materi-

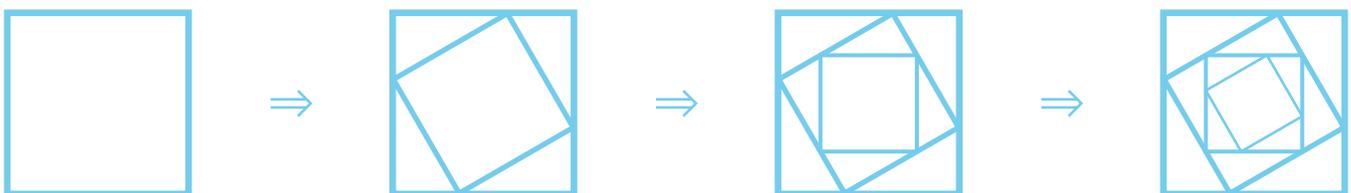


Figure 37

Design Process

al that would be suitable to create these modular units that I was beginning to envision. I wanted to find a material that could be cast in a mold like concrete but would be much more lightweight. I began to look into types of rigid foam materials but quickly discovered Autoclave Aerated Concrete instead. Autoclave Aerated Concrete (or AAC) is a mixture of finely ground aggregates, binders, and water with the addition of an expanding agent that chemically generates millions of air bubbles. During the manufacturing process, this mixture is subjected to a high curing pressure inside of water steam autoclaves which guarantees that the chemical reactions necessary for the dimensional stabiliza-

tion of the material take place. The aggregate used is typically finely ground quartz sand while the added binders are mostly made up of cement and lime. Autoclave curing provides both the necessary temperature and humidity conditions for the mixture to react chemically. This material served as an ideal foundation in which to begin designing around. However, after some time, it became apparent that AAC as a standalone material would likely be too brittle to be involved in a process that would require modules to be shipped from place to place. Fortunately, with the integration of glass fiber reinforcement, Autoclave Aerated Concrete becomes much more stable and has virtually the



Figure 38

Design Process

same qualities that I desired in a material of choice. Due to the millions of micro-air bubbles incorporated into its mass, aerated concrete has great thermal insulation properties. Because of this, aerated concrete has a very low thermal conduction compared to other construction materials which means significant energy savings with an R-value rating of about 1.25 per inch. Autoclave Aerated Concrete also has a great resistance to the absorption of water. This is due to the fact that the millions of air cells that make up its cellular structure have a closed framework making the capillary suction phenomenon practically inexistent within the mate-

rial. AAC products are often made as ready-to-use precast parts. Its low weight makes it an ideal material for quick assembly with optimal structural behavior, as well as vast simplification of construction methods. Its lower weight also reduces loads on foundations and decreases transportation costs. Aerated concrete is a fireproof and highly fire-resistant material, providing maximum fire safety in buildings. Walls built with AAC bricks meet the most demanding fire resistance classifications established by many standards. Aerated concrete does not contain any toxic substances and therefore doesn't represent any danger to human health or



Figure 39

Design Process

the environment. The inorganic composition of the material doesn't attract or favor the formation of pests. Construction that is carried out with the AAC is clean, dry, and produces very little waste. AAC products are manufactured with rigorous industrial processes that guarantee very precise dimensional tolerance. This extreme precision is what makes aerated concrete suitable for quick and simplified assembly. However, one of the main advantages of aerated concrete is the simplicity and convenience involved with manipulating the material. AAC products can easily be cut and punctured by common tools. Nails can also be hammered into it with ease. Aerated concrete has been said to be a combination of the best properties of stone and wood.

Design Concept:

In order to address the need for a streamlined process to make off-site construction work more efficiently, I decided to tackle the issue in the

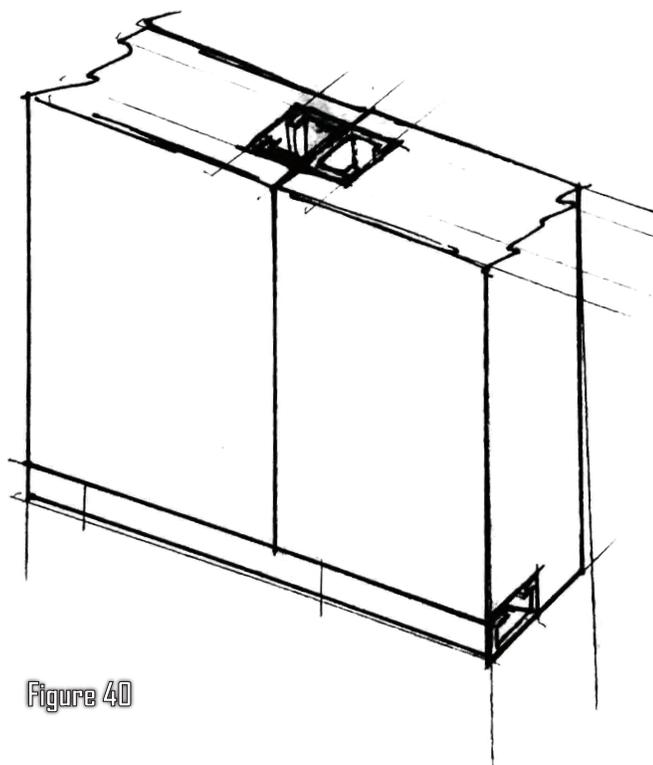


Figure 40

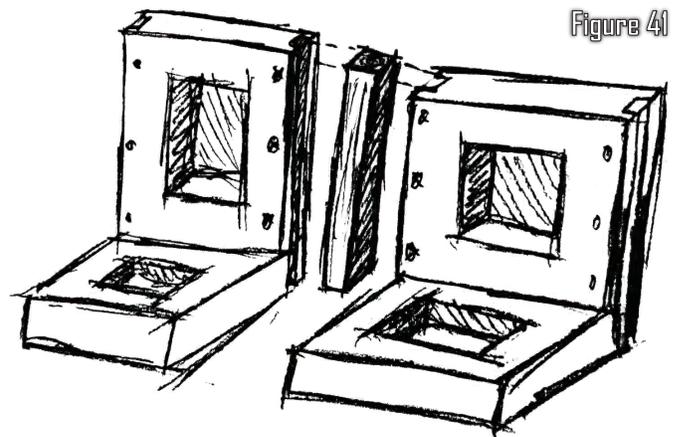


Figure 41

form of a sort of floor and wall assembly. In all of my research, I found that there is a vast amount of time consumed in the process of typical stud wall framing. Along with a large portion of time being wasted in stud wall framing, I found there's often a lot of material that goes to waste in order to ensure structural integrity of the framing itself. In response to this, I developed a modular system of a few different components that can be used to assemble walls more quickly and more efficiently. Various prototypes were developed in regard to shape, size, connectivity, and integration of other functions.

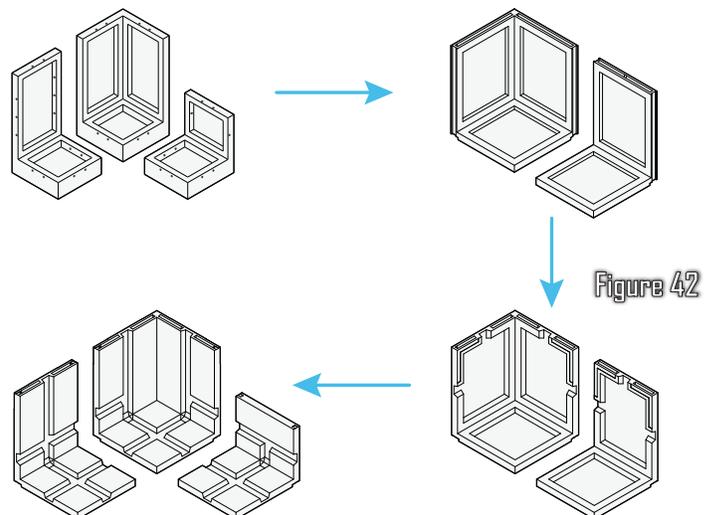
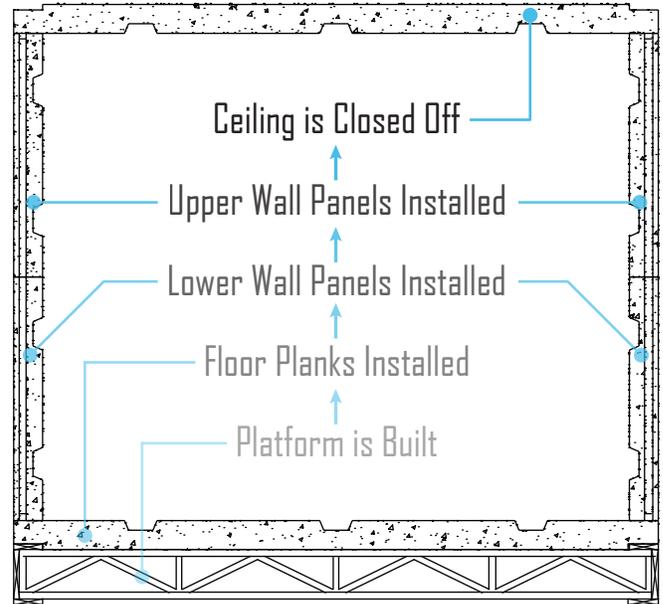


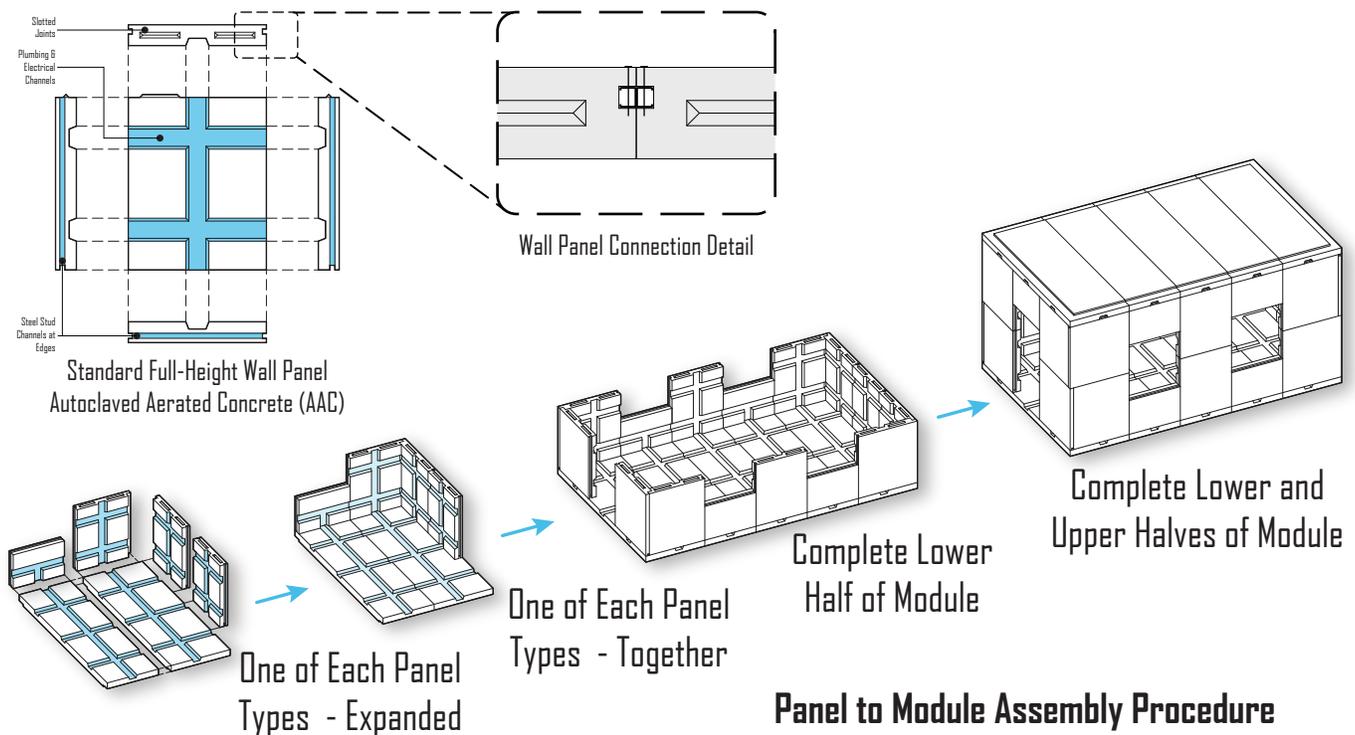
Figure 42

Design Process

The final version of these wall components were designed to be fitted together in a sort of “track and panel” type of assembly. They also have channels running through them in order to provide space for plumbing, wiring, and electrical outlets. The floors are a plank system that feature similar channels. All floor and wall components are meant to be flipped across from each other to create the upper and lower halves of a single module. When it comes down to the actual module assembly process, it all begins with a platform mainly consisting of prefabricated floor trusses. Next, the floor planks are laid out which nest into the place with the help of the outer rim joists. Then, the lower wall panels are put into place followed by the upper wall panels shortly after. Finally, the ceiling is either closed off with the same type of planks as the floor, or with roof joists if a sloped pitch is preferred.



Typical Module Section Figure 43



Panel to Module Assembly Procedure

Figure 44

Design Process

Using these panels, it is possible to create a multitude of arrangements for module-oriented floor plans. Likewise, there are many possibilities for elevations depending on things such as the cladding materials being used as well as the desired aesthetic appearance. In order to enhance the notion of separate parts coming together to form a house, I developed a cladding design that I used for both the house in Hugo and the house located near Scandia also. The mentioned cladding design consists of two different types of standing seam metal siding along with metal composite panels that follow similar geometry as the concrete wall panels. These cladding materials would, for the most part, be attached to the modules before being transported to the final assembly location. Siding would be able to be attached to the aerated concrete wall panels through the use of furring strips being used in between the siding and the modules. When it comes to protecting these houses against the harsh Minnesota winters, the insulating properties of the AAC panels aren't quite adequate. In response to

this issue, I decided to design the following houses with a layer of two inch thick polyiso insulation on the exterior walls as well. This may not be necessary for warmer climates, but this decision would lead to increased energy savings as well as a much more comfortable home environment.

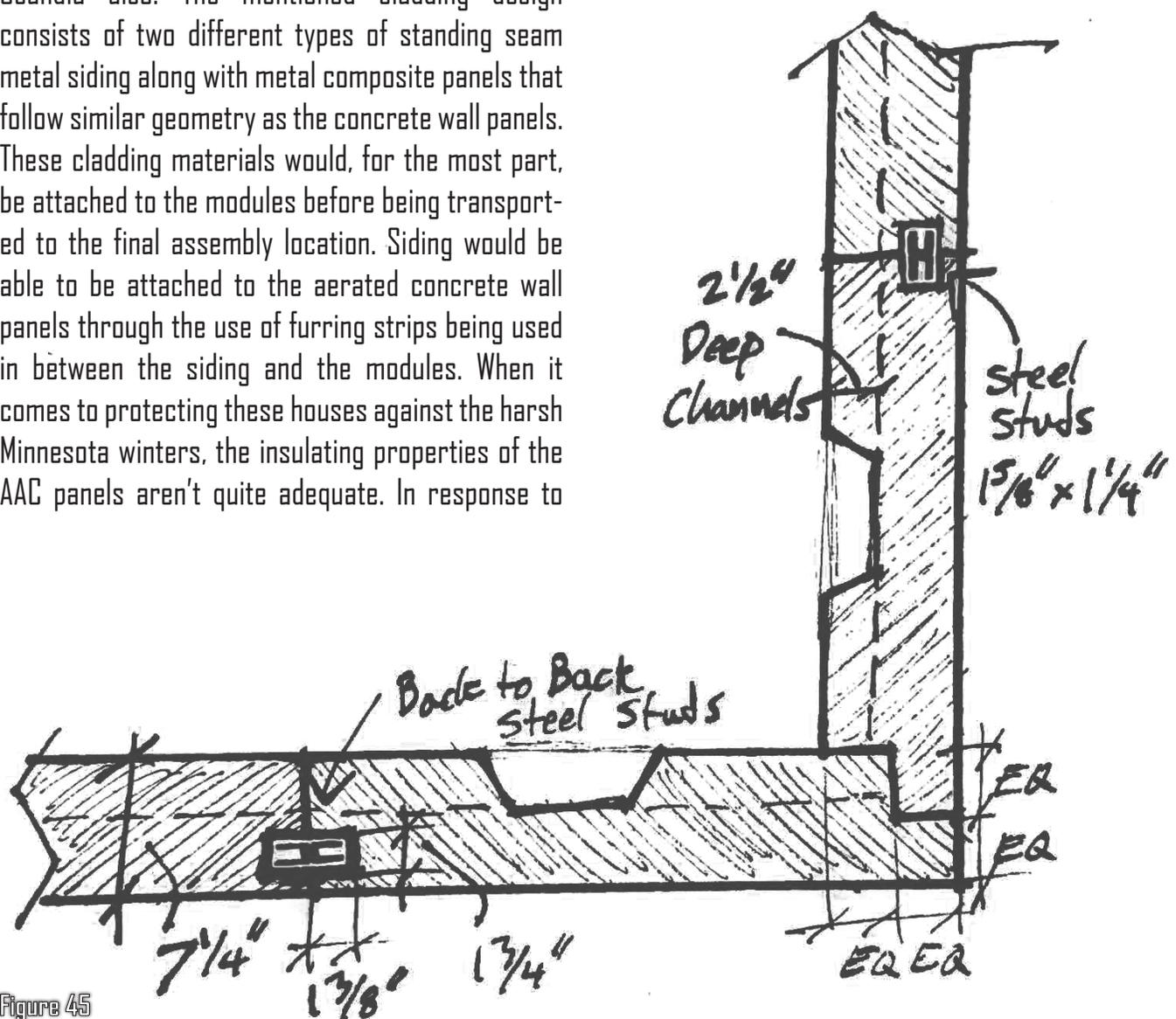


Figure 45

Design Solution

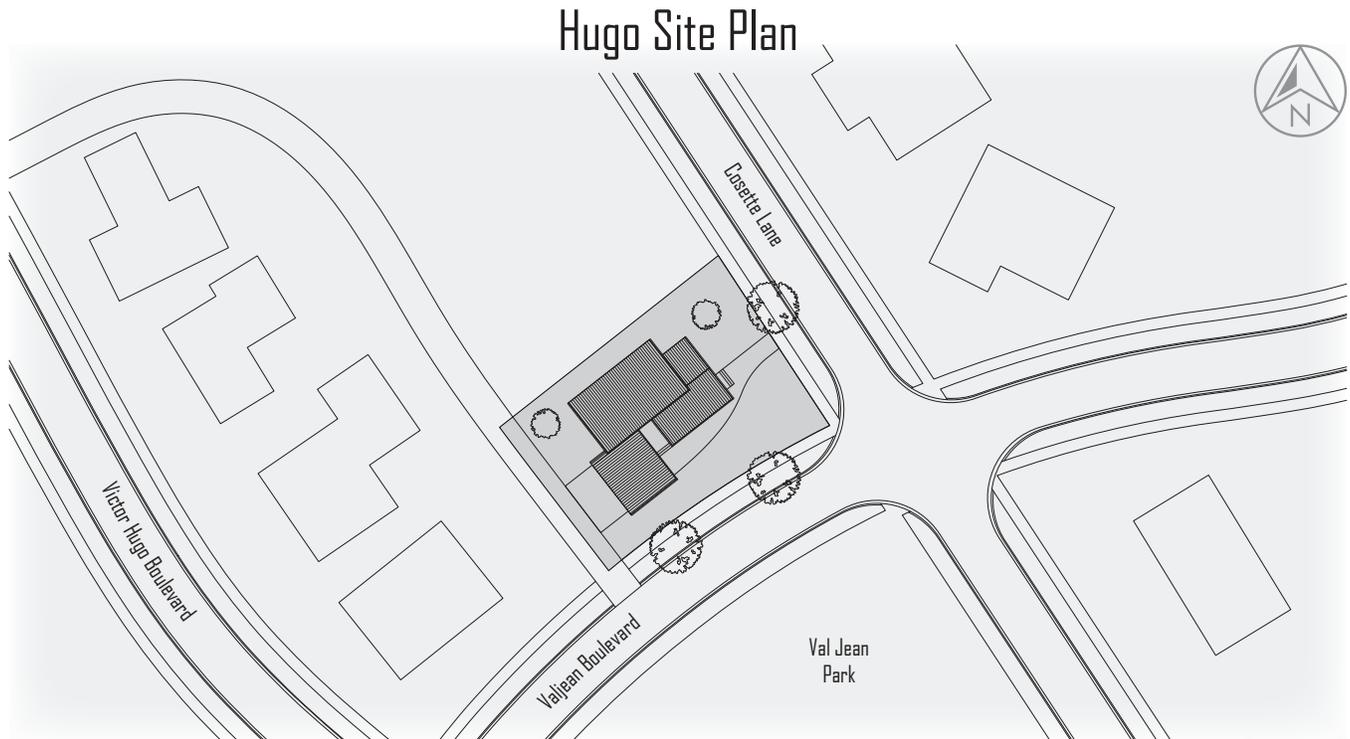


Figure 46

- 1 Entry
- 2 Kitchen
- 3 Dining Room
- 4 Bedroom
- 5 Bathroom
- 6 Laundry & Utilities
- 7 Master Bath
- 8 Master Bed
- 9 Living Room
- 10 Attached Garage

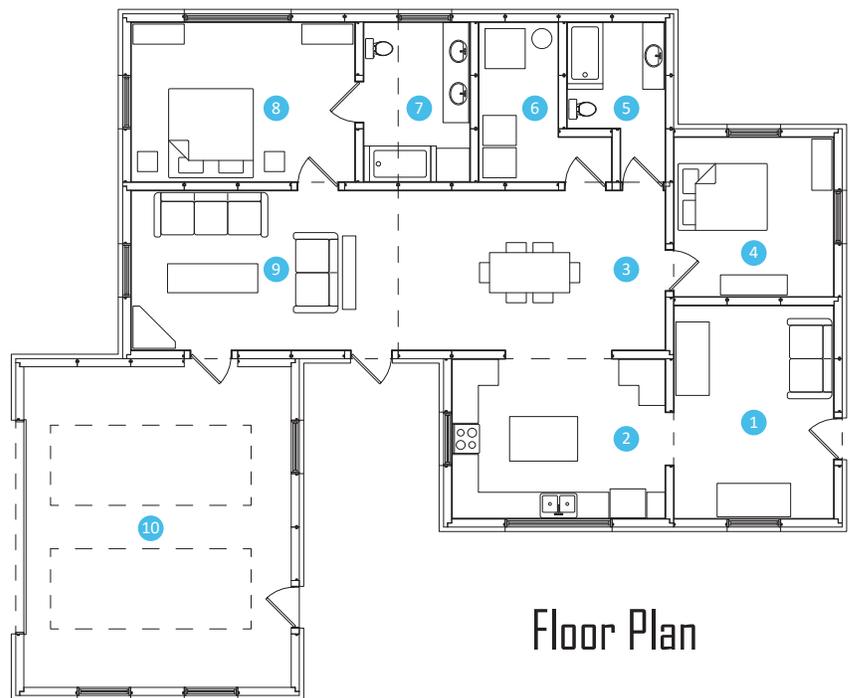


Figure 47

Design Solution



Design Solution



Design Solution

Scandia Site Plan



Figure 52

- 1 Entry
- 2 Dining Room
- 3 Kitchen
- 4 Walk-Out Deck
- 5 Living Room
- 6 Bedroom
- 7 Laundry & Utilities
- 8 Bathroom
- 9 Family Room
- 10 Bedroom
- 11 Master Bedroom
- 12 Master Bathroom



Upper Floor Plan

Lower Floor Plan

Figure 53

Design Solution

Residence at Scandia, MN

- Two Levels
- 10 Modules
- 3 Bed / 2 Bath
- Detached Garage



View of the Entry into the Scandia Site from the West

Design Solution



Design Solution

Conclusion:

The goal of the research behind this thesis project has been to examine the numerous ways that a single-family residence can be built using various forms of off-site construction. There are clearly many approaches to off-site construction that have already been established within today's construction industry. However, the goal of the designs that came in response to this research have been to demonstrate how prefabricated construction can be done more effectively than what we often see nowadays. By designing, manufacturing, and constructing larger components of buildings, we can more successfully coordinate labor, create higher quality of buildings, and do so in a safer, more efficient, and cost-effective manner. When executed correctly, I believe modular prefabrication could easily be a competitive force in today's construction industry.

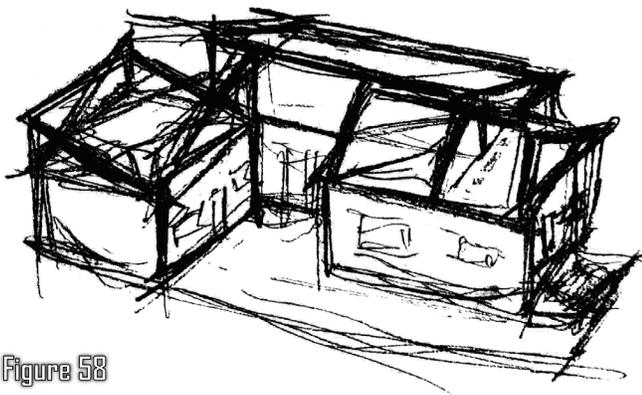


Figure 58

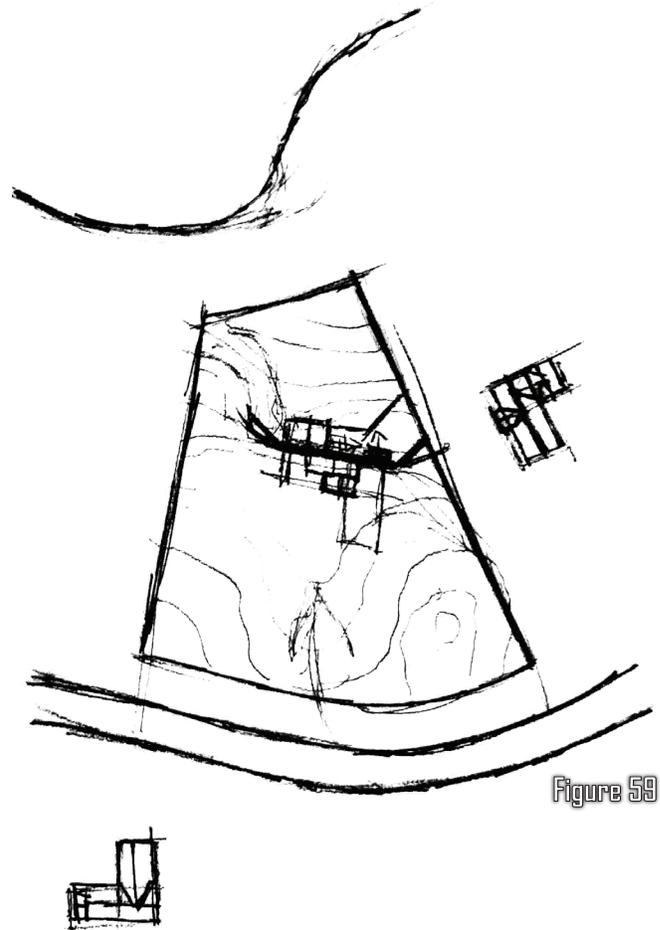


Figure 59

Appendix

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Appendix

Design Studio Experience:

2nd Year:

Fall 2016 | Cindy Urness | Tea House + Waldorf School
Spring 2017 | Milt Yergens | Dance Academy + Marfa Dwelling

3rd Year:

Fall 2017 | Regin Schwaen | Nevis Cabin + Nekoma Refuge
Spring 2018 | Bakr Aly Ahmed | Culinary School + Affordable Housing

4th Year:

Fall 2018 | David Crutchfield | Miami High Rise Studio
Spring 2019 | Mark Barnhouse | Miami Sponge City

5th Year:

Fall 2019 | Ganapathy Mahalingam | Advanced Architectural Studio
Spring 2020 | Ganapathy Mahalingam | Design Thesis Research Studio