A new approach to off-site construction.

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Introduction

- The goal of this thesis project has been 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 most suitable. There are already many methods of off-site construction, most of which can be classified into a few different levels of construction.

- Those groups include **prefabricated construction**, **modular construction**, and **three-dimensional volumetric construction**. These groups are all very similar with the difference being the extent to which buildings are modularized.

- 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 have aimed to resolve these conflicts in an efficient and cost-effective manner.
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 the lack and the demand of skilled laborers that currently exists. With the methods of off-site construction, fewer workers are needed overall. According to Blue Future Partners, a firm that operates around the globe, “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.”
Introduction

- Off-site construction pulls workers off of dangerous scaffolding and out of the hazardous conditions that go along with on-site construction. Instead, the workers involved in off-site construction do so in a controlled environment, such as a factory, with good lighting and safer conditions.

- Not only does a controlled environment allow for improved working 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%.”
Introduction

- **Higher structural durability** of the finished building also means a higher energy efficiency when operating heating and cooling systems within the spaces.
- 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 leaks.
- 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 has overall, been an attempt to develop new methods and technologies to fabricate, transport, and assemble buildings.
- As the building 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?
Theoretical Framework

- The typology of a single-family residence is one of widely varying sizes and characteristics. My research has aimed to identify the necessary parts of a house as well as their ideal sizes and arrangements.
- Through the process of identifying the most important “building blocks” of a house, we can determine how to develop the size and shape of the actual modular units. The size of these housing modules are often determined based on how large they can be made while retaining the ability to be effectively 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 to be taken to transport the pieces there.
- In most cases, modules will be built to the largest size possible that a semi-truck flatbed trailer will allow to haul. 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.
- 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 many modules.
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.
Site Info

- 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 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 sites 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 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.
I have proposed 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 choosing sites in such a manner, they will have nearly identical climate data leaving the only distinctions between them being intended differences.
Additional Research

- **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. 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.

**Typical Process of Shape Grammar**
- Creating and Modifying a Shape
- Organizing the Grammar
- Exploring the Produced Shape Computations

**Complex Sequence of Shape Grammar**
- Creating a Grid Definition
- Establishing the Locations of the Exterior Walls
- Organizing the Floor Plan Arrangement
- Establishing the Locations of the Interior Walls
- Determining Entry and Exit Locations
- Defining Exterior Elements
- Positioning of Windows and Doors
- Termination of the Process
Shape computations set up possible rules for a designer to follow, thus creating a grammar for the design of a building and its components. With the integration of shape grammar software, one can develop a process that is more applicable for a computer program-aided design. In this case, the method of design relied primarily on SortalGI which is a plugin for one of the most well-known Rhinoceros plugins, Grasshopper. The SortalGI software was used to establish a set of shape components that correspond to spaces within a basic single-family residence. These shape components were then altered through transformations that placed them into appropriate positions in relation to each other. The shape components, after being transformed, set up the left-hand-side and right-hand-side (essentially the before and after) of the rule components used to describe the computed floor plan arrangement. These rules are then all combined together to finally form the spatial arrangement of a single-family residence.
Material Selection

- **Autoclave Aerated Concrete** (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 stabilization of the material take place.

- **Thermal Properties**
- **Fire Resistance**
- **Water Resistance**
- **Environmentally Friendly**
- **Lightness**
- **Industrial Precision**
Design Concept

Wall components are designed to be fitted together in a sort of “track and panel” type of assembly using steel studs.

Panel Types Include: Full-Height Wall Panels, Head/Sill Panels, Left Corner Panels, Right Corner Panels, Floor Planks, and Floor Edge Planks
Module Assembly

Step One

Rendered Assembly

Typical Module Section

Platform is Built
Module Assembly

Step Two

Rendered Assembly

Typical Module Section

Floor Planks Installed
Module Assembly

Step Three

Rendered Assembly

Typical Module Section

Lower Wall Panels Installed
Module Assembly

Step Four

Upper Wall Panels Installed

Rendered Assembly

Typical Module Section
Module Assembly

Step Five

Rendered Assembly

Typical Module Section

Ceiling is Closed Off
Module Expansion
Of Residence in Hugo, MN

- Single Level
- 7 Modules
- 2 Bed / 2 Bath
- Attached Garage
Hugo Plans

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
Hugo Elevations

West Elevation

South Elevation

East Elevation

North Elevation
Hugo, MN

View of the Hugo Residence from the Nearby Street Intersection
Hugo, MN

View of the Hugo Residence from the Southeast
View of the Hugo Residence from the Alley Entrance
Module Expansion
Of Residence in Scandia, MN

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

South Elevation

East Elevation

North Elevation

West Elevation
Scandia, MN

View of the Entry into the Scandia Site from the West
Scandia, MN

View of the Scandia Residence from the South
Scandia, MN

View of the Scandia Residence with Integrated Retaining Wall & Patio
Thank You.