Housing Pre-Fabrication and Resource Optimization

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Housing Pre-Fabrication and Resource Optimization

Habitat for Humanity of Michigan

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1. Executive Summary

By creating panelized enclosure components, plans for prefabrication, volunteer instructions, and a process to guide Habitat for Humanity of Michigan towards implementation, it is expected that all 53 Habitat for Humanity of Michigan Affiliates will be able to utilize these designs with minimal adjustment. The required adjustments are found based on individual circumstance, however, a strategy for making necessary changes was provided. In the end Habitat for Humanity of Michigan will be able to panelize, prefabricate, and install with an estimated minimal cost of $13,927.

2. Introduction

Habitat for Humanity offers affordable low-income housing to individuals or families based on merit and need. One problem facing Habitat for Humanity as an organization is delivering quality, sustainable, and affordable houses using volunteer labor and limited resources. Protecting the home from the elements during construction is one of the largest challenges during the building process, specifically in the construction of the roof. Roof construction can take three weeks, during which the house is exposed to harsh weather. This exposure can cause water damage as well as provide higher risk to the workers setting trusses. A lack of dedicated and consistent manpower, skilled labor, and engineered designs leads to bottlenecking when it comes to the roofing and exterior wall elements. The objective of the capstone project is to reduce the time to enclose a house through the development of plans for prefabricated roof and wall sections.

3. Project Description and Background

Enclosure during construction is often time-consuming, expensive, and at the mercy of the weather. By introducing methods for manufacturing prefabricated enclosure components such as wall panels and roof sections, the impact of the three major variables is reduced. Designs for trusses, roof sections, wall sections, and foundations were developed and selected using civil engineering principles; and manufacturing and logistical processes were optimized using engineering and project management skill sets. These multi-disciplinary efforts were combined to create an accessible and versatile set of designs and instructions that can improve the effectiveness of both a skilled and non-skilled volunteer workforce.

3.1 Scope of Work

This project followed the engineering design process and provided Habitat for Humanity with a way to confidently provide enclosure during the construction process. This project focused on prefabricating the roof and wall panels to ensure that exposure to the elements is reduced. Due to the nature of this project, the skills of the Civil Engineering department were utilized for proper structural designs. This report provides Habitat for Humanity with a prefabricated enclosure option that can be employed at any Michigan affiliate. This project provides Habitat for Humanity with volunteer instructions and engineering plans and drawings. We hope our work will increase
the ability for the organization to follow and empower its vision of “A world where everyone has a decent place to live.”

3.2 Deliverables

As a senior design team at WMU we provided a final report, presentation, and poster. Our project team also provided Habitat for Humanity a set of designed drawings, calculations, manufacturing plans, logistics, instruction manuals, alternative analyses. The designs for the roof and wall sections are based on Habitat’s typical family size and floor plans. Foundation design, transportation logistics and sequencing, along with cost analysis are included in the report. Handicap accessibility was maintained. The designs also maintained energy efficiency standards of Habitat for Humanity following the Home Energy Rating System (HERS) Index. Sustainable building practices focusing on waste reduction and reusable materials were also be emphasized.

3.3 Impacts and Constraints

This project is intended for all Michigan Habitat for Humanity affiliates. Preconstructed wall and roofs strive to reduce the overall enclosure time. It is important that the design presented meets Habitat’s standards of energy efficiency and conserve building materials. Since Habitat for humanity primarily uses volunteers, this project focuses on ease of construction.
4. **Design and Analysis**

The complexity of prefabricating panelized wall and roofs required a multitude of calculations ranging from truss loads, wall loads, and foundational strength to name a few. The design and analysis portion of the report goes into detail describing the technical and logical decisions made throughout the process. To begin our design work we used the overall building dimensions shown in **Figure 4-1**, which shows a typical home layout 48 feet long and 24 feet wide. This standard size includes 1 story, 3 bedrooms, and 1 bath.

![Figure 4-1 Habitat Model Home Layout](image)

**4.1 Foundation Design**

For this project two foundation designs were performed using the model house dimensions. Both foundation designs used the Frost Protected Shallow Foundation (FPSF) design process but are located in different cities in Michigan. The first design was performed in Kalamazoo, MI where the Air Freezing Index (AFI) is fairly low compared to other regions of the state. In order to show the versatility of the FPSF design process, the second foundation design was done in Bergland Township, which has the highest AFI in Michigan. The designs were performed using the Revised Builder’s Guide to Frost Protected Shallow Foundations, published in 2004, ACI 332-08 Code Requirements for Residential Concrete and Commentary, and the current Michigan Residential codes primarily from chapters 3 and 4. The full design process can be seen in the appendix.
including a step-by-step design outline for a FPSF using Insulated Concrete Forms (ICF) in Michigan.

4.1.1 Frost Protected Shallow Foundation Design Method

In areas like Michigan where seasonal ground freezing occurs there is a possibility that frost heave will occur causing damage to foundations and homes. Frost Protected Shallow Foundations (FPSF) work by preventing the soil immediately underlaying the foundation from freezing. In some cases, the addition of horizontal insulation also helps prevent frost heave by shedding moisture away from the foundation. If the soil is never able to freeze beneath the foundation, then there is no chance of frost heave occurring. The FPSF method designs insulation requirements to raise the soil temperature beneath a building thereby greatly decreasing the required foundation depth. The frost protected shallow foundation is more sustainable in the number of resources used to build, and when correctly done the heat retention helps lower overall energy use in the home. The use of extruded polystyrene (XPS) and expanded polystyrene (EPS) for FPSF in Europe has been studied and is shown to maintain its integrity upwards of 40 years, with no evidence of failure. While FPSFs are more prominent in European countries they have been used for a variety of projects in the United States since the 1930’s and their effectiveness has been proven. Frost protected shallow foundations are one of the approved foundation methods detailed in the Michigan Residential Codes, and for all of the reasons discussed it is the design method recommended to be used by Michigan Affiliates of Habitat for Humanity.

4.1.2 Structural Requirements

All of the structural requirements were defined using either the Revised Builder’s Guide to Frost Protected Shallow Foundations or a combination of the Michigan Residential Building Codes and ACI 332-08. Ultimately for the style of slab and footing being designed the building and porch footings are specified to include two #4 rebar in the middle third of the footing height for both home locations. In order to secure the wall sections to the foundation anchor bolts were placed at least 7 inches into the concrete at the required spacing for the premanufactured wall sections to be properly secured. In order to be structurally sound, the concrete slabs required the placement of welded wire reinforcement for both building and the porch. In order to withstand all of the required loads and forces the minimum compressive concrete strength for both foundations is f’c=2500 psi.

4.1.3 Frost Protected Shallow Foundation Design Results

4.1.3.1 Kalamazoo

The Kalamazoo footing cross section in Figure 4.1-1 depicts the dimensions of the footing, slab and insulation as specified by the FPSF design performed. The use of ICF is depicted, and the
rebar requirements are called out. Unlike the home in Bergland Michigan the heated home portion of the foundation design does not include any horizontal insulation.

The Kalamazoo porch cross section in **Figure 4.1-2** shows the 1.5-inch layer of insulation starting from the home footing then running directly beneath and extending past the porch. The horizontal insulation is needed here to account for the increased loss of heat through the unheated area.
When looking at the Kalamazoo home from above as shown in Figure 4.1-3 you can see how the horizontal insulation at the porch extends out just over 3.5 feet. The type and thickness of each insulation type is called out and the location of each anchor bolt is marked.

Figure 4.1-3 Kalamazoo Foundation Top View
4.1.3.2 Bergland Township

The foundation cross section along the walls of the Bergland home can be seen in Figure 4.1-4. In this case the AFI is so high that a layer of horizontal insulation will be needed all along the outside of the building. The reinforcements, concrete strength, and footing depth are the same as those required in the Kalamazoo foundation.

Since the AFI for Bergland is the highest in the state, a fair amount of insulation is needed for the Bergland home, this includes wider and thicker insulation at the corners. Heat can be lost more rapidly at the corners of the structure and the extra insulation shown in Figure 4.1-5 helps to slow down this loss.
The insulation along the walls and corners of the heated home is relatively small as compared to the amount required for the unheated porch. As shown in Figure 4.1-6, the insulation for the unheated porch extends more than double that of the Kalamazoo home, and is 5.75 inches thick.
The top view of the Bergland home shows the dimensions and types of all the insulation used. **Figure 4.1-7** also shows the location of all of the required anchor bolt locations. Overall, the concrete portion of the foundation design is similar to the Kalamazoo home, but includes far more and thicker insulation.
4.2 Wall Design

In short, wall design investigated the structural elements of the exterior walls and the feasibility of construction through prefabrication methods. The first step was to standardize rules for the wall panels. Thom Phillips recommended certain standards that the 2015 Michigan Residential Codes require as well as standards that Habitat for Humanity has used in the past. Advanced framing techniques were recommended and maintained structural integrity and increased the sustainability of the wall panels. An objective for this project was to create easily made, prefabricated wall panels that minimized material waste.

4.2.1 Wall Section (WS) Overview

Wall Sections in this project can be defined as the basic wall element combinations that include studs, headers, top plates, bottom plates, fasteners, and sheathing. For this project, only the exterior walls were considered for the prefabricated design. The exterior walls are load bearing and are essential for the rapid enclosure for the structure. The interior walls were neglected since they are non-load bearing and could be constructed within the enclosure using standard construction methods. A further developed plan would include prefabricated interior wall sections.

![Isometric view of all wall panels](image-url)
Figure 4.2-2 The east and west wall layouts are shown above

Figure 4.2-3 The south and north wall layouts are shown above
4.2.2 Wall Elements

The 2015 Michigan Residential Code was heavily used in determining the rules that were used throughout the duration of this project. When (RXX.Y) appears throughout this section it denotes a specific section within the 2015 Michigan Residential Code with “XX” as the chapter and “Y.Y” as the specific section. RISA 3D is the structural design program that was used to help standardize wall design rules. It has a user-friendly interface that can be used to analyze and recommend wall element characteristics.

There are eight different types of wall panels that have a length of either 8 ft or 4 ft (with the exception of P-6 which has a length of 7 ft 1in). When a wall panel length is equal to or less than 8 ft, no lateral bracing is required (R602.12.5). The lumber used for common studs, top plates, and bottom plates used in the wall panels are Spruce-Pine Fur (SPF) or equivalent with a minimum grade of No. 2 shaped as 2 in by 6 in. (R602.1.1, R602.2, R602.3(5)). The studs within the wall panel are spaced at 24 in on-center (OC) (R602.3(5)). The length of each common stud is 7ft 8\(\frac{5}{8}\) in so that the overall height of the frame is 8ft 1in which allows for easy drywalling in later stages of construction. Typically, the top plate consists of one 2 in by 6 in with the topmost plate attached on-site. This is to increase stability by offsetting the spacing (R602.3.2). The bottom plate consist consists of one 2 in by 6 in. Figure 4.2-4 calls out the wall elements that were used in this project.

![Figure 4.2-4 RISA 3D model that calls out specific wall elements](image-url)
There are some typical elements that are missing from this diagram such as the trimmer studs. Those elements have been designed out for this project. Habitat for Humanity’s *High Performance Housing Playbook* was consulted to determine how to design the wall panels. An advanced framing technique called stacked (or in-line) framing was used. This technique conceptually stacks the trusses and studs in-line with each other. This conceptually transfers the loads from the trusses directly to the foundation without the need for additional lumber to help distribute the loads. This has a few effects. It negates the need for trimmer studs and the need for extra cripple studs. This in addition to technique, a structural gable truss was designed at either end of the house; see Section 4.3.8 for structural gable truss. This transforms the east and west walls into non-loadbearing walls. This allows for headers to be designed out of the project which reduces the amount of lumber that is needed.

### 4.2.3 Wall Panel Figures

For more detailed wall panel figures, the appendix has all the drawings for every wall panel.

### 4.2.4 Openings

Rough openings for windows and doors have been considered for the exterior walls. The following table details information for the openings.

<table>
<thead>
<tr>
<th>Opening Type</th>
<th>Window Style</th>
<th>Panel Type</th>
<th>Nominal Size (Length x Height) (in)</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window</td>
<td>Single Hung</td>
<td>P-1</td>
<td>36 x 66</td>
<td>Bedroom</td>
</tr>
<tr>
<td>Window</td>
<td>Single Hung</td>
<td>P-5, P-7</td>
<td>36 x 48</td>
<td>Living Room</td>
</tr>
<tr>
<td>Window</td>
<td>Single Hung</td>
<td>P-3, P-6</td>
<td>30 x 36</td>
<td>Bedroom, Kitchen, Bathroom</td>
</tr>
<tr>
<td>Door</td>
<td>-</td>
<td>P-4</td>
<td>36 x 82</td>
<td>Living Room, Kitchen</td>
</tr>
</tbody>
</table>

The elements included in the openings include the header, king stud, and jack (or trimmer) stud. The header is placed vertically above the opening. The header has been selected as one 2 in by 10 in based off ground snow load, building width, and sponsor recommendation (R602.7). The king and jack studs are installed to support the load distributed from the header to the bottom plate to compensate for the lack of studs due to the opening. Both studs are placed adjacent to each other with the exterior stud labeled as the king stud and the interior stud labeled as the jack stud. A tactic used to reduce the cost of lumber is to strategically place the opening on a natural stud making it the king stud. This is used frequently throughout H4H to reduce costs.
4.2.5 Wind Loads on Walls

The wind loads applied to the walls of the building are derived from ASCE 7-10 Table 27.6-1. The four factors that affect the wind pressures on the wall include the exposure factor, the ultimate wind speed \( V_{ult} \), height of the structure, and the L/B ratio. The following table contains data extracted from Table 27.6-1. See the appendix for the calculations.

<table>
<thead>
<tr>
<th>Table 4.2-2 Wind Load Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure Factor</strong></td>
</tr>
<tr>
<td>( V_{ult} ) (mph)</td>
</tr>
<tr>
<td>Mean Height of Structure (ft)</td>
</tr>
<tr>
<td>L/B</td>
</tr>
<tr>
<td><strong>Wall Type</strong></td>
</tr>
<tr>
<td>Windward</td>
</tr>
<tr>
<td>Leeward (pressure acting outward)</td>
</tr>
<tr>
<td>Side (pressure acting outward)</td>
</tr>
</tbody>
</table>

4.2.6 Fasteners and Sheathing

A summarized table has been created referencing Table R602.3(1) for connections within the wall and the trusses.

<table>
<thead>
<tr>
<th>Table 4.2-3 Fasteners Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Roof</strong></td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
For the OSB sheathing on the exterior portions of the wall, Table R602.3(3) is used for reference.

<table>
<thead>
<tr>
<th>Minimum Nail Size</th>
<th>Minimum Wood Structural Panel Span Rating</th>
<th>Minimum Nominal Panel Thickness (inches)</th>
<th>Maximum Wall Stud Spacing (inches o.c.)</th>
<th>Panel Nail Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>6d Common (2.0&quot; x 0.113&quot;)</td>
<td>1.75</td>
<td>24/16</td>
<td>7/16</td>
<td>16</td>
</tr>
</tbody>
</table>

### 4.2.7 Anchor Bolt Locations Per Wall Panel

Below are the sketches for the anchor bolt locations. The main consideration for this is the spacing of the anchor bolts. R403.1.6 states that the maximum on-center spacing is 6ft with a minimum spacing of 7 diameters of the bolt size. It also states that the minimum size for the diameter is 1/2 in with a length of 7 in.

![Figure 4.2-5 8' Non-Door Panel Anchor Bolt Locations Top-Down View](image)

![Figure 4.2-6 8' Non-Door Panel Anchor Bolt Locations Side View](image)
Figure 4.2-7 8’ Door Panel Anchor Bolt Locations Top-Down View

Figure 4.2-8 8’ Door Panel Anchor Bolt Locations Side View

Figure 4.2-9 7’1” Panel Anchor Bolt Locations Top-Down View

Figure 4.2-10 7’1” Panel Anchor Bolt Locations Side View
4.2.8 Factors That Reduce Cost

A general rule to follow is using the minimum allowable design in order to minimize the cost of materials. For example, using SPF No. 1 wood is structurally better than using SPF No. 2 wood but since SPF No. 2 meets design standards, it is used instead of SPF No. 1 to reduce costs. When
a wall panel length is equal to or less than 8 ft, no lateral bracing is required (R602.12.5). This reduces the cost of lumber. A tactic used to reduce the cost of lumber is to strategically place the opening on a natural stud making it the king stud. This is used frequently throughout H4H to reduce costs. The advanced framing technique stacked framing eliminates the need for trimmer studs, extra cripple studs and a second top plate. These elements help distribute the loads from the roof sections to the studs then into the foundation. With stacked framing, these elements are not needed. The structural gable truss that transforms the east and west walls into non-loadbearing eliminates the need for headers in that wall which further reduces the cost. Figure 4.2-14 shows where these elements reduce cost in an example model.

![Diagram of structural elements reducing cost](image)

**Figure 4.2-14 Shows the design factors that reduce cost**

### 4.3 Roof Design

Simply put, roof design investigated the structural elements of the roof and the feasibility of construction through prefabrication methods.
It began with calculating the various loads to be applied to the roof. Once loads were determined, truss models were loaded using Computer Aided Engineering (CAE), in this case RISA 3D. These models were used for accurately simulating real world conditions.

The roof design consisted of trusses tied together by bracing and roof sheathing and was modeled using various sizes. This was used to test the structural ability of the assemblies against the forecasted loads, find potential failure points, and determine if the WS and foundation design were capable of handling the roof loads.

In order to be useful, the prefabricated roof design must outperform traditional methods of roof construction. Performance was measured through the following metrics: worker safety, ease of construction and transportation, cost, material utilization, labor, consistency and repeatability, and available space on and off-site.

A final analysis was performed to determine if the design is applicable to Habitat for Humanity.

4.3.1 Roof Loads

Design loads were calculated using ASCE 7-10 and the Michigan Residential Codes. The model house was taken as the worst-case scenario in the state of Michigan, so it could be applicable to all affiliates. This house model is Risk Category 2, since all affiliate houses are wood structure homes. Risk categories indicate risk to human life and range from 1-4 with 1 being the lowest risk and 4 being the highest. All loads were applied at the top chord of trusses. Interior trusses account for a two-foot tributary area since trusses are spaced 2-foot on center. Exterior trusses account for a three-foot tributary area because there is a two-foot overhang of the OSB on the exterior section and a one-foot tributary area from the interior section. All trusses were loaded with four different loads: Dead, Live, Snow, and Wind as displayed in Table 4.3-1. It is important that the trusses can handle the combination of these loads. If they fail to do so, the roof will collapse.

<table>
<thead>
<tr>
<th>Loads</th>
<th></th>
<th>psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Load</td>
<td>15</td>
<td>psf</td>
</tr>
<tr>
<td>Roof Live Load</td>
<td>10</td>
<td>psf</td>
</tr>
<tr>
<td>Uniform Snow Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.P.</td>
<td>77</td>
<td>psf</td>
</tr>
<tr>
<td>Lower Peninsula</td>
<td>53.9</td>
<td>psf</td>
</tr>
<tr>
<td>Non-Uniform Snow Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.P.</td>
<td>100</td>
<td>psf</td>
</tr>
<tr>
<td>Lower Peninsula</td>
<td>70</td>
<td>psf</td>
</tr>
<tr>
<td>Wind Load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windward</td>
<td>8</td>
<td>psf</td>
</tr>
<tr>
<td>Leeward</td>
<td>-11.32</td>
<td>psf</td>
</tr>
</tbody>
</table>
4.3.1.1 Dead Load

The dead load of the roof accounts for the weight of roofing materials such as OSB, and shingles. The residential Structural Design Guide suggested using 15 psf for residential roofs. This value was selected as a conservative estimation for the model. Figure 4.3-1 shows the dead load applied along the slope of the roof.

![Figure 4.3-1. Dead Load](image)

4.3.1.2 Roof Live Load

Roof live load accounts for temporary loads placed on the roof. The model house has an uninhibited attic without storage. Using ASCE 7-10, the live load was determined to be 10 psf acting along the horizontal plane. Figure 4.3-2 shows that the load has been transposed on the roof, so the resultant load is less than the 20 lbf horizontal load. The live load was taken as the roof live load in all load combinations.

![Figure 4.3-2 Roof Live Load](image)
4.3.1.3 Wind Load

Wind load calculations account for the location, terrain, and roof properties of a building and were calculated using Chapter 27 from ASCE 7-10. **Table 4.3-2** shows the calculations used to determine the wind load calculations along with the associated references. All roof loads act perpendicular to the roof plane. The maximum windward load, and the minimum leeward load were applied to the truss as shown in **Figure 4.3-3**. Notice that the leeward load, right side of the truss, results in an uplifting force on the roof. The wind direction impacts the internal and external wind pressures of the roof.

<table>
<thead>
<tr>
<th>Wind Load Calcs</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ p = qGC_p - q_l(GC_{pi}) \text{ (psf)} ]</td>
<td>ASCE 7-10 eqn. 27.4-1</td>
</tr>
<tr>
<td>[ q = q_n = 0.00256K_xK_{zt}K_dV^2 = 16.4 ]</td>
<td>ASCE 7-10 eqn. 27.3-1</td>
</tr>
<tr>
<td>V (mph)</td>
<td>115</td>
</tr>
<tr>
<td>[ K_x = 0.57 ]</td>
<td>ASCE 7-10 Table 27.3-1, Height = 0-15ft, Exposure B</td>
</tr>
<tr>
<td>[ K_{zt} = 1 ]</td>
<td>ASCE 7-10 26.8.2</td>
</tr>
<tr>
<td>[ K_d = 0.85 ]</td>
<td>ASCE 7-10 Table 26.6.1, Main Wind Force Resisting System</td>
</tr>
<tr>
<td>[ G = 0.85 ]</td>
<td>ASCE 7-10 26.9.4</td>
</tr>
<tr>
<td>Cp θ=20, h/L =0.5</td>
<td>Windward</td>
</tr>
<tr>
<td></td>
<td>leeward</td>
</tr>
<tr>
<td>[ GC_{pi} ]</td>
<td>0.18</td>
</tr>
<tr>
<td>h mean roof height (ft)</td>
<td>10.67</td>
</tr>
</tbody>
</table>

4.3.1.4 Snow Load

The snow load was modeled acting uniformly and nonuniformly according to ASCE 7-10 chapter 7. **Table 4.3-3** shows the equations and factors used for both the uniform and nonuniform cases along with the applicable references. Snow load was applied to the trusses on the Horizontal plane, so all values were transposed to act along the roof slope in **Figure 4.3-4** and **Figure 4.3-5**. Calculations were performed using the maximum snow load for both the Lower Peninsula and the Upper Peninsula of Michigan. The final loads displayed on the trusses used the Upper Peninsula values since they were the largest values.
### Table 4.3-3 Snow Load Calculations

<table>
<thead>
<tr>
<th>Snow Load Calcs</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_s = C_sP_f = 0.7C_sC_eI_sP_g$</td>
<td>ASCE 7-10 eqn. 7.4-1, eqn. 7.3-1, Uniform Calculation</td>
</tr>
<tr>
<td>$P_s = I_sP_g$</td>
<td>ASCE 7-10 Figure 7-5 W &lt; 20ft, Nonuniform Calculation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Max ground snow load $P_g$ = (psf)</th>
<th>U.P. 100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Peninsula 70</td>
</tr>
<tr>
<td>Exposure Factor $C_e$</td>
<td>Terrain B, partially exposed</td>
</tr>
<tr>
<td>Importance Factor $I_s$</td>
<td>Risk II</td>
</tr>
<tr>
<td>Roof Slope Factor $C_s$</td>
<td>Roof slope less than 30 deg with rough surface</td>
</tr>
<tr>
<td>Thermal Factor $C_t$</td>
<td>ASCE 7-3 Cold Roof</td>
</tr>
</tbody>
</table>

4.3.1.4.1 Uniform Snow Loads

In the uniform case, as shown in **Figure 4.3-4**, loads are applied across the entire roof. The magnitude depends on location, building exposure, risk category, and roof properties.

![Figure 4.3-4 Uniform Snow Load](image)

4.3.1.5 Nonuniform Snow Loads

**Figure 4.3-5** shows that the nonuniform snow load is only applied to half of the roof width since it is less than 20 feet long. Location, level of risk, and roof span are all factors in this load case.

![Figure 4.3-5](image)
4.3.1.6 Load Combinations

Load combinations were calculated using Load Resistance Factor Design according to ASCE 7-10. Figure 4.3-6 shows the different load combinations with the initials of the loads and their associated factors. DL represents dead load, RLL represents roof live load, SL represents uniform snow load, SLN represents non-uniform snow load, and WL represents wind load. The largest load combination controls the design of the trusses. In this case, LRFD 3c controlled and includes dead, wind, and uniform snow load as represented by Figure 4.3-7.

<table>
<thead>
<tr>
<th>Description</th>
<th>Solve</th>
<th>PDelta</th>
<th>SRSS</th>
<th>BLC</th>
<th>Factor</th>
<th>BLC</th>
<th>Factor</th>
<th>BLC</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRFD 1</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD 2a</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>RLL</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD 2b</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SLN</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD 2c</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SL</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD 3a</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>RLL</td>
<td>1.6</td>
<td>WL</td>
<td>0.5</td>
</tr>
<tr>
<td>LRFD 3b</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SLN</td>
<td>1.6</td>
<td>WL</td>
<td>0.5</td>
</tr>
<tr>
<td>LRFD 3c</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SL</td>
<td>1.6</td>
<td>WL</td>
<td>0.5</td>
</tr>
<tr>
<td>LRFD 4a</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>WL</td>
<td>1</td>
<td>RLL</td>
<td>0.5</td>
</tr>
<tr>
<td>LRFD 4b</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>WL</td>
<td>1</td>
<td>SLN</td>
<td>0.5</td>
</tr>
<tr>
<td>LRFD 4c</td>
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<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>WL</td>
<td>1</td>
<td>SL</td>
<td>0.5</td>
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<tr>
<td>LRFD 5a</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SLN</td>
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<td></td>
</tr>
<tr>
<td>LRFD 5b</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>1.2</td>
<td>SL</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRFD 6</td>
<td>✓</td>
<td></td>
<td></td>
<td>DL</td>
<td>0.9</td>
<td>WL</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.3-6 Load Resistance Factor Design

Figure 4.3-7 LRFD 3c
4.3.2 Truss Models

Habitat for Humanity purchases all trusses from licensed truss companies. For the sake of realistic modeling, three different trusses were modeled in RISA. The model habitat house includes Structural Gable, Common, and Plenum trusses since they are the most likely to be used in projects. As shown in Figure 4.3-8, all trusses span 24 feet with 2-foot tails. The trusses have a 16-inch raised heel to provide for a uniform insulation profile. The raised heel is incorporated into Habitat houses to keep warm air from escaping the house thus increasing the overall energy efficiency. The roof was modeled as a 4/12 pitch. Some affiliates use steeper pitches, but steeper roofs pose some safety concerns during construction. Since Habitat uses volunteers, the shallower pitch incorporates safety into design.

Trusses were modeled in RISA with sections made from Spruce Pine Fir of varying grades. RISA was used to ensure that the design was acceptable according the National Design Specification (NDS) 2018 LRFD codes. Multiple trials were performed until all members passed the wood design codes.

4.3.2.1 Structural Gable Truss

The Structural Gable Truss, Figure 4.3-9, is placed at the exterior ends of the house. This truss allows for the wall it rests on to be a non-load bearing wall, since the web members running triangularly distribute the loads to the exterior points of the truss. No load is being taken by the wall the truss directly rests on.
4.3.2.2 Common Truss

The Common Truss, Figure 4.3-10, is used in the first 16 ft of the house. This truss type is the lightest and most available truss option, so it is used in the common areas.

![Figure 4.3-10 Common Truss](image)

4.3.2.3 Plenum Truss

Plenum Trusses, Figure 4.3-11, are used to create a conditioned space for ductwork. During the colder months, pipes run the risk of freezing, so bringing them into the interior of the house prevents this risk. The chases of the truss will be sealed with drywall prior to ductwork installation. Intake and exhaust vents are required to be at least 10 feet from each other, so the chase is 12 feet wide with a height of 16 inches. Plenum trusses are more specialized, so they are used in only the areas of the house where they are needed.

![Figure 4.3-11 Plenum Truss](image)

4.3.2.4 Truss Layout

Figure 4.3-12 shows how the trusses rest on the wall sections. The entrance for the house is on the east side of the building. The first truss on the exterior of the building is the Structural Gable Truss drawn in orange. Common Trusses, drawn in blue, begin after the Structural Gable Truss at the entrance on the eastside. Next, the trusses transition into Plenum Trusses, drawn in green,
and continue to the west end of the building. The final truss is a Structural Gable Truss which is placed on the west wall.

4.3.3 Truss Section (TS) Overview

“Truss Sections” (TS) are prefabricated assemblies consisting of Structural Gable, Common, and Plenum Trusses, held together by bracing, see Figure 4.3-13. During the initial design process two variations of TS designs were investigated: “Double Truss Sections” (DTS) and “Single Truss Sections” (STS). Additionally, several options for both DTS and STS were investigated based on the section width focusing on transportability and crane lifting. STS were selected on the basis of requiring less material, ease of constructability, and lack of compounding dimensional error. Finally, the bracing for the various TS were calculated and drawn Truss sections are dependent on two factors: section connections and section width. Section connection resulted in the DTS and STS design which were performed for multiple section widths.
4.3.3.1 Double Truss Section (DTS) Defined

A Double Truss Section or DTS is a TS which has two TS connected by a truss abutment. This results in a roof which possess additional trusses. The intent for the additional trusses was to provide a means to tie each TS together. Figure 4.3-14 is a preliminary concept of the DTS design.

![Diagram of Double Truss Section (DTS)](image)

4.3.3.1.1 DTS Design and Analysis

As previously mentioned, a primary independent variable in TS design is the width of the section. Site locations and dimensions change for each project. As such, some affiliates may have insufficient available space at the construction site to assemble large TS. Having a smaller width allows for volunteers to construct TS on the ground with minimum space available. Five different widths were created for DTS, 6, 8, 10, 12, and 16-feet. Figure 4.3-15 shows how the DTS were sized up in increments of two-feet to range from six-feet to sixteen-feet.
Six-foot was the smallest width considered in the DTS design and is capable of fitting through a
small garage or barn door if the Habitat affiliate decided to construct these DTS sections off site
and transport. See appendix for more details. **Table 4.3-4** below shows the various DTS widths,
the associated number of DTSs for the roof, and resulting additional number of trusses.

<table>
<thead>
<tr>
<th>DTS Width</th>
<th>Number of DTSs</th>
<th>Additional Trusses</th>
</tr>
</thead>
<tbody>
<tr>
<td>6'</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>8'</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>10'</td>
<td>4.8</td>
<td>4</td>
</tr>
<tr>
<td>12'</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>16'</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

From the Table, the six-foot width DTS requires a total of 8 DTSs which is significantly more
when compared to the 3 DTSs required for the sixteen-foot width DTS. Likewise, the six-foot
width DTS results in an additional 7 trusses compared to the 2 additional trusses for the
sixteen-foot width DTS. Thus, concluding that DTS width has an inverse relationship to total
number of DTS’s.

DTSs faced compounding dimensional errors. These compounded errors resulted in varied total
length, that made sheathing inconsistent, and prevented 2’ o.c. spacing to tie into the wall panels.
Additionally, per the Michigan Residential Building Code, altering trusses with penetrations is not
permitted. Thus, a design for a “Squeeze Plate” was created and can be found in the appendix.
However, this Squeeze Plate was determined to be non-essential. Through sponsor conversations
it was noted the additional cost and labor to utilize the plates would be inefficient. Finally, these
early designs represent significant enough design consideration to be mentioned in the report,
but ultimately were not selected as in the final recommendation.
4.3.3.2 Single Truss Section (STS) Defined

Similar to DTS, STS are a combination of Trusses and bracing that when tied together create a TS. However, the main difference is that an STS is simply a TS that maintains 2’ o.c. spacing between trusses and is not joined to other TS by a truss-to-truss connection. Instead, an STS is a TS that sits on the WS and is joined to other STS via OSB Sheathing and transitional bracing. Both the OSB Sheathing and the transitional bracing will be further elaborated upon in subsequent chapters.

Below in Figure 4.3-16, an example STS Assembly without OSB Sheathing is shown. This STS has a total of 6 sections with widths ranging from 6'-3/4” to 8'-3/4”. The bracing indicated in the picture will be described in more detail later in the report.

![Figure 4.3-16 Single Truss Section (STS) Type A](image)

It is also important to note that the STS are labeled with “Section 1 – Section X” as measured from the East Wall to West Wall respectively.

4.3.3.2.1 STS Design and Analysis

STS were broken up into seven different types. These types were labeled A-G and each type is a different strategy for STS widths. Table 4.3-5 contains the STS width attributes and quantities for the seven Types of STS.

```
<table>
<thead>
<tr>
<th>Section Width</th>
<th>8' 3/4&quot;</th>
<th>9' 1/2&quot;</th>
<th>9' 3/4&quot;</th>
<th>10' 1/4&quot;</th>
<th>10' 5/8&quot;</th>
<th>12' 1/4&quot;</th>
<th>12' 3/4&quot;</th>
<th>14' 1/4&quot;</th>
<th>14' 5/8&quot;</th>
<th>16' 1/4&quot;</th>
<th>20' 1/4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type Definitions</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8' 3/4&quot;</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9' 1/2&quot;</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<td>2</td>
<td>1</td>
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<tr>
<td>9' 3/4&quot;</td>
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<td>2</td>
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<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10' 1/4&quot;</td>
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<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10' 5/8&quot;</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<td>2</td>
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<td>1</td>
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</tr>
<tr>
<td>14' 1/4&quot;</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
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<td>2</td>
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<td></td>
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<td></td>
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<tr>
<td>14' 5/8&quot;</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Number of Sections</td>
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<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

As mentioned previously, STS were selected as the category of TS to be recommended. As bracing and OSB Sheathing will be further explained, consider from here on out that the selected TSs will all be STSs.
4.3.3.3 Bracing

All individual TS will be braced prior to placing trusses on the roof. Bracing is intended to provide extra stability for TSs and maintain rigidity and spacing during lift and installation. Truss manufacturer’s specification sheets were used to determine where bracing is installed. The bracing specifications will be different depending on the type of truss.

Bracing consists of 2X4 wood members running perpendicular to the truss sections. Figure 4.3-17 describes the general bracing rules using the common truss as an example. Each section has bracing along the bottom chord, one foot away from the exterior web member, as indicated by the red blocks. This bracing is meant to keep trusses in place and maintain the necessary center to center spacing. There are three transition points in the roof assembly where truss types change from: Structural Gable to Common, Common to Plenum, and Plenum to Structural Gable. During those transitions, another brace, indicated by the purple blocks, will be added along the bottom chord and five feet away from the exterior web. The bracing between different truss styles is intended to give additional support locations. The green blocks indicate additional bracing required by the truss manufacturer and are specific to the type of truss. The green bracing will be different between the common, plenum, and Structural Gable Trusses. Table 4.3-6 summarizes the bracing details.

<table>
<thead>
<tr>
<th>Which Trusses</th>
<th>Located</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel Brace</td>
<td>All Trusses, One foot from exterior web</td>
</tr>
<tr>
<td>Transitional Brace</td>
<td>Transition Trusses, Five feet from exterior web</td>
</tr>
<tr>
<td>Web Brace</td>
<td>Truss Manufacturer Details, At the midpoint of web members</td>
</tr>
</tbody>
</table>

Figure 4.3-17 General Bracing Guidelines

Figure 4.3-17 thru Figure 4.3-20 breakdown the bracing by each truss type. The transition bracing only occurs on some trusses and spans 4 feet on either side of the new truss section except when the transition happens at the gable truss ends.
Figure 4.3-18 shows the bracing for the two Structural Gable Trusses of the model house. Structural Gable trusses are used at the first and last truss of the building.

![Figure 4.3-18 Structural Gable Truss Bracing](image1)

The Common Truss, Figure 4.3-19, is braced at the interior web members and along the bottom chord as shown.

![Figure 4.3-19 Common Truss Bracing](image2)

The Plenum Truss, Figure 4.3-20, is braced at the midpoint of one of the internal web members in addition to the bracing along the bottom chord.

![Figure 4.3-20 Plenum Truss Bracing](image3)

Figure 4.3-21 shows the bracing of the entire house using a Type A TS. Here it is possible to see the bracing will change depending on what type of TS is used for construction since each TS type has different dimensions. There will be additional bracing, noted by the dashed lines, placed after all the sections are set.

![Figure 4.3-21 Entire House Bracing](image4)
4.3.4 Roof Section (RS) Overview

“Roof Sections” (RS) are prefabricated partial roof assemblies consisting of DTSs or STSs, and OSB Sheathing. There are 28 RS options through the combinations of various STSs width and OSB Sheathing methods to be selected according to the needs and capabilities of each affiliate. These combinations were designed around the following metrics: worker safety, ease of construction and transportation, cost, material utilization, labor, consistency and repeatability, and available space on and off-site.

RS were designed to expedite the enclosure process by making ground level pre-construction possible prior to or in parallel with other work either on or off-site. Upon completion of RS construction, storage, transport, or direct installation is possible.

One primary goal in RS design is to provide a process of enclosing the house in a shorter time period compared to traditional methods. Figure 4.3-22 is a basic example of a traditional Habitat for Humanity versus the proposed roof construction process, Figure 4.3-23.
Figure 4.3-22 Traditional Roof Construction
While the proposed method has more steps, its method allows for the building to be rapidly enclosed when walls are set and prevent damage from the elements. All while putting an emphasis on worker safety, efficient use of materials, and better scheduling.

4.3.4.1 DTS RS Defined

DTS RS incorporates DTS width, OSB layout, constructability and transportability. These considerations would have been used to select optimum DTS RS. Based on the previous explanation in the DTS Design and Analysis Chapter, the decision to not use DTS RS was made. However, it is still worth explaining the procedure used to design the DTS RS.
4.3.4.1.1 DTS RS Design and Analysis

To begin the DTS RS design, the building was split into 6, 8, 12, and 16-foot DTS. After the DTS were created, the overall dimensions were fine-tuned and different OSB layouts were applied for each DTS width.

Based on OSB layout two different DTS RS design dimensions were selected based on the free area on site. If the site had moderate to large free space, it would be more ideal to use larger RS. However, if space was limited, it is better to use smaller RS.

Table 4.3-7 shows a breakdown of section weight and dimensions for two of the original DTS RS designs.

<table>
<thead>
<tr>
<th>Table 4.3-7 DTS Roof Section Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimension</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Name</strong></td>
</tr>
<tr>
<td>Wood (lbs.)</td>
</tr>
<tr>
<td>OSB (lbs.)</td>
</tr>
<tr>
<td>Total (lbs.)</td>
</tr>
</tbody>
</table>

This concept of varied site space was also used for the STS RS design, which will be later elaborated upon.

More information on the DTS Sections can be found in the appendix.

4.3.4.2 STS RS Defined

Over time as the roof design progressed, the original DTS RS was deemed inefficient as previously explained, however, it was used as a building block for the more dimensionally detailed STS RS.

In this STS RS design, combinations for STS and OSB layouts were created. Of which, a total of 28 various selections were developed. All seven A-G Type STS described in the STS Design and Analysis Chapter, were sheathed.

To accomplish the Sheathing, it was split into four layouts. Uniformed, Staggered, Uniformed Centered, and Staggered Centered.
4.3.4.2.1 STS RS Design and Analysis

The OSB Sheathing is what converts an STS into an STS RS. All OSB Sheathing is to be gapped and spaced at 1/8” to allow for expansion, and H-clips are to be included in the vertical spacings. Table 4.3-24 breaks down the four varieties.

<table>
<thead>
<tr>
<th>Sheathing Varieties</th>
<th>Horizontal Reference</th>
<th>Vertical Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformed</td>
<td>East Wall</td>
<td>In-Line</td>
</tr>
<tr>
<td>Staggered</td>
<td>East Wall</td>
<td>Off-Set</td>
</tr>
<tr>
<td>Uniformed Centered</td>
<td>Middle Truss</td>
<td>In-Line</td>
</tr>
<tr>
<td>Staggered Center</td>
<td>Middle Truss</td>
<td>Off-Set</td>
</tr>
</tbody>
</table>

*Middle Truss is the 13th Truss counted in-ward from East Wall

Figures 4.3-25 thru Figure 4.3-28 demonstrate example combinations for each layout type.

Figure 4.3-25 Type B STS, with Uniformed OSB Sheathing Layout

Figure 4.3-26 Type F STS, with Staggered OSB Sheathing Layout
4.3.5 Roof Design Conclusion

Roof Design investigated how Habitat for Humanity could prefabricate RS as a way to reduce the time to enclose a home. The proposed design offers a variety of section sizes and combinations to allow multiple options to fit affiliates needs. In total there were seven different STS and 28 different RS combinations each with detailed and dimensioned drawings. All RS tie into the proposed WS using advanced framing methods. Additionally, can withstand various loads for residential buildings in Michigan.

4.4 Systems, Optimization, & Process Support

The original design goal was to create enclosure elements that could be constructed using an average two-car garage. It was assumed that an affiliate would have easy access to Two-car garages based on personal contributions. However, the strategy to pre-fabricate can be applied to other locations such as barns, sheds, or awnings. The drawings for some various garage sizes are located in the appendix.
4.4.1 Detailed 2-D Drawings

There was a large quantity of detailed 2-D drawings created for this project. They have been included as part of the submission in the original Visio File Format. They have also been complied into the Manual and turned over to the sponsor.

4.4.1.1 Manual

As part of the deliverables, a volunteer manual was produced. The intent for the manual was to provide affiliates with access to the variety of detailed 2-D drawings for the panelized designs. This was completed in an easy-to-read format for volunteers to have at the ready during the volunteer day. The manual was included alongside submission of this report.

4.4.2 Pre-Fabrication Decision Matrix

Prefabrication is primarily dependent on the available space. Space includes considerations for both on-site, and off-site availability. For on-site space considerations, the footprint of the foundation is anticipated to be unavailable for use when pre-fabricating the entire assembly, however, there are an infinite number of options based on individual affiliate resources such as, manpower, budgets, and logistical capabilities. A decision matrix was developed to assist in weighing the options and aiding in decision making. The resultant values are defined in Table 4.4-2, Decision Matrix Legend.

<table>
<thead>
<tr>
<th>Decision Matrix to Pre-Fab/Deliver or Construct On-Site</th>
<th>On-Site Space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ample Space (48'x96')</td>
</tr>
<tr>
<td></td>
<td>Ample Space (20'x30')</td>
</tr>
<tr>
<td></td>
<td>Adequate Space (20'x30')</td>
</tr>
<tr>
<td></td>
<td>Inadequate Space (20'x20')</td>
</tr>
</tbody>
</table>
4.4.2.1 Decision Matrix Analysis

The matrix focused on the space requirements to prefabricate, store, transport and install, the assemblies. In general, if there is inadequate space for storage and prefabrication, it is suggested that traditional construction methods are used. However, there are plenty of scenarios where prefabricating portions of the enclosure may be feasible and worthwhile. The intent is to provide enough general guidance as a decision-making tool to help individual affiliates in deciding if prefabricating and transporting is feasible.
4.4.3  Pre-Fabrication Facilities Planning

Management of the prefabrication process requires a proper location and design. An analysis for an example location was developed. This analysis included examining key factors such as setting up workstations and roles, tools and equipment required, and an example of production standard time. Additionally, a block plan and flow were noted. All of these considerations are flexible based on the affiliate’s current situation. To help identify and problem solve the affiliates have the decision matrix and their own discretion. The tables of these designs can be found in the appendix. Figure 4.4-1 is the block plan for the 20’x20’x8’ Garage example.

4.4.3.1 WS

WS’s were determined to be the most feasible option for prefabrication. The designs were kept to manageable sizes and are able to be assembled at a workbench using a jig or clamps. This kept the workers from having to bend over and allowed for more controlled construction.

4.4.3.2 TS

Based on the constraints of the smallest expected 2-car garage 20’x20’x8’ Garage, prefabricating TS was possible but highly infeasible. For example, Type A TS’s could fit in the width dimension, but would be too long and stick out outside the garage. Additionally, transporting the TS would...
be expensive and difficult to move. Potentially, requiring a crane in both pick up and drop off locations. However, the space required was still examined.

4.4.3.3 RS

As the definitions of RS’s includes TS’s, prefabricating RS’s within the 20’x20’ garage is also not recommended. RS’s are heavier and bulkier than TS’s. However, with proper equipment it may be possible to move.

4.4.4 Transportation/Logistics

In the event that prefabrication is recommended, following manufacturing, the assemblies would require transportation from the point of manufacturing to the point of install. The evaluated method of transportation was by using a 43’x8’4” flatbed trailer. This sized trailer was capable of moving even the largest RS, Type E, STS 2, with Uniformed Centered OSB Sheathing. However, for legal and safe transportation MDOT regulations must be abided by. When loading the travel be sure to load using a LIFO method.

4.4.4.1 Installation Analysis

Based on conversations with the sponsor the expected boom length most commonly used is 40’ to 70’, providing an 80’ to 140’ total diameter of swing. Below in Figure 4.4-2 is an example to compare a site fully loaded site with RS and the potential Boom Swing.

![Figure 4.4-2 Fully Loaded Site Layout Example](image)
In this example, the site is too packed for the crane to pick and set the sections, but the installation logistics would be dependent on supervision, available volunteers, site size, and prefab section size. Below is another example, Figure 4.4-3 that could work with skilled timing and coordination.

![Figure 4.4-3 Tight Site Layout Example](image)

**Figure 4.4-3 Tight Site Layout Example**

4.4.4.1.1 Crane Contractor Advice

A crane contractor was contacted, and the information received noted that crane utilization for lifting RS is feasible, however challenging. One challenge is the risk of racking while lifting.
Another was the need to use a box bar spreader. A box bar spreader is an uncommon and expensive lifting tool. Below in Figure 4.4-4 is an example of a box bar spreader.

![Box Bar Spreader Example](image.png)

4.4.5 Cost Analysis

The cost analysis focuses mainly on creating a spreadsheet for comparing cost of materials based on the various supplier’s regional cost data. The goal was to provide Habitat for Humanity with the option to view the total material takeoff with local prices. However, for designs, the best way was to average the cost of the state’s various costs and apply them to each material. The spreadsheet information is found in the Excel digital appendix.

4.4.5.1 Michigan Cost Data

The widespread scope across the State of Michigan required the collection of regional cost data. This analysis of cost variation was based on the zip codes for each affiliate. Additionally, Google Earth Map Pins of the Affiliates was created. The spreadsheet information is found in the Excel digital appendix.

4.4.5.1.1 Statistical Variation

To understand the variation of Michigan’s Cost Data, price quotes from Lowes, Menards, and Home Depot were taken from Kalamazoo and eleven other random affiliates for raw materials. Then a statistical reliability comparison was made to determine if the data for the twelve affiliates reflected the data of the overall Michigan population. The result was that the cost did not vary significantly enough to require additional quotes. Below in Figure 4.4-5 shows a comparison graph of 2x6xL prices from these twelve affiliates.
4.4.5.2 Cost Estimate

All Materials were itemized to calculate and estimate cost for WS, TS, and RS. Additionally, a rough Foundation estimate was made. As well as an MDOT Permitting Cost Analysis. Details of these estimates are included in the Excel supporting document. Figure 4.4-6 below is one example final cost estimate.

The key takeaway is the transportation and Logistics costs are variable, were as the raw material costs can be optimized based around the size constraints, volunteers available and all other previously mentioned variables. An example of the optimizer for affiliates to compare and work with is also included in the Excel sheet.
5. Conclusion

Through the use Civil Engineering Principles designs for enclosure elements such as Foundation, Exterior Walls, and Roofs were created. By utilizing the skillset of the Engineering Design, Manufacturing, and Management Systems department, the Walls, Trusses, and Roofs were panelized and optimized with an included strategy to manufacture. The designs included are suitable for all 53 Habitat for Humanity of Michigan Affiliates. Each design includes various adjustable components which were intended to bring options for the affiliate staff. The process of implementing the various designs is not standardized. Each affiliate brings with it unique circumstances regarding budget, available space on and off-site, tools, equipment, volunteer manpower, and project schedule. Under the considerations of each affiliate, using the provided designs and decision-making guidelines the ability for prefabricating enclosure components with optimal material usage and volunteer safety can be possible.
6. References

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7. Appendix

Appendix For 2-D Detailed drawings, see included Visio document.

Pre-fab excel inputs and outputs see attached Excel document.

These documents were far too extensive to be fit into the Report.
7.1 Foundation

7.1.1 Kalamazoo Foundation Calculations

**Frost Protected Shallow Foundation Design**

Heated Home with Unheated Porch in Kalamazoo, MI

This design is part of the Western Michigan University student Senior Capstone Project, "Housing Pre-Fabrication and Resource Optimization." This is just one component of the proof of concept for a prefabricated home enclosure in the state of Michigan. None of the work shown below has been reviewed by an engineer, and therefore may not be used as a construction document.


---

**Project Assumptions:** This home is to be designed with a 16" below grade foundation depth with 8" above grade foundation height, 4" slab on grade and the use of Insulated Concrete Forms (ICF). This home is located in Kalamazoo, MI.

**Step 1.) Determine the Site’s 100 Year Air Freezing Index (AFI)**
Reference Figure 4. or NOAA Air Freezing Index
A.) State & Station Name (closest to home location): Michigan, KALAMAZOO STATE HOSP
B.) \( AFI = 1272 \)

**Step 2.) Calculate the R-value of the Floor System Cross Section \( R_f \)**
Reference Figure 6., Table 2., and Appendix III, ACI 332-08 Section 8.4

A.) Determine Slab Thickness:
   \[ T_{ho} = 4 \geq 3.5 \text{ inches} \]
B.) Assume a 4" slab, and 2" EPS Insulation, Type IX.
   \[ R_1 = 4 \times .05 = 0.2 \text{ Concrete Slab} \]
   \[ R_2 = 2 \times 4.2 = 8.4 \text{ Insulation Under Slab} \]
   \[ R_f = R_1 + R_2 = 8.6 \]

**Step 3.) Determine the Required R-Value of Vertical Wall Insulation \( R_V \)**
Reference Table 4.

A.) Specified height of foundation above grade: \( h = 8 \text{ inches} \)
B.) Required Vertical Wall Insulation:
   \( R_V = 5.7 \)

**Step 4.) Select Vertical Wall Insulation**
Reference Table 2. and Table 4. Use EPS Insulation, Type IX

A.) Find Max Effective R-Value for vertical Insulation
   \( R_{vw} = 3.4 \)
B.) Determine Vertical Insulation Thickness for ICF
   \[ T_v = \frac{R_V}{R_{vw}} = 1.676 \text{ inches} \]
C.) Choose an insulation design width based on cost and constructability that is still greater than or equal to the minimum required thickness.
   Choose 2.25" thick insulation based on typical ICF insulation specifications.
Step 5.) Select Foundation Depth or Horizontal Insulation $h_f$, $D_{hw}$, & $R_{hw}$
Reference Figure 6. and Table 6. If AFI < 2250°F-days then horizontal insulation along the walls is not Required.

Foundation Depth Below Grade: $h_f$ = 16 inches
Horizontal Insulation Width at Foundation: $D_{hw}$ = NA
Horizontal Insulation Effective R-Value per depth: $R_{hw}$ = NA

Step 6.) Select Thickness of Horizontal Insulation for Walls
Reference Table 2 and Table 4. Use EPS Insulation, Type IX

Minimum Soil Cover Over Horizontal Insulation: $S_{min} = 12$ inches
Maximum Effective R-Value Table 2 Column 5h: $R_h$ = 2.8

Minimum Horizontal Insulation Thickness: $T_{Hmin} = \frac{R_{hw}}{R_h}$ inches
Design Horizontal Insulation Thickness: $T_H = NA$ inches EPS, Type IX
Design Soil Cover Over Horizontal Insulation: $S_d = h_f - T_H$ inches

Step 7.) Select Foundation Depth or Horizontal Insulation at Corners $h_{fc}, D_{hc}, R_{hc}, L_c$
Reference Table 5 and Table 7. Use EPS Insulation, Type IX

Specified Foundation Depth Below Grade at Corner: $h_f = h_{fc}$
Choose 16" for constructability: $h_{fc} = 16$ inches
Required Horizontal Corner Insulation R-Value per depth: $R_{hc} = NA$
Required Horizontal Corner Insulation from Corners: $D_{hc} = NA$
Required Length of Horizontal Insulation from Corners: $L_c = NA$
Maximum Effective R-Value Table 2 Column 5h: $R_h$ = 2.8

Minimum Horizontal Corner Insulation Thickness: $T_{HCmin} = \frac{R_{hc}}{R_h}$ inches
Design Horizontal Corner Insulation Thickness: $T_{HC} = NA$ inches EPS, Type IX

Minimum Soil Cover Over Horizontal Insulation: $S_{min} = 12$ inches
Design Soil Cover Over Horizontal Insulation: $S_d = h_{fc} - T_{HC}$ inches

Step 8.) Determine Footing Width
Reference Michigan Residential Building Codes: Chapter 4 Foundations, Section R401.4, Table R401.4(1), Section R403.1, Table R403.1(1)

A.) Determine the Load-Bearing Pressure of the Site’s Soil
According to R401.4 the building official will decided if soil testing is required. If it is not required, assume the load bearing values based on the class of material and the associated load-bearing pressure listed on Table R401.4.1

For this design a minimum of 1500 psf is required beneath the footing.
According to R403.1 footings must be supported by undisturbed natural soils or engineered fill.
B.) Minimum Footing Width:
Use Table R403.1(1) for Concrete Footings for Light-Frame Construction
Snow Load: \( D_s = 30 \) psf
Story and Type of Structure: 1 story-slab-on-grade
Minimum Footing Width: \( W = 12 \) inches

Step 9) Determine Footing Rebar Requirement and Placement
Reference ACI 332-08, Section 6.2.7.2
A.) Choose Installation Method: Slab and footings are cast monolithically.
B.) Use two longitudinal No. 4 Bars in the middle third of the total footing depth.

Step 10.) Slab Support and Reinforcement:
Reference ACI 332-08, Section 8.2.1 and 8.6.1
A.) Slabs on ground will be supported by undisturbed soil or a maximum of 24 inches of clean sand or gravel.
B.) Use welded wire reinforcement with a minimum 3/4" cover in the top half of the slab depth for interior conditions. For this design place the the welded wire reinforcement at 1 inch from the top of the slab.

Step 11.) Foundation Anchorage
Reference Michigan Residential Building Codes, Chapter 4 Foundations, R403.1.6
Wood walls supported by a continous foundation must be anchored to the foundation.

Minimum Anchor Bolt Diameter: \( d_{ab} \geq 0.5 \) inches
Choose Anchor Bolt Diameter: \( d_{ab} = 0.5 \) inches
Minimum Depth Anchor Must Extended into Concrete: \( L_{ab} \geq 7 \) inches
Maximum On-Center Spacing between Anchor Bolts: \( S_{ab} \leq 6 \) feet
Minimum Anchor Bolt Distance from Section End: \( D_{SE1} = 7 \cdot d_{ab} = 3.5 \) inches
Maximum Anchor Bolt Distance from Section End: \( D_{SE2} = 12 \) inches

Bolts must be placed in the center third of the width of the wall section's bottom plate.
Each anchor bolt must be secured to the wall sections with a tightened nut and washer.
Each wall section must have a minimum of 2 anchor bolts.

In this project there are various wall section lengths. For each wall section we recommend placing anchor bolts 8 inches from each end. This is sufficient for any wall section specified in the plans as less than 8 ft. For the 8 ft wall sections one additional anchor bolt must be placed to satisfy the 6' maximum on center spacing. We recommend placing the third anchor bolt 8' left of center for the 8 ft wall sections. For the two wall sections with doors, the third center anchor bolt will be placed 1 8' from center. The specific anchor locations can be seen in the top view foundation drawing below.

Use 10" anchor bolts with 0.5" diameters.
Step 12) Site Grading Around Home
Reference Michigan Residential Building Codes, Chapter 4 Foundations, R401.3
Minimum Grading Downward Away From Foundation: \( g \geq -6 \) inches within the first 10'

If there are physical limitations to achieving a greater than or equal to 6 inch slope down from the foundation in the first 10 feet, then drains or swales are required to ensure drainage. All impervious surfaces within 10 ft of the home must be sloped 2% away from the foundation.

Step 13) Concrete Strength Requirement
Reference Michigan Residential Building Codes, Chapter 4 Foundations, Table R402.2, Chapter 3 Building Planning, Table R301.2, and Figure R301.2(3).
A.) Weathering Index:
   SEVERE (all of Michigan)

B.) Foundation and slab concrete minimum strength requirement at 28 days:
   When using ICF forms for the footings and slab on grade use rows 1 and 2 Table R402.2.
   \[ f'_{c1} = 2500 \, \text{psi} \]
   If during construction the concrete may be subject to freezing and thawing then the concrete must be air entraained between 5 and 7%.

C.) Porch concrete minimum strength requirement at 28 days:
   Porches, carports, and exterior steps use row 3 Table R402.2.
   \[ f'_{c2} = 3500 \, \text{psi} \]
   The concrete used for the porch must be air entraained between 5 and 7% due to the increase in weather exposure. The porch concrete is likely to be exposed to deicing agents and therefore the percentages of total weight of cementitious materials can not exceed those specified in Section 19.3.3.4 of ACI 318.

Step 14) Unheated Porch FPSP Design
Reference Figure 7, Table 8, Figure 14 and NOAA Air Freezing Index.
A.) Determine Air Freezing Index, AFI, and Mean Annual Temperature, MAT:
   \[ AFI = 1272 \quad MAT = 49.7 \, \, \, (^\circ F) \]

B.) Select Minimum Soil Cover & Insulation length: \( D_g \)
   The entire unheated slab must be placed over a layer of ground insulation and a 6-inch layer of gravel or other non-frost susceptible base. Use Table 8 to determine how far the the insulation must extend past the unheated section.
   Depth of Non-Frost Susceptible Base: \( G_d = 6 \) inches
   Minimum Soil Cover Over Insulation: \( S_{min} = 10 \) inches
   Minimum Length of Extended Insulation: \( D_{min} = 49 \) inches

C.) Select the Minimum Effective R-Value: \( R_g \)
   Use Table 8 and AFI and MAT values from step 14-A.
   Minimum R-Value for Ground-Insulating Layer: \( R_{min} = 6.8 \)
Assume soil cover expected and reiterate to optimize:  \( S_d = 16.5 \)
Design R-Value for Ground-Insulating Layer:  \( R_g = R_{g\text{min}} - (0.25 \cdot (S_d - S_{d\text{min}})) = 5.175 \)

D.) Select the Thickness and Performance of Ground Insulation:

Use Table 2 and the \( R_g \) Value from step 14-C.

Choose Insulation Type: Extruded (XPS) Type VI

Effective R-Value for Insulation Below the Porch:  \( R_{hp} = 4.0 \)

Determine Minimum Insulation Thickness Below the Porch:
\[
T_{hp} = \frac{R_g}{R_{hp}} = 1.294
\]

Minimum Insulation Density:
\( D_{hp} = 1.8 \) pc/f

Allowable Bearing Capacity:
\( B_{hp} = 1920 \) psf

Choose an insulation design width based on cost and constructability that is still greater than or equal to the minimum required thickness.

Choose 1.5" thick XPS Insulation, Type VI.
\( I_{FP} = 1.5 \) inches

E.) Determine Footing, Slab Size, and Insulation Length:

Determine the Load-Bearing Pressure of the Site's Soil:

According to R401.4 the building official will decided if soil testing is required. If it is not required, assume the load bearing values based on the class of material and the associated load-bearing pressure listed on Table R401.4.1.

For this design a minimum of 1500 psf is required beneath the footing.

According to R403.1 footings must be supported by undisurbed natural soils or engineered fill.

Minimum Footing Width:
Use MI Residential Building Codes Table R403.1(1) for Concrete Footings for Light-Frame Construction.

Snow Load: \( D_s = 30 \) psf

Story and Type of Structure: 1 story-slab-on-grade

Minimum Footing Width: \( W = 12 \) inches

Below Grade Unheated Porch Footing Height: \( h_{fp} = 16.5 \) inches

Minimum Slab-on-ground Thickness=3.5"

Unheated Slab Thickness: \( T_{ps} = 4 \) inches \( T_{ps} = 4 \geq 3.5 \)

Design Soil Cover Over Insulation: \( S_d = 24 - G_d - I_{FP} = 16.5 \) inches

Design Length of Extended Insulation: \( D_g = D_{g\text{min}} - (S_d - S_{d\text{min}}) = 42.5 \) inches

Fill the space between the slab, footing, and ground insulation with non-frost susceptible fill.
F.) Unheated Porch Footing and Slab Reinforcement:
Reference ACI 332-08 8.2.1, 8.6.1, and 6.2.7.2.

Choose Installation Method: Slab and footings are cast monolithically.
Use two longitudinal No. 4 Bars in the middle third of the total footing depth.
Slabs on ground will be supported by undisturbed soil or a maximum of 24 inches of clean sand or gravel.
Use welded wire reinforcement with a minimum 1.5" cover in the top half of the slab depth for exterior conditions. For this design place the the welded wire reinforment at 1.75" inch from the top of the slab.
Note: If not otherwise indicated the tables and figures referenced are located in the Revised Builder's Guide to Frost Protected Shallow Foundations.
7.1.2 Bergland Foundation Calculations

**Frost Protected Shallow Foundation Design**
Heated Home with Unheated Porch in Bergland, MI

This design is part of the Western Michigan University student Senior Capstone Project, "Housing Pre-Fabrication and Resource Optimization." This is just one component of the proof of concept for a prefabricated home enclosure in the state of Michigan. None of the work shown below has been reviewed by an engineer, and therefore may not be used as a construction document.


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**Project Assumptions:** This home is to be designed with a 16” below grade foundation depth with 8” above grade foundation height, 4” slab on grade and the use of Insulated Concrete Forms (ICF). This home is located in Bergland, MI.

**Step 1.) Determine the Site's 100 Year Air Freezing Index (AFI)**
Reference Figure 4. or NOAA Air Freezing Index
A.) State & Station Name (closest to home location): Michigan, BERGLAND DAM
B.) $AFI = 3020$

**Step 2.) Calculate the R-value of the Floor System Cross Section $R_f$**
Reference Figure 6., Table 2., and Appendix III, ACI 332-08 Section 8.4
A.) Determine Slab Thickness:
   - Minimum Slab Thickness = 3.5” $T_{lw} = 4 \geq 3.5$ inches
B.) Assume a 4” slab, and 2” EPS Insulation, Type IX.
   - $R_1 = 4 \times 0.05 = 0.2$ Concrete Slab
   - $R_2 = 2 \times 4.2 = 8.4$ Insulation Under Slab
   - $R_f = R_1 + R_2 = 8.6$

**Step 3.) Determine the Required R-Value of Vertical Wall Insulation $R_V$**
Reference Table 4.
A.) Specified height of foundation above grade: $h = 8$ inches
B.) Required Vertical Wall Insulation: $R_V = 8.0$

**Step 4.) Select Vertical Wall Insulation**
Reference Table 2. and Table 4. Use EPS Insulation, Type IX
A.) Find Max Effective R-Value for vertical Insulation $R_{vw} = 3.4$
B.) Determine Vertical Insulation Thickness for ICF
   - $T_V = \frac{R_V}{R_{vw}} = 2.353$ inches
C.) Choose an insulation design width based on cost and constructability that is still greater than or equal to the minimum required thickness.
   - Choose 2.5” thick insulation based on typical ICF insulation specifications.
Step 5.) Select Foundation Depth or Horizontal Insulation $h_f, D_{hw}, & R_{hw}$

Reference Figure 6. and Table 6. If AFI < 2250°F-days then horizontal insulation along the walls is not Required.

Foundation Depth Below Grade: $h_f = 16$ inches
Horizontal Insulation Width at Foundation: $D_{hw} = 24$ inches
Horizontal Insulation Effective R-Value per depth: $R_{hw} = 7.4$

Step 6.) Select Thickness of Horizontal Insulation for Walls

Reference Table 2 and Table 4. Use EPS Insulation, Type IX

Minimum Soil Cover Over Horizontal Insulation: $S_{dmin} = 12$ inches
Maximum Effective R-Value Table 2 Column 5h: $R_h = 2.8$

Minimum Horizontal Insulation Thickness: $T_{Hmin} = R_{hw} R_h = 2.643$ inches

Design Horizontal Insulation Thickness: $T_H = 2.75$ inches EPS, Type IX

Design Soil Cover Over Horizontal Insulation: $S_d = h_f - T_H = 13.25$ inches

Step 7.) Select Foundation Depth or Horizontal Insulation at Corners $h_{fc}, D_{hc}, R_{hc}, L_c$

Reference Table 2 and Table 7. Use EPS Insulation, Type IX

Specified Foundation Depth Below Grade at Corner: $h_f = h_{fc}$
Choose 16'' for constructability: $h_{fc} = 16$ inches
Required Horizontal Corner Insulation R-Value per depth: $R_{hc} = 9.8$
Required Horizontal Corner Insulation from Corners: $D_{hc} = 36$
Required Length of Horizontal Insulation from Corners: $L_c = 60$
Maximum Effective R-Value Table 2 Column 5h: $R_h = 2.8$

Minimum Horizontal Corner Insulation Thickness: $T_{Hcmin} = R_{hc} R_h = 3.5$ inches

Design Horizontal Corner Insulation Thickness: $T_{HC} = 3.75$ inches EPS, Type IX

Minimum Soil Cover Over Horizontal Insulation: $S_{dmin} = 12$ inches
Design Soil Cover Over Horizontal Insulation: $S_d = h_{fc} - T_{HC} = 12.25$ inches

Step 8.) Determine Footing Width

Reference Michigan Residential Building Codes: Chapter 4 Foundations, Section R401.4, Table R401.4(1), Section R403.1, Table R403.1(1)

A.) Determine the Load-Bearing Pressure of the Site's Soil

According to R401.4 the building official will decided if soil testing is required. If it is not required, assume the load bearing values based on the class of material and the associated load-bearing pressure listed on Table R401.4.1

For this design a minimum of 1500 psf is required beneath the footing.

According to R403.1 footings must be supported by undisturbed natural soils or engineered fill.
B.) Minimum Footing Width:
Use Table R403.1(1) for Concrete Footings for Light-Frame Construction
  
  Snow Load: \( D_s = 70 \text{ psf} \)
  
  Story and Type of Structure: 1 story-slab-on-grade
  
  Minimum Footing Width: \( W = 12 \text{ inches} \)

Step 9) Determine Footing Rebar Requirement and Placement
Reference ACI 332-08, Section 6.2.7.2

A.) Choose Installation Method: Slab and footings are cast monolithically.
B.) Use two longitudinal No. 4 Bars in the middle third of the total footing depth.

Step 10) Slab Support and Reinforcement:
Reference ACI 332-08, Section 8.2.1 and 8.6.1

A.) Slabs on ground will be supported by undisturbed soil or a maximum of 24 inches of clean sand or gravel.
B.) Use welded wire reinforcement with a minimum 3/4" cover in the top half of the slab depth for interior conditions. For this design place the the welded wire reinforcement at 1 inch from the top of the slab.

Step 11) Foundation Anchorage
Reference Michigan Residential Building Codes, Chapter 4 Foundations, R403.1.6

Wood walls supported by a continuous foundation must be anchored to the foundation.

- Minimum Anchor Bolt Diameter: \( d_{ab} \geq 0.5 \text{ inches} \)
- Choose Anchor Bolt Diameter: \( d_{ab} = 0.5 \text{ inches} \)
- Minimum Depth Anchor Must Extended into Concrete: \( L_{sd} \geq 7 \text{ inches} \)
- Maximum On-Center Spacing between Anchor Bolts: \( S_{ab} \leq 6 \text{ feet} \)
- Minimum Anchor Bolt Distance from Section End: \( D_{SE1} = 7 \cdot d_{ab} = 3.5 \text{ inches} \)
- Maximum Anchor Bolt Distance from Section End: \( D_{SE2} = 12 \text{ inches} \)

Bolts must be placed in the center third of the width of the wall section's bottom plate.
Each anchor bolt must be secured to the wall sections with a tightened nut and washer.
Each wall section must have a minimum of 2 anchor bolts.

In this project there are various wall section lengths. For each wall section we recommend placing anchor bolts 8 inches from each end. This is sufficient for any wall section specified in the plans as less than 8 ft. For the 8 ft wall sections one additional anchor bolt must be placed to satisfy the 6 maximum on center spacing. We recommend placing the third anchor bolt 8" left of center for the 8 ft wall sections. For the two wall sections with doors, the third center anchor bolt will be placed 19" from center. The specific anchor locations can be seen in the top view foundation drawing below.

Use 10" anchor bolts with 0.5" diameters.
Step 12.) Site Grading Around Home
Reference Michigan Residential Building Codes, Chapter 4 Foundations, R401.3
Minimum Grading Downward Away From Foundation: \( g \geq -6 \text{ inches} \) within the first 10'

If there are physical limitations to achieving a greater than or equal to 6 inch slope down from the foundation in the first 10 feet, then drains or swales are required to ensure drainage. All impervious surfaces within 10 ft of the home must be sloped 2% away from the foundation.

Step 13.) Concrete Strength Requirement
Reference Michigan Residential Building Codes, Chapter 4 Foundations, Table R402.2, Chapter 3 Building Planning, Table R301.2, and Figure R301.2(3).
A.) Weathering Index:
- SEVERE (all of Michigan)

B.) Foundation and slab concrete minimum strength requirement at 28 days:
- When using ICF forms for the footings and slab on grade use rows 1 and 2 Table R402.2.
  \[ f'_{c1} = 2500 \text{ psi} \]
- If during construction the concrete may be subject to freezing and thawing then the concrete must be air entrained between 5 and 7%.

C.) Porch concrete minimum strength requirement at 28 days:
- Porches, carports, and exterior steps use row 3 Table R402.2.
  \[ f'_{c2} = 3500 \text{ psi} \]
- The concrete used for the porch must be air entrained between 5 and 7% due to the increase in weather exposure. The porch concrete is likely to be exposed to deicing agents and therefore the percentages of total weight of cementitious materials can not exceed those specified in Section 19.3.3.4 of ACI 318.

Step 14.) Unheated Porch FPSP Design
Reference Figure 7, Table 8, Figure 14 and NOAA Air Freezing Index.
A.) Determine Air Freezing Index, AFI, and Mean Annual Temperature, MAT:
  \[ AFI = 3020 \quad MAT = 39.0 \text{ (°F)} \]

B.) Select Placement of Ground Insulation: \( D_g \)
- The entire unheated slab must be placed over a layer of ground insulation and a 6-inch layer of gravel or other non-frost susceptible base. Use Table 8 to determine how far the the insulation must extend past the unheated section.
  - Depth of Non-Frost Susceptible Base: \( G_d = 6 \text{ inches} \)
  - Minimum Soil Cover Over Insulation: \( S_{dmin} = 10 \text{ inches} \)
  - Minimum Length of Extended Insulation: \( D_{gmin} = 91 \text{ inches} \)

C.) Select the Minimum Effective R-Value: \( R_g \)
- Use Table 8 and AFI and MAT values from step 14-A.
  - Minimum R-Value for Ground-Insulating Layer: \( R_{gmin} = 22.7 \)
Assume soil cover expected and reiterate to optimize: \( S_d := 12.25 \)

Design R-Value for Ground-Insulating Layer: \[ R_g = R_{g_{\text{min}}} - (0.25 \cdot (S_d - S_{d_{\text{min}}})) = 22.138 \]

D.) Select the Thickness and Performance of Ground Insulation:
Use Table 2 and the \( R_g \) Value from step 14-C.
Choose Insulation Type: Extruded (XPS) Type VI
Effective R-Value for Insulation Below the Porch: \( R_{hp} = 4.0 \)
Determine Minimum Insulation Thickness Below the Porch:
\[ T_{hp} = \frac{R_g}{R_{hp}} = 5.534 \]

Minimum Insulation Density: \( D_{hp} = 1.8 \) pcf
Allowable Bearing Capacity: \( B_{hp} = 1920 \) psf

Choose an insulation design width based on cost and constructability that is still greater than or equal to the minimum required thickness.
Choose 5.75" thick XPS Insulation, Type VI.
Insulation may be layered if needed to reach the required thickness.

\( I_{TP} = 5.75 \) inches

E.) Determine Footing and Slab Size:
Determine the Load-Bearing Pressure of the Site's Soil:
According to R401.4 the building official will decide if soil testing is required. If it is not required, assume the load bearing values based on the class of material and the associated load-bearing pressure listed on Table R401.4.1.

For this design a minimum of 1500 psf is required beneath the footing.
According to R403.1 footings must be supported by undisturbed natural soils or engineered fill.

Minimum Footing Width:
Use MI Residential Building Codes Table R403.1(1) for Concrete Footings for Light-Frame Construction.

Snow Load: \( D_s = 70 \) psf
Story and Type of Structure: 1 story-slab-on-grade
Minimum Footing Width: \( W = 12 \) inches

Below Grade Unheated Porch Total Footing Height: \( h_{fp} = 12.25 \) inches
Minimum Slab-on-ground Thickness=3.5"
Unheated Slab Thickness: \( T_{ps} = 4 \) inches \( T_{ps} = 4 \geq 3.5 \)
Design Soil Cover Over Insulation: \( S_d = 24 - G_d - I_{TP} = 12.25 \) inches
Design Length of Extended Insulation: \( D_g = D_{g_{\text{min}}} - (S_d - S_{d_{\text{min}}}) = 88.75 \) inches

Fill the space between the slab, footing, and ground insulation with non-frost susceptible fill.
F.) Unheated Porch Footing and Slab Reinforcement:
Reference ACI 332-08 8.2.1, 8.6.1, and 6.2.7.2.

Choose Installation Method: Slab and footings are cast monolithically.
Use two longitudinal No. 4 Bars in the middle third of the total footing depth.
Slabs on ground will be supported by undisturbed soil or a maximum of 24 inches of
clean sand or gravel.
Use welded wire reinforcement with a minimum 1.5" cover in the top half of the slab
depth for exterior conditions. For this design place the the welded wire reinforce at
1.75" inch from the top of the slab.
FOUNDATION CROSS SECTION
HORIZONTAL CORNER INSULATION
BERGLAND, MI
Note: If not otherwise indicated the tables and figures referenced are located in the Revised Builder's Guide to Frost Protected Shallow Foundations.
7.2 Wall Sections

7.2.1 Wall Loads Calculations

CHAPTER 27 WIND LOADS ON BUILDINGS—MWFRS (DIRECTIONAL PROCEDURE)

Main Force Resisting System – Part 2

Table 27.6-1 Wind Pressures - Walls

Enclosed Simple Diaphragm Buildings

<table>
<thead>
<tr>
<th>Wind Pressures - Walls</th>
<th>Application of Wall Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>h ≤ 160 ft.</td>
<td></td>
</tr>
</tbody>
</table>

Notes to Wall Pressure Table 27.6-1:

1. From table for each Exposure (B, C or D), V, L/B and h, determine $p_t$ (top number) and $p_b$ (bottom number) horizontal along-wind net wall pressures.

2. Side wall external pressures shall be uniform over the wall surface acting outward and shall be taken as 54% of the tabulated $p_t$ pressure for 0.2 ≤ L/B ≤ 1.0 and 64% of the tabulated $p_b$ pressure for 2.0 ≤ L/B ≤ 5.0. Linear interpolation shall apply for 1.0 < L/B < 2.0. Side wall external pressures do not include effect of internal pressure.

3. Apply along-wind net wall pressures as shown above to the projected area of the building walls in the direction of the wind and apply external side wall pressures to the projected area of the building walls normal to the direction wind, simultaneously with the roof pressures from Table 27.6-2.

4. Distribution of tabulated net wall pressures between windward and leeward wall faces shall be based on the linear distribution of total net pressure with building height as shown above and the leeward external wall pressures assumed uniformly distributed over the leeward wall surface acting outward at 38% of $p_t$ for 0.2 ≤ L/B ≤ 1.0 and 27% of $p_b$ for 2.0 ≤ L/B ≤ 5.0. Linear interpolation shall be used for 1.0 < L/B < 2.0. The remaining net pressure shall be applied to the windward walls as an external wall pressure acting towards the wall surface. Windward and leeward wall pressures so determined do not include effect of internal pressure.

5. Interpolation between values of V, h and L/B is permitted.

Notation:

- L = building plan dimension parallel to wind direction (ft.)
- B = building plan dimension perpendicular to wind direction (ft.)
- h = mean roof height (ft.)
- $p_t$, $p_b$ = along-wind net wall pressure at top and base of building respectively (psf)
### Table 27.6-1
MWFRS – Part 2: Wind Loads – Walls
Exposure B

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<th>V(mph)</th>
<th>110</th>
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MINIMUM DESIGN LOADS
7.3 TS

7.3.1 DTS Squeeze Plate

7.3.2 DTS Garage Fit

7.3.3 TS Information

<table>
<thead>
<tr>
<th>Truss Variants</th>
<th>Weight (lbs)</th>
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<td>Plenum</td>
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7.4 RS

7.4.1 DTS RS Designs

Section 1

The first RS, Figure 1.5-12, of the large roof design is a rough 14-foot section. To maintain the exact house dimension the gable truss is measured from the outside to the center of the next member making it smaller than the 2-foot center to center spacing of the other trusses. OSB overhangs 2 foot over the gable truss. OSB will be set starting at the peak of the roof so that the last section remains open. Doing this, allows for the entire roof to be finished at the same time.

Section 2

Section two, Figure 7.4-1, so spans a rough 14 feet. All trusses are 2 foot on center and there is a 2-foot overhang on the common truss connecting to section 1.
Section 3
Section three, Figure 7.5-2 rough 16-foot section. The gable to plenum truss is 2 foot measured from the outside of the gable end. OSB overhangs 2 foot on either side of the section.

Section 1
Section one is a rough 6-foot section. Like Section 1 from the large area roof design, the OSB overhangs 2 foot past the gable truss. The spacing from the exterior gable to the center of the first common truss is 2 feet. The rest of the trusses are 2 foot on center. The first two common
trusses closest to the gable truss have bracing applied at all points indicated in the bracing section. The last common truss only has bracing applied at red and green sections.

![Figure 7.4-4 Small Roof Design Section 1](image1)

Section 2
Section two is a rough 6 feet. Like section one, the OSB overhangs 2 feet to tie into section one. Trusses are set 2 foot on center. Bracing is applied to only the red and green areas as described in the bracing section.

![Figure 7.4-5 Small Roof Design Section 2](image2)

Section 3
Section three is similar in layout to section two for the OSB and trusses. The only change is that plenum trusses replace three of the common trusses. Since there is a transition between TSs, additional bracing is added to two of the plenum trusses and the common truss.
Section 4 and 5
Section four and five are identical. All trusses are plenums. The OSB layout is the same as the previous sections. There is no transitional bracing.

Section 6
Section six is a rough 8 foot. OSB overhangs 2 feet on either side of the trusses. There is transitional bracing between the gable truss and the closest plenum trusses. The gable truss is 2 foot from the plenum truss measured from the exterior to the center of the plenum.

7.4.2 Google Earth Pins

Below is a site map of all the Michigan Habitat for Humanity Affiliates offices or locations.

The pin represented with the Letter “B” is Bergland Township, location used in the foundation calculations.
The pin represented with the Letter “K” is Kalamazoo, the location used in the foundation calculations.