Deliverable J: Final Design Report
Engineering Design
GNG1103

Construction of a Self-Sustainable, Modular Shed

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Abstract

This project required us to design and construct a modular, self-sustainable shed for the Algonquins of Barriere Lake Reserve. The shed needs to have basic utilities which included running water, heat, and electricity. The shed will be a prototype for future self-sustainable, modular homes. Our lab section designed and built the shed together, with 4 teams assigned to construction, solar, water and automation. This report was written by the construction team for shed 2, whose responsibilities were focused on the design and construction of the shed.
The report will cover all aspects of our project from meeting with our client to defining the design criteria of the shed, benchmarking the design criteria, brainstorming concepts to add to the shed, prototyping and testing, and presenting our final solution as we, the construction team, worked to provide a solution to our client's problem. Our report will conclude with what we have learned as a team and things we would do differently if we did this project again.

Introduction

Ottawa is Canada's Capital City, known for Parliament Hill, the Rideau Canal and Beaver Tails. However just three hours north from this wonderful city is Mitchikanibikok Inik (The Algonquins of Barriere Lake), a reserve that is home to 400 indigenous peoples. Current problems on the reserve are as follows:

- The current housing is inadequate for the harsh climate
- The generator is operating at maximum capacity and is unable to support any new buildings
- Local water sources are contaminated
- Sewage systems are non-existent
- Heat is currently being generated under unsafe conditions

The reserve has a need for domestic structures that are self sustainable, cost effective and durable.

Our lab section was entrusted with the design and construction of these structures for our client; Monique Manatch. Since it would be impractical to build full-sized houses, it was agreed upon that the structures would be made on a smaller scale (sheds) and if the project was successful, apply everything to a larger scale. After the initial meeting with our client, it was clear that the users' needs for the structure were:

1. It had to have a heating system, a water collection system and a running water system
2. It was eco-friendly, modular and cost-effective

Dr. Muslim Majeed, Dr. Gamal Elnabelsya and the course TAs split the lab sections into 3 sheds, with 4 teams assigned to each shed. Multiple sheds were built in hopes of connecting all three sheds nearing the end of the construction phase. The four teams involved were construction, solar, water and automation. This report was written by the construction team for shed 2, whose responsibilities were focused on the design and construction of the shed. The solar team was responsible for providing heat to the shed and heating the water with solar panels, the water team was responsible for water collection and the water flow throughout the structure and finally the automation team was responsible for coding and wiring the automation system (fail-safe override, controlling how the water/lights was turned on or off). Each team was given a budget of $100.00 except for the construction team which had to budget.

Key features that our team implemented were:

1. A modular design, which is extremely important because the sheds needed to be easily transported from the structures lab to the reserve
2. Hammocks instead of beds. This provided more interior space because the hammocks could be taken down at a moments notice
3. A wood furnace. Although this may not be a renewable source of energy, it would provide extra heat during exceptionally cold nights if needed

Empathize

Our client, Monique Manatch, a resident of the Barriere Lake Reserve in Quebec commissioned our class to design and build a net zero home that could be assembled at the reserve for additional housing. She stated that the residents at the Barriere Lake reserve have a need for a domestic structures that are self sustaining, cost effective, and climate appropriate. These structures must be self sustainable as the reserve's generator is already currently operating at maximum capacity and the local water sources are contaminated. Sewage systems are non-existent and heat is currently being generated under unsafe conditions. The reserve is located 3.5 hours north of Ottawa and is accessible only by air or ATV. The location is on the Canadian shield and suffers from erosion. There is a high unemployment rate; there are few-to-no repairmen in the area. Currently, there are 10-12 people living in 1-2 bedroom houses. It is imperative that the structure is cost-effective as the financial resources of the reserve are managed by a third party.

After meeting with our client, we completed a needs identification. From the information provided by our client, the shed needs to meet the following criteria:

- Low maintenance
- Green materials
- Withstand year-round climate
- Modular
- Provide basic utilities (potable water, sewage removal, heat, and electricity)
- Cost-efficient
- Self-sustainable

We also established the following the identified who we would be catering our design to:
The user (residents of Barriere Lake Reserve), client (Monique Manatch), and customer (3rd party financial group Deloitte).

Define

With the above needs identified, we concluded that the problem could be defined by the following problem statement.

"The residents on the reserve near Barriere Lake have inadequate housing and are missing basic utilities. A shed that is self sustainable, durable and cost effective with the basic utilities will be provided to the residents to inhabit."

Our solution was to create and build a shed that is self-sustainable, durable, and cost-effective; being able to provide electricity, heat, and water for the residents.
After establishing a base with a our clients needs and wants for the design of the shed, developing a problem statement. We then proceeded to create the design criteria for our shed. This was important to do, because it gave us a concrete base of what our shed needed to accomplish, as well as setting what constraints we would be facing in our design. Using the problem statement as well as the identified needs of our shed design we created the design criteria for our shed with the following table (Table 1).

	Design Specifications	**Relation (=, < or >)**	**Value**	**Units**	**Verification Method**
	Functional Requirements				
1	Needs to be low maintenance	=	Yes	N/A	Analysis
2	Weight Supported: Roof	=>	1 + solar panel	KPa	Analysis
3	Weight Supported: Floor	=>	Weight of shed + loads	lb	Analysis
4	Have electrical power	=	130	W	Testing

5	Lighting	=	Yes	N/A	Testing
6	Running water	=	Yes	N/A	Testing
7	Needs to withstand high wind	=	Yes	N/A	Analysis
8	Modular design	=	Yes	N/A	Testing
9	Opening window/ Cooling	=	Yes	N/A	Testing
10	Heating	=	Yes	N/A	Testing
11	Bedding	=>	1	Person	Testing
	Constraints				
1	Cost efficient	<=	1,500	$	Cost estimation Final calculation
2	Operating conditions: Temperature	=	-40 to 40	°C	Analysis
3	Weight of the shed	<=	Max load of worksho p crane	N/A	Measurement
4	Size	=	4X8X10	ft	Measurement
5	Transportable	=	Yes	N/A	Analysis
	Non-Functional Requirements				
1	Colour of the shed	=	Yes	N/A	Test
2	Mold resistance	=	Yes	N/A	Test
3	Safety	=	Yes	N/A	Test
4	Product life	=>	35	Years	Test
5	Design of Interior	=	Yes	N/A	Analysis
6	Shape of door and window	=	Yes	N/A	Analysis

Table 1

Ideate

After creating the design criteria for our shed, we needed to make sure that the design for a net-zero shed was competitive with the market. We wanted our shed to be a versatile asset to our own client as well as provide opportunity for future development and launch into the marketplace. Researching several designs already on the open market that filled some or most of our design criteria, we were able to benchmark these sheds so that we might produce a good design. The compact homes that we chose were researched by the internet and chosen based on following as close to our criteria as was available.[1,2,3,4,5] We formatted the gathered information from the compact houses into the following table (Table 2)

	Nomad Micro 	Single-section mobile home 	Hive Modular 	Lighthouse 	Neptune 
Company	Nomad	Wholesale Housing	Hive Modular LLC	Camera Buildings	Kent Homes
Cost	less than $30,000 (CAD)	$ 65,000 - 70,000 (CAD)	$249,200 - USD ($327,000 CAD)	$30,000 (CAD)	$60,000.00 to $80.000.00 (CAD)
Transportable	Yes	Yes	Yes	Yes	Yes
Size	100 sq. ft.	500 sq. ft	1780 sq. ft.	100 sq. ft	217 sq. ft.

[1] (n.d.). Products - NOMAD Micro Homes. Retrieved April 9, 2018, from http://www.nomadmicrohomes.com/products/
[2] (n.d.). Single Wide Brochure | WHOLESALE HOUSING INC - mobile homes .... Retrieved April 9, 2018, from http://wholesalehousing.ca/fairmonts-popular-floorplans/mobile-brochure/
[3] (n.d.). Hive Modular. Retrieved April 9, 2018, from http://www.hivemodular.com/
[4] (n.d.). Tiny House Design: Plan Your Prefab Camera Buildings Home. Retrieved April 9, 2018, from http://camerabuildings.com/design.php
[5] (n.d.). Neptune - Kent Homes. Retrieved April 9, 2018, from http://kenthomes.com/Microhome-Neptune/

Window	2	5	Low Emission, Argon-filled windows	4 windows and 2 windows on roof	5 windows and 1 window on the roof
Heating	Yes	Yes	Yes	Yes	Yes - Propane
Modular	Yes	No	Yes	No	Yes
Self-Sustainable Water System	Yes	No	No, can be added	No, can be added	No, or open tank
Self-Sustainable (Electricity)	Nomad Solar	No	No, can be added	No	Propane Tank
Sewage System	Septic field or composting toilet	No	Yes, but not self-sustainable	No, can be added	Yes, a tank
Bathroom	Yes But no shower	1	3	Yes and a shower	Yes
Bed #	1	1	3	1	1

Table 2

After benchmarking the compact houses we determined which compact house was the best design to base our own design off. We did this by using a ranking system we created that reflected the priorities of the client and users. The ranking system weighted cost at a 5 because the shed is a smaller scale of what will be a bigger house with a bigger budget, so to produce a high quality product at minimal cost would benefit our client greatly. We also prioritized heating as a 5 due to the inclement weather and tough climate. Finally, self-sustainability (electricity) and # of beds were also ranked 5 because the reserve's generator was at maximum capacity and the shed needed to house more than one person. We ranked the the five sheds using a simple point scheme where each colour represented which shed placed first in that category, which was then multiplied by the "weight" of each category. (Table 3)

	Importance (Weight)	Nomad Micro	Single-section mobile home	Hive Modular	Lighthouse	Neptune
Company		Nomad	Wholesale Housing	Hive Modular LLC	Camera Buildings	Kent Homes
Cost	5					
Transportable	4					
Size	1					
Window	2					
Heating	5					
Modular	3					
Self-Sustainable Water System	4					
Self-Sustainable (Electricity)	5					
Sewage System	4					
Bathroom	2					
Bed #	5					
Total	40	30.66	12.66	35	24	30.66

Table 3

Our Ranking System We Created for colour values:
Green--------1 Yellow-------⅔
Orange-------⅓ Red ----------0

Even though the Hive house had the highest rating, its price is beyond the clients budget, so it was not a good model to follow. Instead we followed the Nomad house since it scored second

and its price is significantly cheaper and much closer to what our budget would allow. The client meeting impacted the development of our design criteria and specifications; and impacted which criteria is relatively more important. During our first client meeting when we discovered that the shed will be in a cold environment, we made heating have a very high priority. Also the self-sustainability of the house became very important in our design criteria because we were told that the shed will be located in a deep forested area. Finally the size was determined to be the least important in our design criteria because of our limited budget. This is why in our design criteria we chose the heating and self sustainability to have the highest weighting; and this also explains why the size of the shed has one of the lowest weightings.

After creating the design criteria and benchmarking five different sheds currently in the market, we got together as a group and brainstormed various conceptual designs and components of the shed by drawing sketches of conceptual ideas that would provide a solutions to any of the design criteria. Once the brainstorming had been completed, we analyzed the ideas that had been generated and concluded that the best three options focused on portability, self-sustainability, and utilities. The first idea was to make the shed portable by having bolted joints that attach the walls, floor, and roof of the shed (Figure 1). This will allow the shed to be dismantled for compact storage and transported easier. The second idea was to make the shed self-sustainable by keeping the water tank(s) in the attic for storage (Figure 2). This concept allows for maximization of living space and allows gravity to move the water throughout the house instead of using a pump. The third and final idea was to make a wood furnace for creating power in emergencies (Figure 3). The furnace would be beneficial if the solar panel was damaged or if the resident needed additional heat than what the solar panel could generate. The following sketches show the concepts generated in the brainstorm session followed by a short explanation of why the concept was selected.

Sketches

Subsection 1: Portability (Bolted Joints)

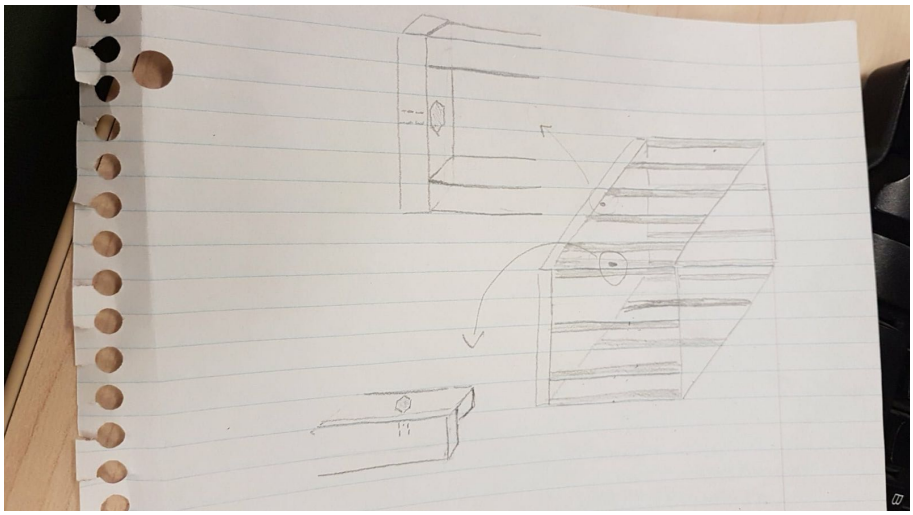

Figure 1

We chose this concept because it allowed the shed to be modular. The shed did not require a complicated assembly process which allows the residents on the reserve to assemble these sheds by themselves with a few written instructions. These joints are also beneficial during the transportation process because the shed can be compacted into smaller components rather than one big entity.

Subsection 2: Self-Sustainability (Water Tank in the Attic)

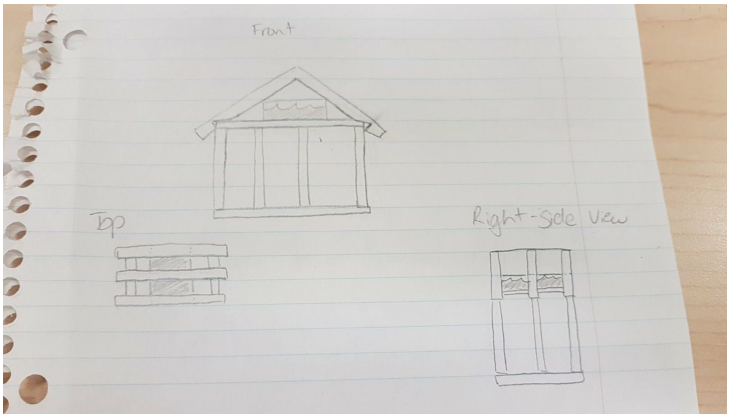

Figure 2

We chose the concept of putting a water tank in the attic to eliminate the use of a pump. This design relies on gravity to feed water through the system and would require less electricity consumption.

Subsection 3: Utilities (Outdoor Wood Furnace)

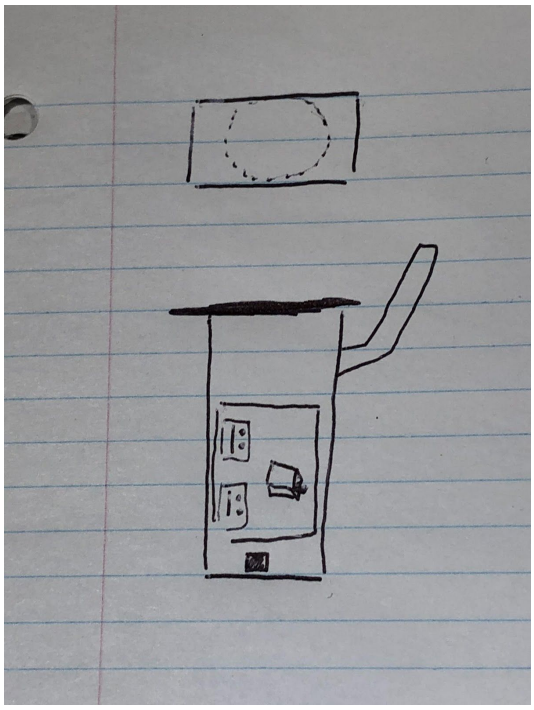

Figure 3

We chose the concept of installing a wood furnace for additional heat.This was not a mandatory component of the shed but allows for extra heat to be generated in an emergency. In the event the heating or solar system is damaged or fails, the residents will need a way to produce heat. Although the furnace will not use renewable energy, it will be effective during cold periods.This would allow the shed to be heated without consuming energy from the battery.

Our Final Design

AutoCAD diagrams of our shed are shown below in figures 4 through 7.

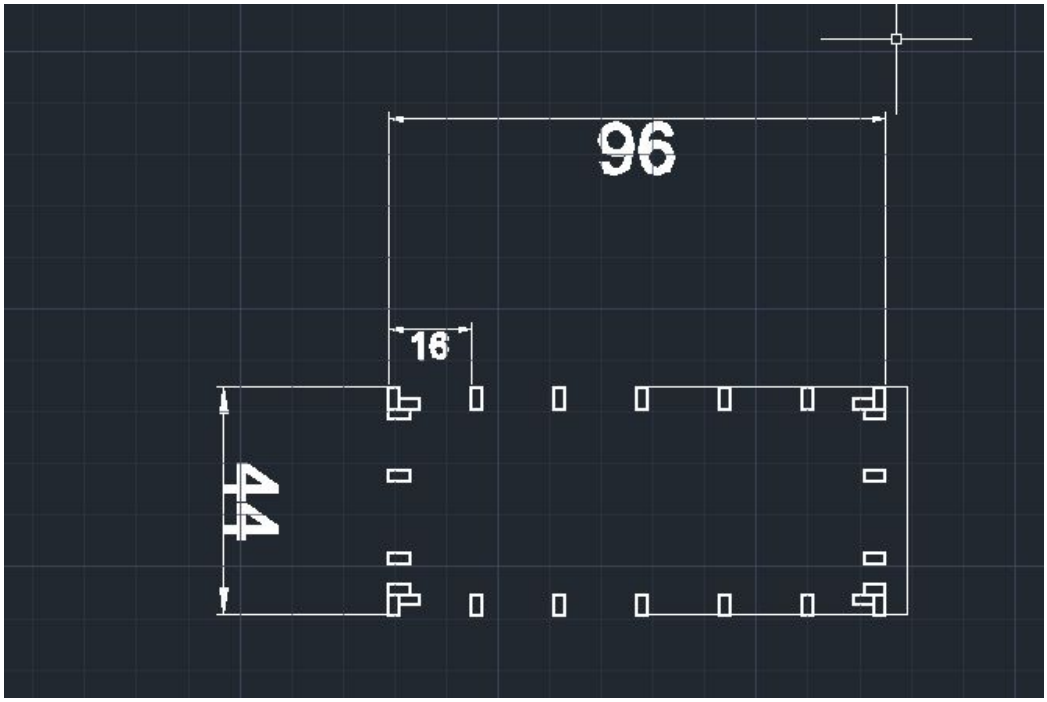

Figure 4

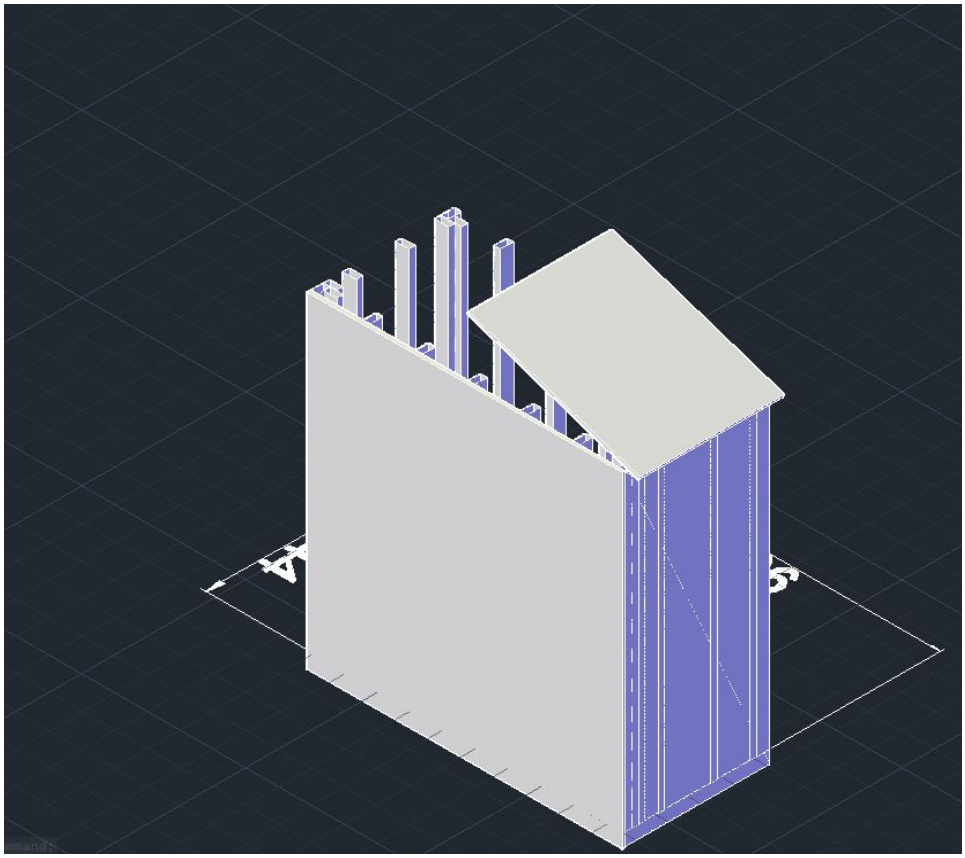

Figure 8; Back view of splinter board used

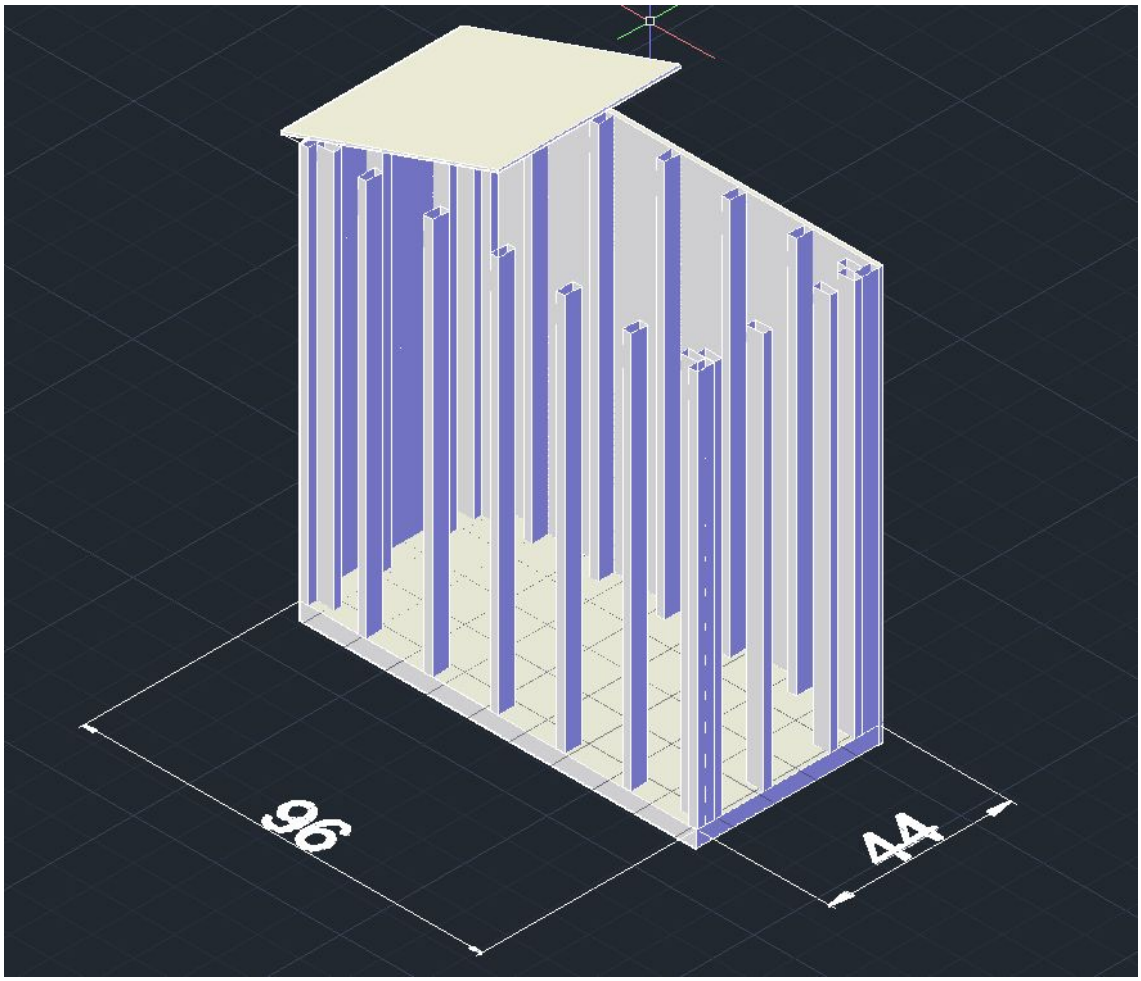

Figure 6

Project Plan

To complete our project, we followed the design process steps: Empathize, Define, Ideate, Prototype, and Test. Each week we spent 3 hours working on the project in the structures lab and additional 3 hours working on the deliverables that were due each week. The beginning steps of the project plan were outlined by Dr. Majeed in class and the remainder by our team and are shown in the table below.

Project Plan for Shed			
Task	Duration (hours)	Task	Duration (hours)
Design of floor plan	2	Allowed time for solar team to do wiring	3
First prototype	4	Allowed time for water team to install plumbing	6
Frame of shed	3	Outdoor wood Furnace	15
Bolt each wall to each other and the floor	3	Installation of heating system and water tank	3
Roof Trusses	3	Building of shelf	1
Second prototype	10	Setting up beds	1
Framing for the door and window	2	Building sink/counter	2
Installation of window and door	2	Building of collapsible desk	3
Siding outside of shed	1	Paint exterior	2
Strapping for roof	1	Testing of all systems	2
Roof boards, and tin roofing	2	Preparing Shed to move	2

Table 4

Detailed Description of the Project Design and Features

Hammock

When planning the interior of the shed, we realized the furniture limitations of a 32 square foot building/room. As a result, we decided to use hammocks for beds to maximize the interior space. The hammocks can be set up and taken down within a minute, and placed inside a small, compact bag. Each hammock is attached to eye hook bolts that are through both 2x4 studs in the california corners and are kitty-corner from each other. The hammock can safely support 201 lbs and through prototype 2 and respective testing, we confirmed the eye hooks attached to the studs are also able to support that mass. Figure 4 below shows prototype 2 in the bottom right and side pictures and the final setup in the center and top pictures.

Figure 7

Desk

The desk consisted of a 2ft by 1.5ft piece of plywood that was an inch thick. It is connected to the studs with hinges. Airplane cables were attached to the bottom right corner of the desk to prevent the desk from lowering more than 90 degrees. A hook is also attached to the bottom right corner of the desk to attach the desk to the wall when it is in storage. The desk is solely for writing/paperwork and is not able to support more than 5 lbs. Figure 5 below shows the desk in “storage” mode and its “in-use” mode.

Figure 8

Furnace

The furnace was an idea that was discussed in the brainstorming session at the beginning of the semester. As we continued to work on the shed we realized the need for an alternative source of heat, allowing the energy generated from the solar panel to be used elsewhere.

Using an old 100lb propane tank, we cut out a door from the center and welded hinges to the door and reattached the door to the tank. Four smaller circles were also cut out for air flow and the copper tubing that spiralled through the tank. Exterior air flowed through the copper tubing inside the wood furnace leading to the bottom of the hot water tank inside the shed. We also attached a 1”x1.5”x1/16” steel sheet to the top of the furnace, creating a small stovetop.

Figure 9

Figure 6 above shows the different parts of the wood furnace including the finished product, door and hinges, handle and locking mechanism, air intake, and the copper tubing that was used to heat the water.

Shelf

Attached to the studs on one of the long sides of our shed, the shelf is sturdy and able to support a large amount of weight. The shelf is ideal for storage as it is high enough that items placed on top would be out of the way, but not placed too high that the items are inaccessible. Figure 7 below shows the final product in our shed.

Figure 10

Prototyping and Testing

Prototype I:

The specific test objectives were:

1) determine if the shed can hold a load
2) determine and analyze where stress points may occur under extremes and how they may be reinforced
3) communicate the strength of our shed using vertical beams, similar to our design of our actual shed

There were two possible results:

a) the shed supports the weight
b) the shed cannot support the weight

The test showed where the shed might fail under extremes on a larger scale. The criteria for test success or failure was that prototype 1 had to be able to withstand a minimum load of 2 textbooks in order for the test to be successful. If prototype 1 broke with less than 2 textbooks on top of it, then the test would be a failure.

The first prototype type was a focused physical prototype. The prototype was made from popsicle sticks, to represent the 2x4 framing, and cardboard, representing the plywood siding. The reason for this choice of prototype was chosen because we needed a way to test a load without risking breaking our project and wasting large amount of money and time. The second was that we needed the structure to fail so that we could determine where our shed might fail, and reinforced if needed. Since we did not have the computer software to make a analytical prototype we made a physical one that focused on the support system for the load.

The testing process for the first prototype was the following and took approximately 5 minutes to complete:

1. Gather all materials
2. Add weight to the prototype. Increase the total weight on top of the prototype by an increment of one textbook.
3. Record the weight added above the prototype via video recording or a camera.
4. Repeat steps two and three until the prototype collapses.

After the test we found that the design approach we took to shed proved to be able to withstand the load or stress that would be applied to it. The weight the prototype supported surpassed our test requirement of 2 books, leading to the conclusion that the beams don’t need any additional reinforcement.

In conclusion, prototype 1 was a success. The prototype test was successful in gathering the information that we looked to achieve, the information was analyzed and then applied that the design that used will hold loads under extremes.

Prototype II:

The specific test objectives were:

- validity of the eye-hook system can support a hammock with one person in it (150lbs)
- analyze where stress points may occur in the frame under extremes and how they will react
- strength of shed frame

There were four possible results:

(a) The eye hook design for supporting the hammocks supports the force (1471 N) of the person

(b) The eye hook is not strong enough and the wood bends or breaks under the force

(c) The supporting board that the eye hook is mounted into snaps and breaks

(d) The eye hook rips out of the board

Prototype 2 was a focused physical prototype. The prototype was created using two 2x4 boards with eye hooks attached at each end of the board. This prototype was chosen because we needed a way to test the load of one person on the hammock without risking breaking our shed and wasting a large amount of money and time. We also needed to determine if more reinforcement, a stronger frame or a stronger eye hook was required. Since we do not have computer software to make an analytical prototype we made a physical prototype that focused on the support system for the hammock load.

The testing process that we created for prototype 2 was the following and took approximately 30 minutes to complete:

1. Drill hole on both end of both 2x4 is the same spot.

2. Place eye hooks through holes attached with a washer and nut on both sides.
3. Put the boards on the top of a monkey ladder found at local play structure, then hang the hammock below the monkey ladder attached to the eye hooks.
4. Record weight of a group member
5. Add weight to the hammock. One person has to lie in the hammock.
6. Perform calculations to determine maximum force applied to 2x4 footer by eye screw that will not break the wood and ensure that maximum force applied by hammock is less than the breaking point.

The materials required to build the prototype was a hammock, 2 2x4x10, 2 eye-hooks. 2 washers, 2 nuts. The estimated cost was $26.

The test was conducted at a local park. Since no monkey bars were available at the park, a part of the play structure was used. A ¾ bit was used to drill through the hole and mount the eye hook. The eye hook was mounted in a vertical position. The weight of 153 lbs was added.At first the supporting board pulled in a horizontal direction causing the weight to fall. This told us as we apply the force in crossways direction there will be a sheer force pulling sideways. We changed the design by moving the hammock so that it lay perpendicular to the support beam, reducing stress horizontally. We then added the weight again. After measuring the bowing with a ruler and the angle of the eye hook from the support board there appeared to be no change. We then increased the weight to 201 lb and measured a bowing of 3mm and no change in angle.

In conclusion, prototype 2 proved to be able to withstand the load or stress that will be applying to it. When the prototype was placed under stress from the weight, we observed that the eye hook was able to hold the force of the weight applied and did not pull out or bend. It was also observed that the supporting board only bowed by 3mm. This lead to the conclusion that eye hook bolts will hold the hammock if mounted to the roof. The prototype test was successful in gathering the information that we looked to achieve, the information was analyzed by measuring the bowing in the wood and taking the angle of the eye hook bolt after applying the force to it.

Prototype III:

The specific test objectives were:

- determine if the shed and eye-hook system can support a hammock with 150lb load
- analyze where stress points may occur in the frame under extreme loads
- determine which areas need to be reinforced if needed be
- communicate the validity of the eye-hook system that can support the hammock
- verify the strength of our shed frame (the vertical beams)

There were four possible results:

(a) The shed and eye hook design for supporting the hammocks supports the forces applied

(b) The shed and eye hook is not strong enough and the wood bends or breaks under the force

(c) The supporting board that the eye hook is mounted into snaps and breaks

(d) The eye hook rips out of the board

Prototype 3 was a comprehensive physical prototype. The prototype was created by attaching 2 eye hooks to the vertical boards (through the california corner) on opposite ends of the interior of the shed. The reason for this choice of prototype was because we needed to test the actual frame of our shed and determine if it could support the load of one person on the hammock. We also needed to determine if more reinforcement, a stronger frame or a stronger eye hook was required. Since we do not have computer software to make an analytical prototype we made a physical prototype that tested all the components of the shed as a whole.

The testing process that we created for prototype 3 was the following and took approximately 30 minutes to complete:

1. Drill hole in the frame - kitty-corner to each other at the same height.
2. Place eye hooks through holes attached with a washer and nut on both sides.

3. Record weight of a group member
4. Add weight to the hammock. One person has to lie in the hammock.
5. Perform calculations to determine maximum force applied to frame by eye screw that will not break the wood and ensure that maximum force applied by hammock is less than the breaking point.

The materials required to build the prototype was a hammock, 2 2x4x10, 2 eye-hooks. 2 washers, 2 nuts (Total: $26). For the shed; $292 for 80 pieces of 2x4, $26 for 4 boxes (of 100) with 8x1-3/4 screws, $22 for 4 boxes (of 100) 8x1-1/4 Flat, $200 for a set of torque drill and impact drill (Total: $540). Additional costs were omitted because we worked in a shop and we didn't have to pay for other tools such as a miter saw, vertical saw, etc. The estimated cost was $566.

The test was conducted in the structures lab. The eye hook was mounted in 2 studs that were located on opposite ends of the frame of the shed. When the weight of 153 lbs was added to the hammock, the supporting board bent in a horizontal direction towards the center of the shed causing the weight in the hammock to fall. The hammock with the weight bowed approximately 15 cm. This told us as we apply the force in crossways direction there will be a sheer force pulling sideways. Since the hammock with the weight did not bow by a lot, this leads to the conclusion that the prototype passed the first test. We then increased the weight to 201 lb and measured a bowing of similar magnitude.

In conclusion, prototype 3 proved to be able to withstand the load or stress that will be applying to it. When the studs were placed under stress from the weight, we observed that the eye hook was able to hold the force of the weight applied and did not pull out or bend. The eye hook bolts held when the hammock was occupied. The prototype test was successful in gathering the information that we looked to achieve, the information was analyzed by measuring the bowing in the wood and taking the angle of the eye hook bolt after applying the force to it. The hammock fit, and worked well inside the shed.

Conclusions and Recommendations for Future Work

From meeting with our client, Monique Manatch, to defining the design criteria of the shed, benchmarking the design criteria, brainstorming concepts to add to the shed, prototyping and testing, and finally presenting, our team worked to provide a solution to our client's problem; that the residents on the Barriere Lake Reserve have inadequate housing and are missing basic utilities and need a shed that is self sustainable, durable and cost effective with the basic utilities for the residents to inhabit. Our final shed met each need identified by the client in the interview: modularity, basic utilities, and self-sustainable.

Throughout the each stage of the design process for our project, including labs, the biggest challenge for our group was definitely communication. Our group struggled to communicate through social media, resulting in delays and/or miscommunication that could have been prevented. We worked well together during the labs, but struggled to find times where we could all meet and work on the deliverables. Unfortunately, we were not able to all meet to work on deliverables despite attempts to find times and dates that accommodated all group members and in many cases the deliverables were left to a few group members to complete. However, the better we communicated as a group, the more efficient we were as a team, completing tasks quickly and correctly.

Another challenge we faced was sharing tools during the lab periods. There were times where only two group members were able to work on the shed due to lack of tools available in the structures lab. This challenge grew exponentially when all twelve groups were working in the lab, and all 4 group working on the interior of the shed for the last two labs before the 2018 uOttawa Design Day. All of the groups working during the labs were able to minimize the inconvenience the lack of tools created by collaborating together and sharing the tools with all the groups, allowing groups that had the most work to complete priority to use the tools.

In the future, it would be best to complete all construction tasks for the interior of the shed to prevent time wasted waiting for access to the interior of the shed. In addition, we also learned that when we began tasks with a plan already made, we were more effective and could complete tasks more efficiently, maximizing our time spent in the lab and minimizing the waiting time for other teams. If we were to redo this project, we would have made a project plan earlier in the project to better manage our lab time.

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