FINAL DESIGN REPORT

Construction Team B1

GNG1103B – Engineering Design

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INTRODUCTION

This document represents a high-level summary of the design process, from initial needs identification to final construction and testing, implemented by our team. This document first addresses the context which motivated the design problem – the client's context, background, and specific needs. Next, these needs are associated with specific design criteria, developed by the team, which are used to evaluate potential existing solutions as benchmarks and to provide a set of target specifications for the final design solution. An overview of the team's preliminary design and analysis is then presented. The prototyping process is then discussed, including modeling, analysis, construction, and testing. Finally, the lessons learned from the design process are discussed in accordance with recommendations for future work.

CLIENT CONTEXT AND REQUIREMENTS

Initial Meeting

To determine the best course of action for the design of our project, we first needed to speak to our client to develop more precise specifications. In the first meeting our client, Monique Manatch, identified a number of problems affecting the Algonquin of Barriere Lake, an Indigenous reserve community in La Vérendrye Wildlife Reserve, Rapid Lake, and the end-users of the project. The houses originally built for the community are riddled with mould and other structural issues and are no longer able to support the growing population. Because of its remote location, the community relies on a generator for power, which is now at maximum capacity. Also, contamination from nearby mining operations has rendered the only nearby body of water unusable for drinking water. Our client, Monique Manatch, identified that ideally the entirety, or at least part of the structure, would be transportable as many families relocate to their hunting camps in the summer months. The community's financial resources are limited and managed by a third party, thus making any conventional solutions to the above problems financially prohibitive. These problems have led the client to seek an alternative, inexpensive housing structure which is better suited to the needs of the community. After inquiring about the above problems, a set of needs was determined from both Monique's initial explanation of the problem and her answers.

Identification of Needs

The following problem statement was developed after careful consideration of the client's needs:

> *There exists a need by the Algonquin of Barriere Lake for a safe, inexpensive, and self-sufficient single-person housing structure capable of being transported between the reserve and seasonal grounds. The structure should generate all of its own electricity, provide an integrated septic system, offer adequate heating, and supply enough potable water for daily needs. Ideally, the structure should be easily assembled, disassembled, and repaired by members of the community, and it should be capable of being joined with similar structures in a modular way. The solution should offer its occupant(s) as much functional space as possible within a 4'x8' structure.*

An initial attempt was made to provide a hierarchy of the specific needs, but subsequent meetings with the client required us to amend the needs and their relative priorities. Thus, the needs are categorized according to their relative classifications (see Table 1).

Table 1: Summary of identified needs and relative priority

Needs Group	Specific Needs			
Structure and Safety	Meets load requirements	Even load distribution	Mold-resistant	-
Self-Sufficiency	Generates all required power Provides potable water Provides adequate heat	Integrated septic system	Energy-efficient	Easily repaired
Cost	Inexpensive	Uses recycled materials	-	-
Modularity	Easy to transport	Reversible, straightforward assembly	Joinable into larger structure	Maximized functional space

STRUCTURE AND SAFETY

Although not explicitly defined as a need by the client, any candidate solution must meet certain structural requirements in order to be considered viable. Most importantly, the structure must be capable of supporting its own weight in addition to all snow and wind loads as required by applicable building codes. Furthermore, the client has indicated that the structure will likely be resting on sand at the target site. In order to prevent the load from shifting, the structure should distribute its load in such a way that avoids it sinking into the ground. The client has also reported that many of the community's current residences are affected by mould. This is quite dangerous as mould exposure can cause minor to severe respiratory issues (Fisk, Lei-Gomez, & Mendell, 2007). Any candidate solution should thus provide adequate moisture and mold resistance.

SELF-SUFFICIENCY

The client has indicated that the structure must be fully self-sufficient with respect to basic services: the structure must provide enough power to operate all necessary electrical appliances, a means of providing potable water, and a system capable of heating the interior. The client has also indicated a desire for an integrated septic system, although this is not a strict requirement for a solution's candidacy. Given the constraints of our available power generation and heating systems, in order to ensure that the services described above can be met, it is necessary to implement these systems in an energy-efficient way. This may include the use of thermal insulation, low-resistance wiring, and automated systems for minimizing energy use. As this section of the project is specifically focused on the basic structure of the shed, the self-sufficiency focus will be on supporting solutions to the self-sufficiency problems implemented by other design teams.

The client has noted that the target community has a shortage of skilled tradespeople. To ensure the solution can meet the continued needs of the users, the structure should be capable of being repaired with available materials and a minimum of skill. Additionally, members of the community should be taught how to make basic repairs and improvements.

COST

Given the strict budgetary constraints of the users, the solution should be as inexpensive as possible. A tentative overall budget of $1000 has been proposed by the course instructor, but this amount should be further reduced if possible. As indicated by both the client and course instructor, this may be achieved through the use of recycled and/or readily-available materials.

MODULARITY

The structure will be assembled off-site and then transported to the target community. The structure may also be moved by end-users from the reserve to seasonal grounds. These two conditions require that the structure can be easily transported, and that assembly is both straightforward and reversible. Constraints on the dimensions of the final structure have made it desirable to be able to join multiple copies into a single structure capable of housing multiple individuals. Whether housing a single individual or having been joined to house several, the structure should be organized in such a way as to maximize the amount of functional space available to occupants.

DESIGN CRITERIA AND BENCHMARKING

In order to provide a framework through which to interpret the suitability of both novel and existing solutions to the client's stated problem, the team developed a set of design criteria. Moreover, the team sought existing products which may serve as solutions to the design problem and compared them in order to inform target specifications for our specific design solution. The developed criteria and specifications of benchmark products were then combined to produce a preliminary set of target specifications.

Design Criteria and Metrics

After carefully reviewing and interpreting the client's needs, a set of design criteria were developed through which to evaluate the performance of any design solution. These criteria were organized according to the needs categories defined above and are displayed in Table 2.

Table 2: Summary of design criteria

<table>
<tr><th colspan="2">Need</th><th>Criteria</th><th>Type of Criteria</th><th>Unit of Measure</th></tr>
<tr><td rowspan="4">Safety and Structure</td><td>Meets load requirements</td><td>Adherence to relevant building regulations</td><td>Constraint</td><td>yes/no</td></tr>
<tr><td rowspan="2">Even load distribution</td><td>Maximum foundation pressure</td><td>Functional</td><td>kPa</td></tr>
<tr><td>Mean foundation pressure</td><td>Functional</td><td>kPa</td></tr>
<tr><td>Mold-resistant</td><td>Mold-resistant</td><td>Functional</td><td>yes/no</td></tr>
</table>

Self-Sufficiency	Generates all required power	Generated power	Functional	W
		Battery capacity	Functional	W·hr
	Provides potable water	Has filtration system	Functional	yes/no
		Storage capacity	Functional	L
		Refill rate	Functional	L/day
	Provides adequate heat	Maximum heat generation	Functional	W
		Maximum heat loss	Functional	W
	Integrated septic system	Has septic system	Functional	yes/no
		Waste capacity	Functional	L
	Energy-efficient	Power efficiency	Functional	percentage
		Thermal insulation	Functional	R-value
	Easily repaired	Made from available materials	Nonfunctional	yes/no
		Mean component life	Nonfunctional	yr
Cost	Inexpensive	Initial cost	Constraint	$CAD
		Maintenance cost	Nonfunctional	$CAD/yr
	Uses recycled materials	Uses recycled materials	Nonfunctional	Yes/No
Modularity	Easy to transport	Number of modular components	Functional	count
		Mass	Functional	kg
		Stackable modular components	Functional	yes/no
	Reversible, straightforward assembly	Number of modular components	Functional	count
		Reversible assembly	Functional	yes/no
		Assembly time	Nonfunctional	person·hr
	Joinable into larger structure	Degrees of freedom	Functional	count
	Maximized functional space	Base dimensions	Constraint	ft·ft
		Fraction of unoccupied indoor area	Functional	percentage

Benchmarking

Using the design criteria outlined in the previous section, much research was done in an attempt to find a similar solution to identify specifications that would need to be improved in our own design. However, the majority of current solutions are either incomparable cost-wise or entirely theoretical designs with no specifications. For the purposes of this class, it was decided to compare exclusively with solutions that provided specifications rather than ideas.

The first product to be compared was The Nugget. As seen in Table 3, the Nugget's features were consistent with the majority of the design criteria, even including many extras such as a trailer hitch and wheels, which provides a solution to the mobility component of the project and a full kitchen and bathroom. However, the cost is around 36 times the budget for the client (Modern Tiny Living, 2017). Thus, the Nugget can be used as a cost goal for the project; if the design from the new shed was to include all of the necessary specifications, the cost should be lower than the cost of The Nugget. This would ensure that the product created would be competitive in its market.

The second product used as a comparison was the MurchTech Durabilt, which was designed as a low-cost housing solution for those with low income living in Canada. In Table 3 it can be observed that the cost of the structure is approximately $7000, which is over budget (MurchTech Consulting Corporation, n.d.). However, when the cost is taken in terms of square feet, it is comparable. In contrast to The Nugget, the MurchTech structure does not include many of the self-sufficiency features required for this project. Thus, this benchmark should be used as a specification goal; if the cost of the shed is comparable to the cost of the MurchTech Durabilt, the shed should include a solution more of the self-sufficiency needs.

Table 3: Benchmark comparison of existing products

Specification \ Product	The Nugget	MurchTech Durabilt
Generated power	Solar panel*	None
Battery capacity	Four batteries*	None
Has filtration system	No	No
Storage capacity (water)	379 L	None
Refill rate (water)	None	None
Maximum heat generation	Propane heater*	None
Has septic system	Yes	No
Thermal insulation	R-28 roof/floor, R-21 walls	R-20
Initial cost	$36,000	$7,560
Uses recyclable materials	No	Yes
Mass	2045 kg	**See discussion below**
Base dimensions	12' x 8.5'	12' x 18'

**Specifications do not correspond directly to design criteria*

Overall, the specific budgetary constraints of the target users makes both of the above products largely unsuitable as benchmarks for solution performance. More suitable existing products were sought but, given manufacturing and labor costs (excluded from our budget), no products were found which adequately meet the constraints of the design problem to serve as suitable benchmarks.

Target Specifications

A number of target specifications were developed jointly from solution constraints, the benchmarking analysis, and preliminary analysis of the design problem. When the specifications were developed, a number of values could not be reliably estimated as they were contingent on values which could not be known. Nevertheless, the target specifications, as they were at the time of the creation, are presented in Table 4.

Table 4: Target specifications

Criteria	Relation	Value	Units of Measure
Adherence to relevant building regulations	=	Yes	-
Maximum foundation pressure	<	*	kPa
Mean foundation pressure	<	*	kPa
Mold-resistant	=	Yes	-
Generated power	>	*	W
Battery capacity	>	*	W·h
Has filtration system	=	Yes	-
Storage capacity	>	*	L
Refill rate	>	*	L/day
Maximum heat generation	>	*	W
Maximum heat loss	<	*	W
Has septic system	=	Yes	-
Waste capacity	>	*	L
Power efficiency	>	*	-
Thermal insulation	>	*	R-value
Made from available materials	=	Yes	-
Mean component life	>	5*	yr
Initial cost	<	1,000	$CAD
Maintenance cost	<	100	$CAD/yr
Uses recycled materials	=	Yes	-
Number of modular components	>	6	-
Mass	<	1600*	kg
Stackable modular components	=	Yes	-
Number of modular components	<	12*	-
Reversible assembly	=	Yes	-
Assembly time	<	6	person·hr
Degrees of freedom	>	1	-
Base dimensions	=	4·8	ft·ft
Fraction of unoccupied indoor area	>	0.50*	-

CONCEPTUAL DESIGN AND PRELIMINARY ANALYSIS

Following the development of design criteria and metrics, the team developed a number of ideas for subsystems to provide potential solutions. A full treatment of conceptual design activities can be found in our previous conceptual design deliverable, but the following discussion contains a summary of some more significant aspects of our conceptual design work and preliminary analysis.

Note that the design of the primary structure was determined largely by the course instructors, and so the following discussion concerning the overall structure of the shed is descriptive of the work that has been completed, rather than indicative of the team's intent for its final design.

Primary Structure

As specified by the course instructors, the primary structure of the shed was to be constructed by connecting three 4’x8’ sheds, with the overall shed design containing a shorter central shed with taller sheds connected on opposite sides. This arrangement is depicted in Figure 1.

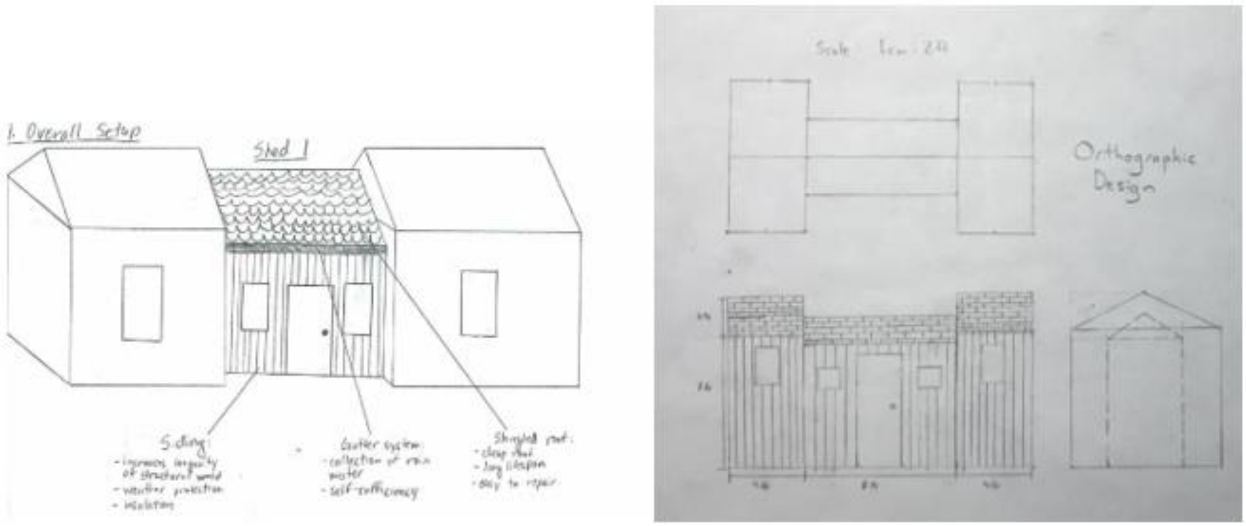


Figure 1: Overall shed design

The smaller, central shed was constructed by our team. For the design of this shed, the floor was first constructed by laying support beams across the deck piers. Afterwards, multiple wooden beams were nailed perpendicular to the support beams. This connected the support beams and provided a frame-like structure for the floor. To complete the floor, plywood was nailed on the top of the structure.

Next, the framework of the walls was constructed by attaching vertical 2”x4” studs between the top plate and bottom plate. The top plate is the wooden beam above the vertical studs while the bottom plate is the beam below. The walls were attached to the floor modularly, as shown in Figure 2.

Once the walls were attached, trusses were constructed for the roof. To construct the trusses, rafters were created by cutting two pieces of wood on an incline. These rafters were then connected to the ridge board. To support the roof structure, a collar tie and rafter tie were nailed to each pair of rafters, as shown in Figure 3.

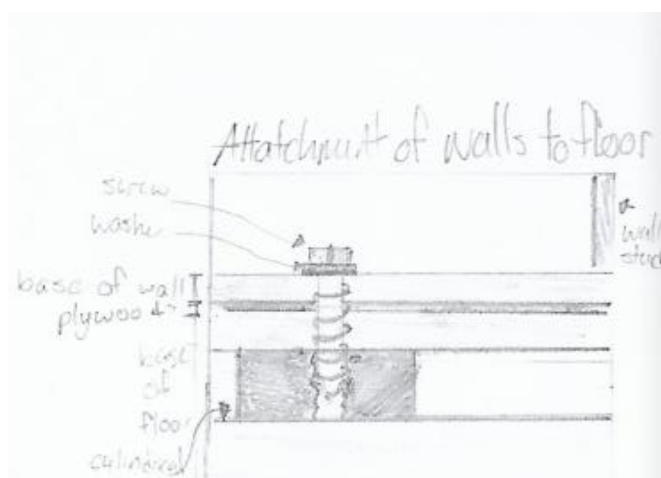


Figure 2: Wall-attachment mechanism

Once the entire framework of the shed was completed, plywood sheets were attached to each side of the shed. Each side, except the front side, was painted over. For the front side, additional plywood siding was to be nailed on top of the sheets. For the roof, plywood sheathing was to be nailed on top of the rafters and asphalt shingles would be layered onto the roof. After completing the roof and walls, two windows and a door were to be attached to the front of the shed, as shown in Figure 4.

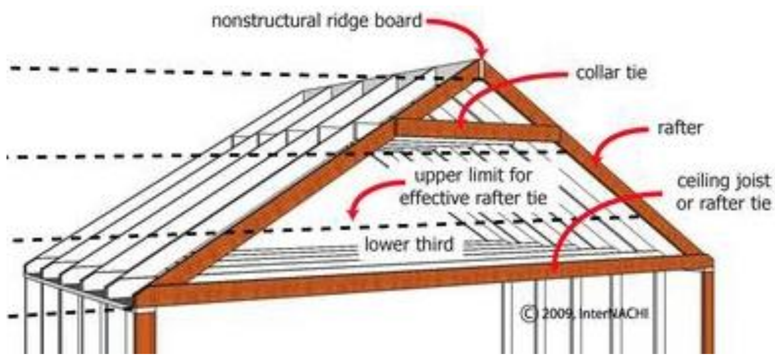


Figure 3: Truss structure for shed roof
Source: Channell, J.(2011, February 13)

Upon completion of the structure, the other teams are expected to implement their designs to make the shed self-sufficient. The solar team will attach solar panels to the roof of the shed to absorb energy. The water team will create the gutter system to help collect rainwater from the roof. The automation team will integrate electronic devices into the shed.

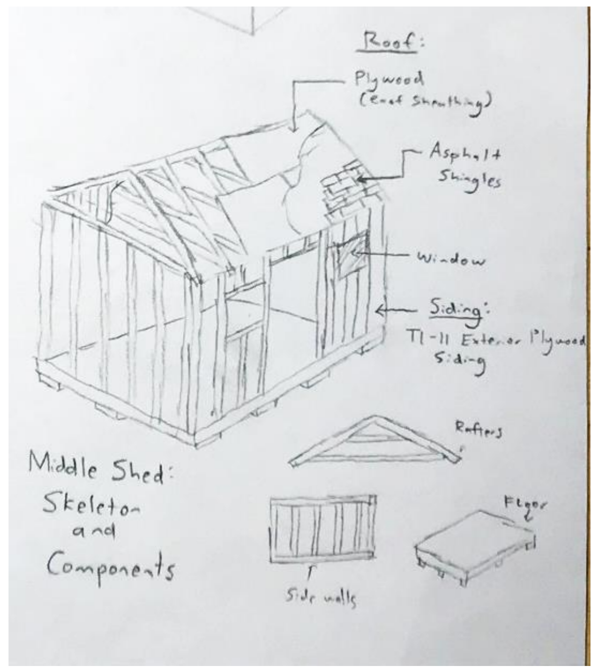


Figure 4: Skeleton view of central shed

Solar Panel Mount

The addition of a solar panel to the shed to provide the necessary power to the other components required some design analysis to have the most cost efficient and suitable design. Our team had to develop and analyse several options to provide the best choice available. After some research we found two main options that can be used, either a fixed mounting bracket or an adjustable tilting mechanism to change the angle of the panel according to the seasonal position of the sun.

Our first simple option was a fixed bracket that would be attached in the middle and highest point on either side of the roof. This bracket would be held in place with 4 screws on all four corners. While this gave the lowest cost possible to mount a solar panel, it surely wouldn't give the full potential in producing electricity due to change in solar irradiance through out the seasons. In our case, it was still enough energy to power necessary components in the shed. Using computer design software, we were able to design the panel mount and implement it on our shed. The design is shown below.

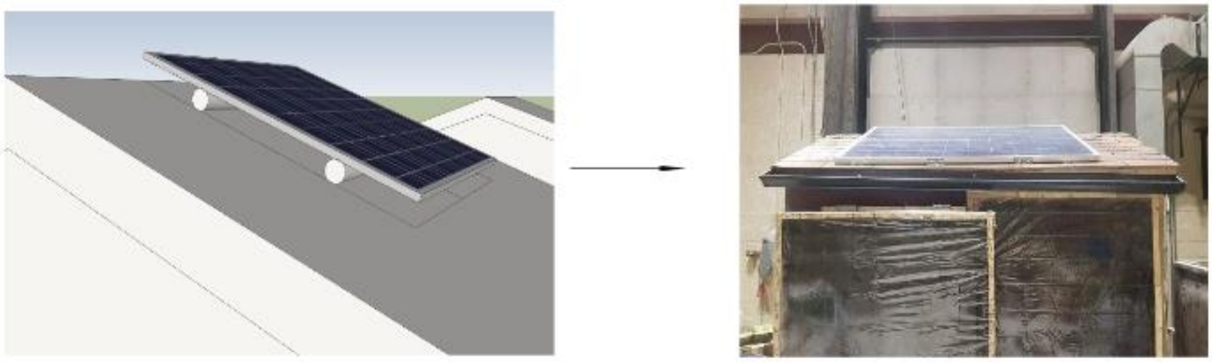


Figure 5: Concept and actualization of fixed solar panel mount

While the fixed design surely suited our structure needs, we still considered a tilting mechanism in the case that the calculated energy needs could only be met throughout the seasons with such design. A tilt-enabled bracket allows for adjustment of the solar panel according to optimal seasonal angles, thus maximizing the amount of power generated by the solar panel. In Ottawa, optimal angles vary between 22 and 68 degrees. Our team had to leave this in mind and have such bracket available to order. We found that the best, most reliable option was to order it from Amazon in case we needed it as the student Prime shipping would deliver it within 1-2 business days.

Our main concern was to meet and exceed the client needs. Prior to choosing which of the design options above is more suitable, we had to consider solar irradiance in our location. Every option had its advantages and disadvantages. The fixed bracket option saves the cost of a tilt enabled bracket that can cost anywhere between $30-$100 although the power supply might be limited. Since our budget was limited, our best option was to go with a fixed bracket and to ensure it was set at the best possible angle to mediate between all seasons and produce the electricity needed. The solar irradiance calculations and diagrams are shown below.

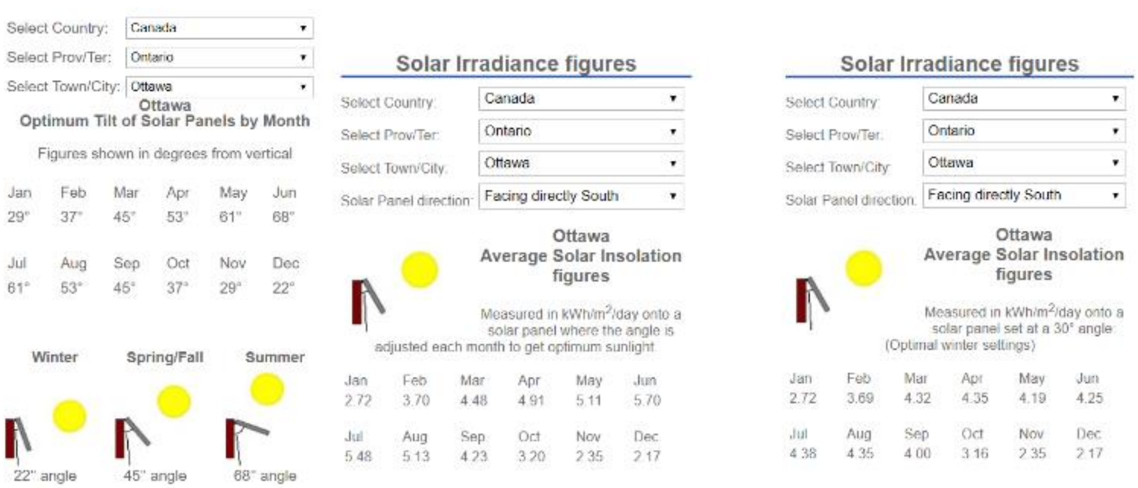


Figure 6: Optimal angles and solar irradiance figures for fixed and tiltable panels, Ottawa
Source: Solar Electricity Handbook (n.d.)

Snow Load Analysis

An important constraint identified in our Design Criteria deliverable is that the structure meets defined snow-load requirements. The Ontario Building Code (BuildingCode.Online, n.d.) defines an upper limit state (ULS), which ensures a structure does not collapse during peak load capacity, and serviceability limit state (SLS), which ensures a structure can remain functional for its intended use, according to a snow-load equation which is dependent upon the type, form, and location of a structure: $S = I_s[S_s(C_b C_w C_s C_a) + S_r]$.

The values of the above factors have been obtained from the properties of the structure and the intended location of use:

Importance factor: $I_s = 1$ for ULS and $I_s = 0.9$ for SLS as the structure is a normal residential building

Roof snow-load factor: $C_b = 0.8$ given the small size of the structure's roof

Wind-exposure factor: $C_w = 0.75$ as the structure falls within the normal importance category

Slope factor: $C_s = 1$ as the roof of the structure has a slope near 30 degrees

Shape factor: $C_a = 1$ as the roof of the structure has no curvature

Ground snow-load: $S_s = 2.5$ according to 1-in-50-year data corresponding to the target location

Rain load: $S_r = 0.4$ according to 1-in-50-year data corresponding to the target location

Substituting the above values into the snow-load equation yields the following ULS and SLS for the structure:

$\text{ULS} = 1.9 \text{ kPa}$

$\text{SLS} = 1.71 \text{ kPa}$

PROTOTYPING PROCESS

Given the attendant time constraints of the project, the team decided that it was prudent to focus efforts on a single, significant aspect of the design. Thus, prototyping efforts were focused on integrating the bed with necessary amenities to effectively utilize the space within the structure. This aspect of the design was chosen over other ideas developed during the conceptual design phase for several reasons:

- The design of the primary structure was determined almost exclusively by the lab instructors and was, in fact, nearly completed at the time prototyping design work was initiated
- The design of the solar panel and related systems was delegated primarily to another team, and there was no guarantee that they would implement a solution developed by our team
- Without developing a space-efficient solution for integrating the bed and required amenities, there would be inadequate space within the structure to suit its purpose as a residence

The prototyping process was conducted in three stages. The first stage involved developing a zero-cost model (excluding labour) through which to analyze the feasibility of the design. The second stage required adapting this model to address concerns raised in the first model and to provide higher-fidelity analysis. The final stage was concerned with the construction and testing of a functional prototype in accordance with the models previously developed. This three-stage process is summarized below. For additional details concerning the prototyping process, consult the earlier prototyping deliverables.

Preliminary Modeling and Analysis

Given the zero-cost requirement, a CAD model was developed in preference to a physical model. Not only is such an approach more cost-effective, it also allows for analysis which would be infeasible in a physical model. Specifically, this first CAD model was developed to:

- Determine whether or not the folding bed can be accommodated given the dimensional constraints of the structure
- Evaluate the functional space in the structure when the bed is in horizontal or upright position
- Determine the material requirements and cost of the bed
- Determine the mass, center of gravity, and forces on the bed to inform methods of joining components and restraining the bed in the upright position and to determine whether or not a mechanism for assisted lifting is required

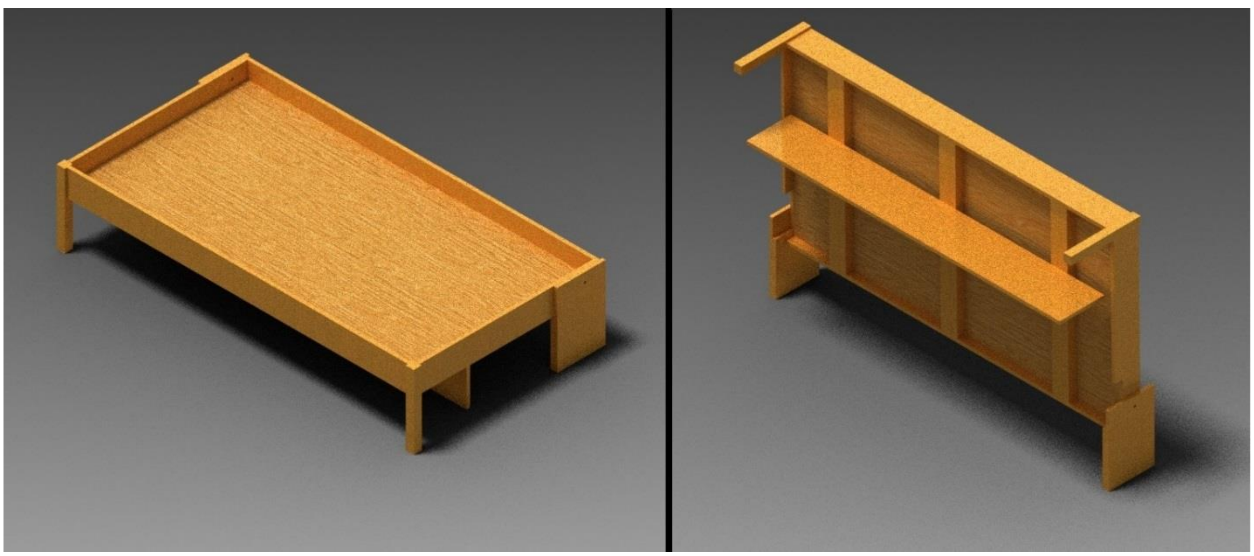


Figure 7: Isometric CAD visualization of first prototype

DIMENSIONS AND FUNCTIONAL SPACE

In this first model, two dimensional constraints on the size of the bed were recognized: a twin-sized mattress ($39" \times 75"$) represented the lower bound and the interior dimensions of the structure, after accommodating interior studs and drywall ($40.25" \times 88.25"$), represented the upper bound. The minimum width of the bed itself was found to be $40.5"$, exceeding the interior width of the structure and rendering this solution infeasible.

Despite the infeasibility of this solution, additional dimensional analyses were conducted to provide insight into the requirements for the next iteration of the prototype model. Since the bed is required to rotate through an arc, the maximum projected width is even greater than the minimum width specified above. For this model, that maximum width was determined to be $w_{proj} = d + \sqrt{w^2 + h^2} \cong 44.81 \text{ in.}$

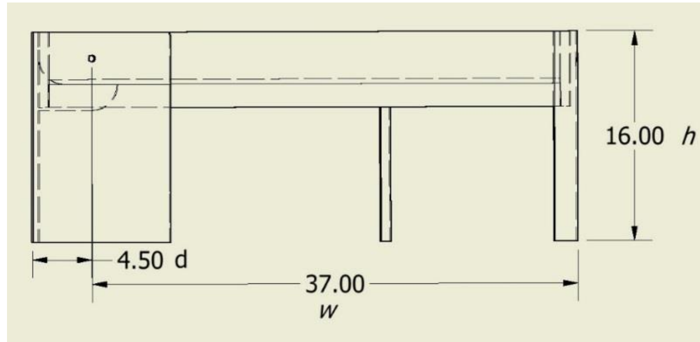


Figure 8: Relevant parameters for maximum projected width

In accordance with our design criteria, it was also necessary to consider the total space occupied by the bed in both upright and horizontal positions. This was calculated as the ratio of the projected area of the bed onto the floor plane to the total interior area of the shed. For this model, the area occupied in the horizontal and upright positions, respectively, was found to be $F_h = \frac{78.00 \times 41.50}{40.25 \times 88.25} \cong 91.1\%$ and $F_u = \frac{78.00 \times 16.00}{40.25 \times 88.25} \cong 35.1\%$.

MATERIAL REQUIREMENTS AND COST

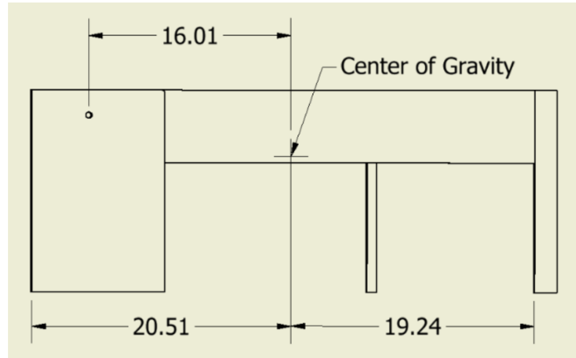
Despite the dimensioning problems discussed above, any implementation of the prototype would be on roughly the same scale and composed of similar materials. For these reasons, a cost estimate was produced for the given model despite the need for changes in subsequent iterations.

The materials were selected by grouping bed components according to common dimensions and finding available sizes from Rona which minimized overall cost. Specific hardware requirements were not considered in this prototype, so their cost was estimated at 20% of the combined cost of lumber.

Table 5: Cost estimate for first prototype

Material	Unit Cost	Quantity	Total Cost
Knotty pine – 1”x6”x8’	$13.59	3	$40.77
Knotty pine – 1”x12”x6’	$20.29	2	$40.58
Spruce – 2”x4”x7’	$1.84	2	$3.68
White pine – 2”x2”x6’	$5.39	1	$5.39
Fir plywood – 3/8”x4’x8’	$19.03	1	$19.03
		Subtotal	$109.45
		Hardware (20%)	$21.89
		Tax	$17.07
		Total	$148.41

PHYSICAL PROPERTIES



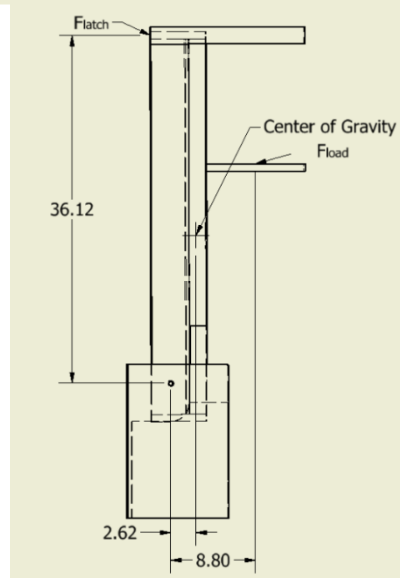


Figure 9: Moment arms for latch and lift force analysis

Several physical characteristics of the bed were estimated by analyzing the CAD model. These properties were mass, required lifting force, and required latching force. Simplifying assumptions, detailed in previous deliverables, were made to expedite the analysis. The mass of the bed, computed by assigning built-in materials to each component of the model in Autodesk Inventor, was found to be $66.5\ \mathrm{lbs} - \mathrm{mass}$. This mass, and the center of gravity of the assembly as determined in Inventor, was used in simple torque analyses to provide estimates of the lifting and latching forces.

Although the lifting and latching forces are dependent upon the specific dimensions and materials assumed in the model, minor changes to the model would result in commensurately minor changes to these values. The required lifting force was found to be $30.2\ \mathrm{lbs}$, well within the physical capabilities of an expected user and thus eliminating any need to design an assisted lifting mechanism. The latching force, considering both the weight of the bed and a uniform $100\ \mathrm{lb}$ load applied to the table, was found to be $14.6\ \mathrm{lbs}$. This value is well within the bounds of standard latching hardware and precludes any need to redesign the bed to accommodate working loads at the table.

Revisions to Design

The second prototyping phase required redesign of the CAD model to rectify the inconsistency between its dimensions and the limits set by the size of the structure. A number of other changes were made, as specified in the second prototyping deliverable and restated here for convenience:

- The bed has been narrowed to meet the dimensional constraints of the structure
- After discussion with the water design team, the counter has been lowered to increase water pressure; it has also been extended to provide more counterspace and to accommodate a sink
- Hardware requirements and costs have been included
- Mattress weight and subassembly-specific center of gravity have been calculated to provide a more accurate estimate of latching and lifting forces

Overall, the second prototype was developed to:

- Determine whether or not the revised bed meets the dimensional constraints of the structure
- Recalculate the functional space in the structure given changes in the bed's width

- Determine hardware requirements and costs
- Calculate, with higher fidelity, the mass, center of gravity, and forces on the bed
- Ensure the dimensional consistency and alignment of all components and hardware to provide a basis for technical drawings and construction workflow (this is not included explicitly in this deliverable, but is implicit in the constrained assembly used for the CAD model and drawings presented throughout the document)

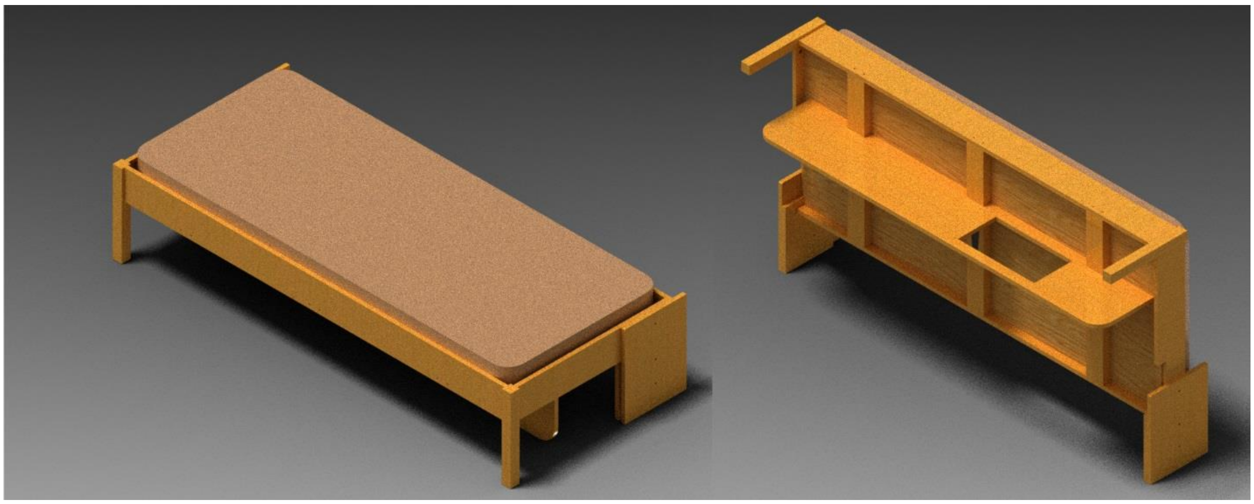


Figure 10: Isometric CAD visualization of second prototype

After making revisions to the design, all properties determined for the previous prototype were recomputed. A number of simplifying assumptions were dropped in order to provide a more accurate estimate of the characteristics of the final prototype. Again, the assumptions made for both models are detailed in their respective deliverables. The following table provides a comparative summary of both prototypes.

Table 6: Comparison of properties of first and second prototypes

Property		Prototype I	Prototype II
Dimensions	Width	40.5"	34.0"
	Length	78.0"	78.0"
	Maximum width	44.81"	38.25"
	Required space (horizontal)	91.1%	74.7%
	Required space (upright)	35.1%	35.1%
Physical	Total mass	66.5 lbs – mass	72.6 lbs – mass
	Mass of rotating subassembly	not computed	66.1 lbs – mass
	Required latching force	14.6 lbs – force	18.9 lbs – force
	Required lifting force	30.2 lbs – force	30.4 lbs – force
Cost	Estimated cost	$148.41	$173.41

Construction and Testing

Prior experience with lumber dimensions and a rigorous approach to constraining the CAD model in Inventor ensured that there were minimal difficulties encountered during the purchase of materials and construction of the prototype. Nevertheless, three minor issues were encountered. First, estimates of the actual dimensions of 12” nominally-sized lumber were inaccurate by 1/2”, requiring a small redesign of the bed’s supports. Second, where the hanger bolts connect to the rails and supports, the original design specifications failed to provide enough space to fit a wrench with which to tighten the bolts (Figure 11). Accordingly, these cavities had to be enlarged manually – a time-consuming process which added significantly to the labour requirements for the bed’s construction. Lastly, the prototype was designed such that the supports secured directly to the drywall; since no drywall was installed in the shed, horizontal studs had to be installed between the vertical studs on the structure’s rear wall in order to provide proper alignment with the bed’s supports.

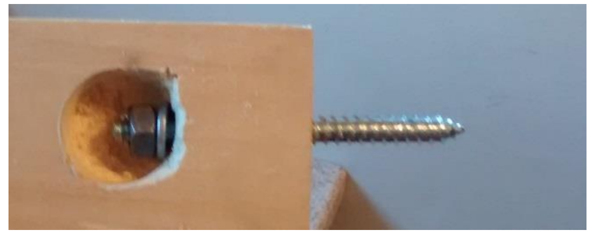


Figure 11: Original specification for hanger bolt cavity

Given the tight timeline for the shed’s final construction, there was insufficient time to perform formal tests on the bed as other design teams needed immediate access to the structure. Nevertheless, the dimensional consistency of the bed through its full range of motion, as well as the rigidity of its frame, were immediately evident upon installation. Additionally, the built-in counter was used extensively by the other design teams as a work surface during the installation of their subsystems, suggesting strongly that it would stand up to its intended usage by the client.

LESSONS LEARNED AND RECOMMENDATIONS FOR FUTURE WORK

Given the scope of the design project and the number of people involved, it was inevitable that difficulties would arise. Most of these issues were organizational in nature, reflecting a poor allocation of time and resources and an overall lack of communication between design teams.

The size of our team made it infeasible to hold regular meetings outside of class, and thus we were limited to three hours each week to handle design, construction, and organizational tasks related to the project. Although the team used an online platform to communicate and to share files, the limitations of this approach were evident, especially with respect to making important design decisions, as conversations could not be held in real-time with all group members. In the future, the team would benefit from having more time where they could meet to discuss and work on the project.

A lack of regular communication posed issues for the integration of the subsystems within the structure. The problem with this lack of communication was not evident until the final stages of construction, where inconsistent assumptions about design elements between teams required ad-hoc design changes in order to ensure successful installation of each teams’ respective systems. Regular meetings between team leaders throughout the course of the project may have rectified this issue, but such meetings run up against the time constraints defined above.

Overall, the design project was an effective introduction to the importance of time and resource management practices and a tangible demonstration of the difficulties which arise when such practices are inadequate for the given project.

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