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SANTA CLARA UNIVERSITY

Department of Civil Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION
BY

Julia Anderson, Katie Bipes, Antonio González, Danny O'Malley, Colin Skaggs, and La'akea Warren

ENTITLED

JOHN BROWN UNIVERSITY DISASTER SHELTER COMPETITION

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF

BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

Thesis Advisor Hisham Said 6/15/17
date

Thesis Advisor Tracy Abbott Tracy Abbott 6/14/17
date

Department Chair Mark Aschheim for Mark Aschheim 6/15/17
date

JOHN BROWN UNIVERSITY DISASTER SHELTER COMPETITION

By

Julia Anderson, Katie Bipes, Antonio Gonzalez, Danny O'Malley, Colin Skaggs, and La'akea Warren

SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Civil Engineering
of

SANTA CLARA UNIVERSITY

in Partial Fulfillment of the Requirements
for the degree of
Bachelor of Science in Civil Engineering

Santa Clara, California

2017

Acknowledgements

We wish to thank John Brown University for hosting the competition and allowing the team to participate in it with our design. Additionally, we would like to recognize our advisors, Professor Hisham Said and Professor Tracy Abbott, for their continued support throughout the course of the project.

Abstract

John Brown University hosted the 6th annual Disaster Shelter Relief Competition in April 2017 for which the team built a prototype shelter and proposed a camp plan. Both the shelter and the camp plan were designed to house refugees coming into Greece from the Middle East. The shelter would accommodate a family of four and the camp plan was designed to hold 1250 shelters, or 5000 people. The shelter was built on site at John Brown University and was required to take less than two hours to fully construct. This report summarizes the work the team did for the competition, including a review of existing shelter designs currently in use, a description of the method of design of the prototype, validation that the prototype meets the criteria, a discussion of the cultural appropriateness of the shelter to the scenario, suggested modifications and improvements that can be made, photos and drawings of the prototype, and the camp plan.

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Problem Statement

When large numbers of people are removed from their homes, as is the case in the Syrian Refugee Crisis, temporary disaster shelters are essential for providing for the basic needs of refugees. Since many European countries have closed off their borders to refugees, millions of refugees are stuck in Greece, living in tent communities, under less than ideal living conditions. This project addresses the need for more efficient and sustainable disaster shelters to provide temporary homes (one year minimum) for Middle Eastern refugees in Greece.

The UN estimates that there is a total of eleven million people that have been displaced by the current Syrian Civil War. Countries throughout the northern Middle East and Europe are struggling to find a way to quickly and efficiently house and care for the millions of refugees pouring into their countries. Of the eleven million refugees, the UN estimates that only one in ten refugees are living in refugee community camps. Figure 1, below, shows the distribution of Syrian Refugees throughout Greece and the rest of Europe.

Figure 1. Syrian Refugee Migration in Europe.

Providing Refugee housing is a very complicated process. Not only are the economics difficult to address, but finding a way to provide housing that is easily assembled, structurally sufficient, and durable is very important. Together with the team's Jesuit core education and Civil Engineering knowledge, our group aimed to address this issue in this Senior Design Project.

Project Goal

The purpose of this project was to develop a sustainable, economically efficient, and stable "temporary" disaster shelter that could be used to house refugees from the Middle East in Greece. This shelter could serve as a temporary home for refugee families and should be able to withstand seismic and wind loading. As seen in Figure 2, current refugee camps are unsuitable for long-term living, and unprotected from most weather and natural disaster events.

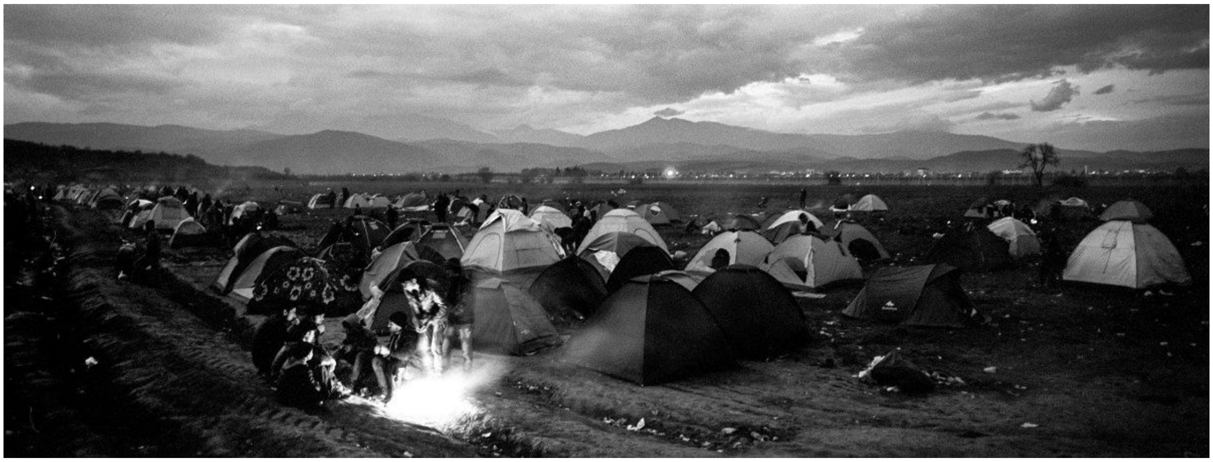


Figure 2. Current Syrian Refugee Camp in Greece.

The goal of the team was to design a lightweight structure that would be easy to construct, structurally sound, and able to withstand all of the environmental conditions that refugees from the Middle East face as they live temporarily Greece.

Prototype Design Method

Design Assumptions

1. All calculations performed using strength design and IBC (International Building Code) factored load combinations
2. Wind loads based on ASCE 7
3. Lateral loads on windward walls were split evenly between the front and back walls of the structure including leewards winds, this wind load is the dominant loading scenario
4. Tension cables were assumed to represent a concentric braced case in the design
5. All framing connections considered pinned
6. Gravity systems loaded only with self-weight
7. Assume flooring does not add gravity load to the structure because it is separate from the structure

Structure Design and Prototype Construction

The John Brown University competition provided detailed criteria that the shelter design needed to comply with. The main factors taken into consideration were the structural integrity and assembling the shelter in under two hours, as well as having to disassemble it. The complete competition requirements are listed in the project design summary with specifications on wind, rain and earthquake loading as well as dimensions of the shelter.

Frame Design

The first step taken was to decide on the material used for the shelter's main structure. Based on availability, team experience with working with wood as well as available tools, the team agreed to use wood for the frame. As well wood is commonly used in construction, easy to build with, and affordable. The entire frame was connected with bolts, making the frame easy to assemble and disassemble. Since the structure contains only pinned connections, tension cables were added on all four sides as bracing for seismic and lateral support. The tension cables were connected to eye bolts on both ends. One end consisted of a hook and the other was simply looped through the eye bolt and locked into place with a clamp set. This process allowed the tension cables to be assembled and disassembled easily and could be self-tensioned as needed.

Figure 3. Shelter Structure frame, showing the bolted connections and tension cables.

Roof Design

The next step taken was to brainstorm ideas for the outer roof. After looking into several options, the team decided upon corrugated PVC panels, overlapped and taped together with Gorilla Tape in order to maintain a lightweight, affordable, weather resistant material. The roof was sloped for drainage, and the channels of the corrugated panels were aligned parallel to the slope of the roof to stream the water off in a downward direction. The roof was bolted to the wood beams by using angled metal brackets and rubber washers for waterproofing. An aerial view of the structure is shown below in Figure 4.

Figure 4. Corrugated PVC Panels bolted on to the shelter structure.

The PVC roof panels were then lined with construction grade foil bubble wrap insulation due to the benefits of having a lightweight insulation material, as well as flexible, making it easy and quick to assemble. This insulation was connected to the roof using velcro strips. After the main frame of the structure was built, four cross members were added for support of the roof to prevent sagging. The insulation was sandwiched between the roof cross members and the roof panels themselves, as shown below in Figure 5.

Figure 5. Inside view of roof with insulation.

Wall Design

The walls of the shelter consisted of foam board insulation wrapped in a waterproof tarp. This method for the siding was extremely lightweight, helping to reduce the total load of the structure to meet the competition weight limit. For added insulation inside the shelter, the foam sides of the wall panels were covered with thermal emergency blankets, which retain heat very well. The wall panels were attached to the structure by using metal channels screwed on the wood beam. These metal channels made it very easy to slide the wall panels on to the wooden frame. To connect and waterproof the wall panels on the outside of the shelter, strips of tarp were spread over the connections between the walls and secured at the top and bottom with heavy duty velcro strips that adhere to the wood framing. The sides of the strips were secured along the wall panels with several layers of waterproof Gorilla tape. To keep the flexible walls from moving or bowing due to wind, the entire structure was wrapped in three tightly bound heavy duty ropes.

Figure 6. Typical Wall Panel Outside View.

Figure 7. Typical Wall Panel Inside View.

Floor Design

Due to cost and weight constraints, the team decided to create the floor out of tarp and bubble wrap insulation, resembling a tent floor instead of plywood. It was flexible enough to be able to lay on uneven ground, and the insulation was sandwiched between two sheets of tarp sealed with Gorilla tape. The floor was laid out inside of the shelter and secured on the wood framing columns with bungee hooks. Rope strung along the perimeter of the floor tarp was used to pull the floor taught so that it does not sag. The excess side of the floor came up approximately two feet from the ground on each of the four sides, as shown in Figure 8. This ensured that no water could get into the shelter from the exterior and also allowed for the sides of the floor to be laid down flat on the inside for more ventilation on a hot day.

Figure 8. Tarp & Insulation Floor Inside View.

Door and Window Design

To create the door to the structure, a tarp zipper was used to create an air and water proof entryway, similar to a tent entrance. The sheet of tarp making the door is secured to the wall panels on either side by strips of velcro, as seen in Figure 9 below.

Figure 9. Door Outside View.

Two windows were added to make the structure more liveable and comfortable for the inhabitants. These windows could be opened for ventilation and daylight or closed in case of bad weather. A box cutter was used to cut a square hole in two of the wall panels. The tarp was secured to the window's edges using layers of waterproof Gorilla Tape on the inside and outside. The window was made out of a 2 ft x 2 ft square of insulation sandwiched in between two pieces of tarp and sealed with tape. The window cut out was smaller than the flap so that there would be overlap to prevent air leakage. The flap was secured over the window hole with tape, and the sides were attached to the wall panel using zippers so that the residents could open and close the windows as needed.

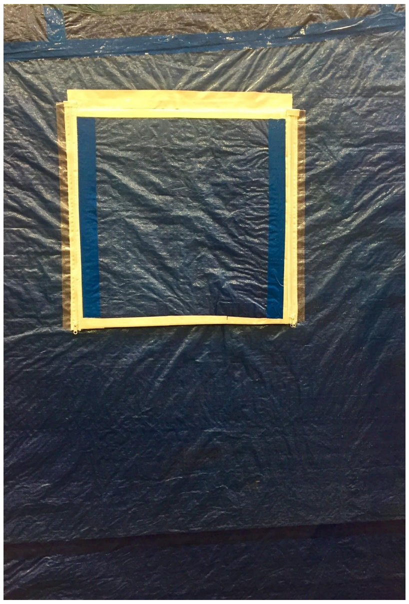


Figure 10. Window Outside View, Closed.
Figure 11. Window Inside View, Closed.

Shipping the Structure

The competition required that the shelter be able to fit in an 8 ft x 40 ft shipping container when disassembled. Many parts of the shelter were designed to be foldable in order to facilitate its constructability and transportation. The front and back wood structures were foldable due to the pinned connections reducing the amount of bolts needed to install during the two hour building period. This method also improved space efficiency when needed to be transported. However, once the metal channels were added to hold the wall panels in, the folding could no longer occur without damaging the channels. A future design would hopefully be able to fold and would not use channels.

The entire structure was disassembled for ease of shipping. All of the wooden connections and bolts were color coded using paint to make reassembly easier. This method of lean construction also ensured that the structure was easily buildable by any person, regardless of previous construction knowledge or experience. The PVC roof panels, tarp floor, and insulation were simply rolled up for shipping, and the panels were piled on top of each other to minimize shipping space.

The team was able to contract a flatbed, open-air shipping truck for transportation to the competition, though no shipping containers were provided. This caused the team to have to manufacture wooden shipping containers to hold the materials. Knowing that the truck bed had straps every four feet to secure the load, the team created one shipping container for the PVC roof with supports every four feet so the straps did not pull down on the PVC roof itself and break it. The second shipping panel was used for the wall panels, insulation, and tarp floor. In order to not break the panels with the straps, the container was made to have a rigid frame for the straps to secure, leaving the panels inside untouched. Figure 12 below shows the wooden crates holding the PVC roof panels and the wall insulation panels.

Figure 12. First Two Shipping Containers with Shelter Materials on Truck.

The third shipping container was for the wooden members. This container had end walls and framing around the top perimeter with supports every four feet for the straps to secure. Figure 13 below shows this shipping container.

Figure 13. Third Shipping Container with Shelter Frame on Truck Bed.

Design Considerations

Additional Design Issues

Weather

The environmental conditions in Greece vary greatly with hot and dry summers, as well as cold and wet winters. Seasonal temperatures in Greece range from 50 degrees fahrenheit in the winters and 84 degrees fahrenheit in the summers. Greece is also prone to high winds, earthquakes and snow. The podcast Are we there yet? By This American Life, states that one of the major issues that refugees face are extremely hot temperatures. The podcast states that the current shelters that refugees occupy are similar to tents. In the summers, due to lack of insulation, refugees spend their time looking for shade outside of their tents because it is too hot.

Sustainability

There are many factors that contribute to a design's sustainability. Stephen Wheeler claims in *Sustainable Urban Development Reader*: "people and organizations conceptualize sustainability in different ways." Whether this is based on economics, environmental impact etc., all projects have different criteria for sustainability.

For this project, the most important criteria to achieve was efficient use of space. By designing a shelter that used space efficiently, the project could be easily transported in larger quantities, thereby minimizing environmental impact. Another criteria the group aimed to achieve was minimizing the amount of members required to construct the shelter. This not only saved on material but allowed the structure to be easily assembled.

Insulation/Ventilation

As mentioned in the environmental conditions section above, one issue that refugees face are cold winters and hot summers. In order to combat this problem, the group considered many different insulation options and ventilation options. The cold winters require proper insulation in order to retain heat, and ventilation is required to allow airflow during the summer months to keep the shelter cool. Along with insulation and ventilation, another factor that the group considered was floor covering and protection against conductive heat loss to the ground and exposure to dusty ground.

John Brown University stated in its competition guidelines that the structure was subject to thermal testing and hence the group was required to consider insulation/ventilation as major design factors. This 30 minute thermal test simulated temperature change from day and night with a thermometer inside the shelter to record the changes.

Technical Issues

Material Availability

According to the John Brown University design guidelines, the team assumed that the shelters would be manufactured in the U.S., or other similar industrialized countries, and shipped to the point of use. According to "*An Overview of the Design of Disaster Relief Shelters*" by Abdulrahman Bashawri, it is important to consider the environmental impact of materials, the ease of manufacture and construction, and the quality of materials when designing disaster relief shelters. Table 1, below, lists common building materials in the U.S. as well as the pros and cons for each. The group not only had to consider these materials, but other more sustainable options as well when the design was created. .

Table 1: Common building materials in the U.S.

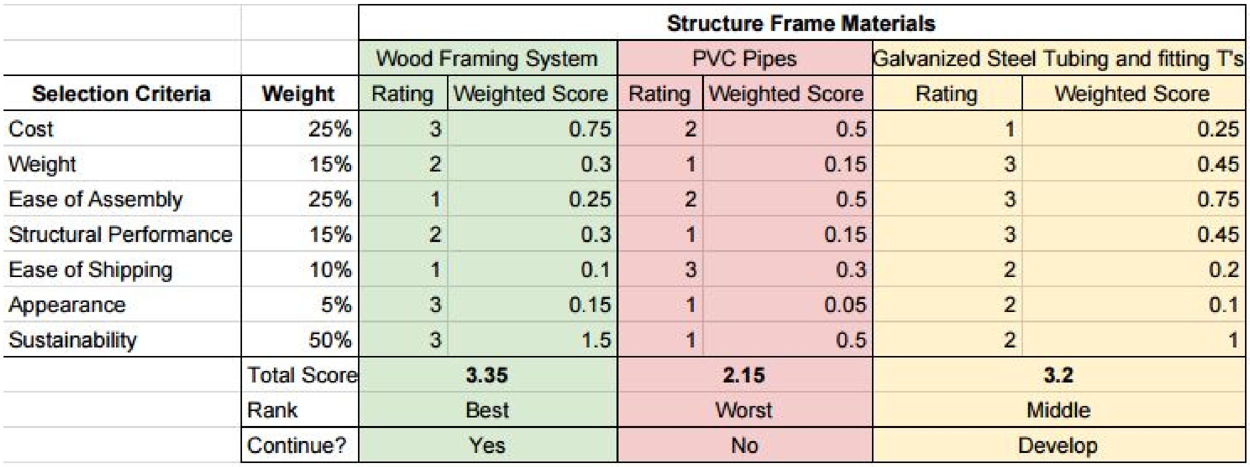
Building Material	Pros	Cons
Steel	High strength and ductility. Light-weight. Fast construction.	Subject to fire and corrosion. Cost
Timber	Light-weight. Easy to construct with. High strength for small structures.	Subject to fires, decay. Rain causes expansion and weakening.

Trade-off Decisions

The first trade-off decision that the team made was deciding between using light gauge steel, aluminum piping, Polyvinyl Chloride (PVC) pipe, and wood. The team eliminated PVC as a design option because after completing basic wind loading calculations, it was felt that PVC would not provide the lateral support needed. Light gauge steel and aluminum were the next options because of their high strength and lightweight. Pursuing these options, however, would take up too much budget on framing members alone. Ultimately the team decided on using wood framing because wood is strong enough for load scenarios, great for small structures, relatively cheap, and easy to construct with the use of bolted connections.

The following design matrix also assisted in deciding which frame material to use. Seven influencing factors were chosen and each was given a weight based on importance in the final decision. Then, each material was given a rank from 1 to 3 (with 3 being the best) for each of the seven categories. The weighted score was then calculated for each and the highest score was chosen.

Table 2. Structure Frame Materials Design Matrix.



		Structure Frame Materials					
		Wood Framing System		PVC Pipes		Galvanized Steel Tubing and fitting T's	
Selection Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	25%	3	0.75	2	0.5	1	0.25
Weight	15%	2	0.3	1	0.15	3	0.45
Ease of Assembly	25%	1	0.25	2	0.5	3	0.75
Structural Performance	15%	2	0.3	1	0.15	3	0.45
Ease of Shipping	10%	1	0.1	3	0.3	2	0.2
Appearance	5%	3	0.15	1	0.05	2	0.1
Sustainability	50%	3	1.5	1	0.5	2	1
	Total Score	**3.35**		**2.15**		**3.2**	
	Rank	Best		Worst		Middle	
	Continue?	Yes		No		Develop	

An important decision made by the group was choosing the type of lateral support for the structure. The team assumed that using a concentric braced system was the most appropriate for this type of design.

The team decided between using a rigid material such as aluminum and steel, and a flexible material such as nylon come-alongs and steel tension cables. The rigid materials were eliminated because they are much more expensive and are heavier than what was budgeted.

Lastly, it was decided not to use the come-along nylon straps, although very easy to install, because this material is not typically used for long term purpose and could loosen over time. Therefore, the tension cables were chosen because out of all the options, they were the most affordable, very light, and quick to assemble and disassemble.

The next trade-off that the team made was deciding between corrugated panels for the roof or tarp. The group initially wanted to use tarp because it would have been easier to install, but realized that rain would cause pools of water on the roof if tarp was used. Although corrugated panels would have additional installation time, the team found an efficient method of attaching the roof to the frame with bolts and L-shaped metal brackets attached to wood members. The PVC panels also offered more strength and rigidness to the roof so that pooled water would no longer be an issue.

Prototype Design Summary

The following table summarizes the required specifications in the competition guidelines, as well as achieved specifications. Supporting calculations can be found in Appendix B.

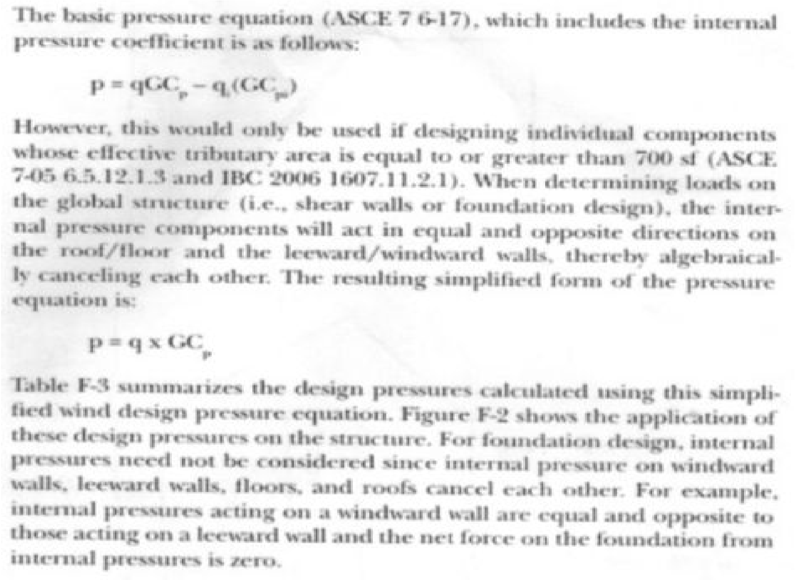
Table 3. Summary of Required and Achieved Specifications.

Criteria	**Required Specifications**	**Achieved Specifications**
Wind	46.6 mph	46.6 mph was used in the calculations, so the structure is expected to perform successfully at this wind speed.
Rain	Four inches (4”) per hour for 12 minutes above shelter	An exact test could not be performed, but the constructed shelter was left out for a week in heavy rain and no damage was found
Heat Retention	No exact requirement	Expected heat loss of 30.5^{o}F
Dimensions	16’ x 20’ x 10’	12.5’ x 12.5’ x 9’
Square Footage	151 square ft minimum	156.25 square feet
Earthquake	Withstand simulation of a magnitude 7 earthquake. Shelter would be visually inspected after the test by the judges.	Shelter properly withstood the simulation.Exact calculations were not performed due to structure assumption having a low weight to not be greatly affected by an earthquake. All connections were designed and pinned to aid in earthquake resistance, and tension cables can withstand 740 lbs, which is expected to not be exceeded.
Weight	440 pounds	About 750 pounds, including shipping container and tools
Set-Up Time	120 minutes	100 minutes in rough weather conditions with all the material wet.
Cost	$1500	$1458.30

Wind Calculations

Detailed calculations can be found in Appendix C1.

To determine the design requirements for the shelter, given the competition wind test maximum of 46.6 mph, the following calculations shown were performed using ASCE standards for wind calculation of structures. The tension cable strength calculations are included as well because they provide additional lateral support that can resist wind forces.



The basic pressure equation (ASCE 7 6-17), which includes the internal pressure coefficient is as follows:

$$p = qGC_p - q_i(GC_{pi})$$

However, this would only be used if designing individual components whose effective tributary area is equal to or greater than 700 sf (ASCE 7-05 6.5.12.1.3 and IBC 2006 1607.11.2.1). When determining loads on the global structure (i.e., shear walls or foundation design), the internal pressure components will act in equal and opposite directions on the roof/floor and the leeward/windward walls, thereby algebraically canceling each other. The resulting simplified form of the pressure equation is:

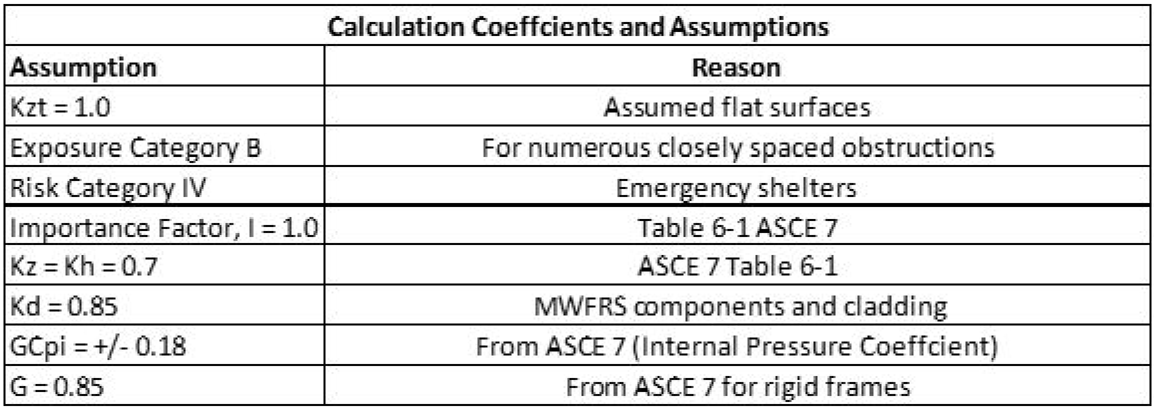
$$p = q \text{ x } GC_p$$

Table F-3 summarizes the design pressures calculated using this simplified wind design pressure equation. Figure F-2 shows the application of these design pressures on the structure. For foundation design, internal pressures need not be considered since internal pressure on windward walls, leeward walls, floors, and roofs cancel each other. For example, internal pressures acting on a windward wall are equal and opposite to those acting on a leeward wall and the net force on the foundation from internal pressures is zero.

Figure 14. Equations Used in Wind Calculations from ASCE 7.

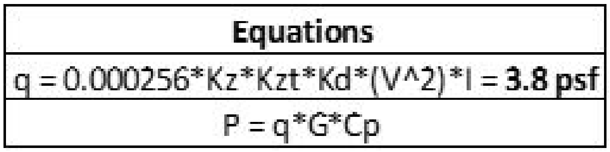
The tables shown below simplify and consolidate all the calculations made during the wind loading analysis. Using the basic design assumptions shown in Table 4, and the equations in Table 5 we were able to calculate internal and external pressures on all the walls as well as the roof.

Table 4: Design Assumptions and Coefficients.



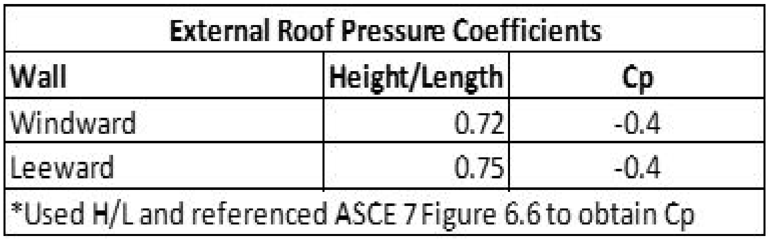
Calculation Coeffcients and Assumptions	
Assumption	**Reason**
Kzt = 1.0	Assumed flat surfaces
Exposure Category B	For numerous closely spaced obstructions
Risk Category IV	Emergency shelters
Importance Factor, I = 1.0	Table 6-1 ASCE 7
Kz = Kh = 0.7	ASCE 7 Table 6-1
Kd = 0.85	MWFRS components and cladding
GCpi = +/- 0.18	From ASCE 7 (Internal Pressure Coeffcient)
G = 0.85	From ASCE 7 for rigid frames

Table 5: Wind Pressure Equations.



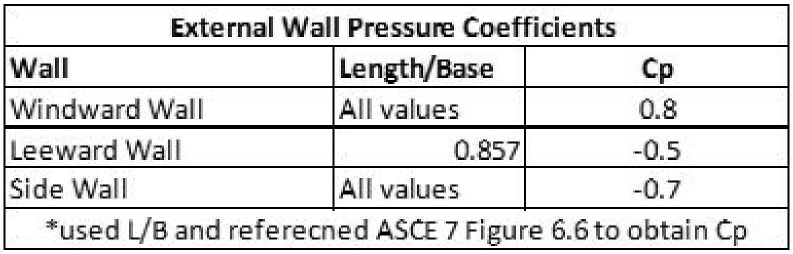
Equations
q = 0.000256*Kz*Kzt*Kd*(V^2)*I = **3.8 psf**
P = q*G*Cp

Table 6: External Roof Pressure Coefficients Calculated.



External Roof Pressure Coefficients		
Wall	**Height/Length**	**Cp**
Windward	0.72	-0.4
Leeward	0.75	-0.4
*Used H/L and referenced ASCE 7 Figure 6.6 to obtain Cp		

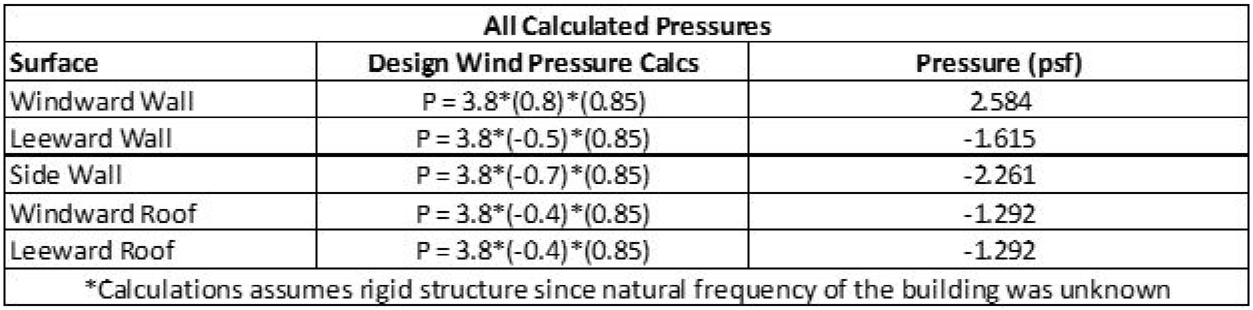
Table 7: External Wall Pressure Coefficients Calculated.



External Wall Pressure Coefficients		
Wall	**Length/Base**	**Cp**
Windward Wall	All values	0.8
Leeward Wall	0.857	-0.5
Side Wall	All values	-0.7
*used L/B and referecned ASCE 7 Figure 6.6 to obtain Cp		

Table 8 below shows the calculations made to obtain both wall pressures and roof pressures. These pressures would later be added together and used to determine the required lateral strength our tension cables needed to provide.

Table 8: Calculated Pressures for both Walls and Roof.



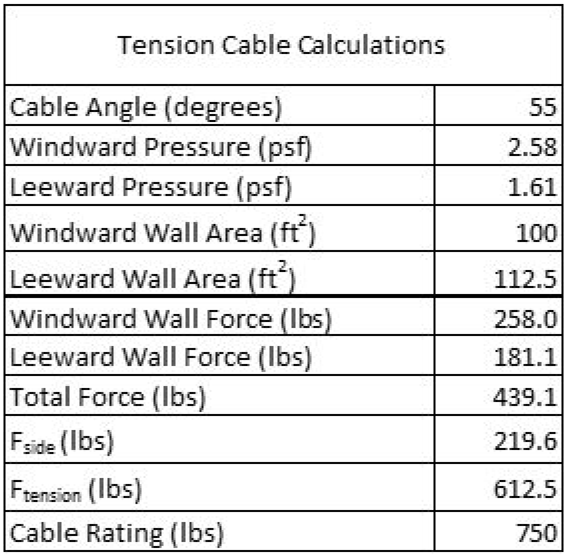
All Calculated Pressures		
Surface	**Design Wind Pressure Calcs**	**Pressure (psf)**
Windward Wall	P = 3.8*(0.8)*(0.85)	2.584
Leeward Wall	P = 3.8*(-0.5)*(0.85)	-1.615
Side Wall	P = 3.8*(-0.7)*(0.85)	-2.261
Windward Roof	P = 3.8*(-0.4)*(0.85)	-1.292
Leeward Roof	P = 3.8*(-0.4)*(0.85)	-1.292
*Calculations assumes rigid structure since natural frequency of the building was unknown		

Tension Cable Calculations

Detailed calculations can be found in Appendix C1.

Table 9 below shows the results of the tension cable calculations. In order to complete these calculations the windward and leeward wall pressures were multiplied with their respective wall areas in order to find the force on each wall. These forces were then added together and divided in half to obtain F_{side}. Fside was then multiplied by the wind factor of 1.6, as specified in LRFD, and divided by the cosine of the cable angle to obtain $F_{tension}$. The cable rating and $F_{tension}$ were then compared.

Table 9: Tension Cable Calculations.



Tension Cable Calculations	
Cable Angle (degrees)	55
Windward Pressure (psf)	2.58
Leeward Pressure (psf)	1.61
Windward Wall Area (ft^2)	100
Leeward Wall Area (ft^2)	112.5
Windward Wall Force (lbs)	258.0
Leeward Wall Force (lbs)	181.1
Total Force (lbs)	439.1
F_{side} (lbs)	219.6
$F_{tension}$ (lbs)	612.5
Cable Rating (lbs)	750

Rain Design

As mentioned in the Prototype Design Method section of this report, to make sure that the shelter withstood the competition requirement of four inches per hour for 12 minutes above the shelter, it was decided to use a monoslope roof to make sure that water could easily run off of the roof. The roof was constructed of corrugated PVC panels which are overlapped and held together by several layers of gorilla tape. Where the panels were bolted to the structure, rubber washers were used for waterproofing around the drilled hole, and the PVC panels were placed so that the ridges ran along the slope for the easiest rain slide off.

The team did not have the proper testing machine to perform an accurate rain test, so the fully constructed shelter was left out in on-and-off heavy rain for a week, and no water damage was found. This was assumed to be an adequate test for the waterproofing of our structure.

Heat Loss Calculations

Detailed Calculations can be found in Appendix C2.

To conduct heat retention calculations, the team used notes from polydynamics.com. These notes and other references can be found after the heat calculations. Calculations for two different types of insulation were performed because the trade-offs between the two were being considered.

The following assumptions were made in the calculations:

1. Air inside shelter heated to an average of 90 degrees Fahrenheit.
2. All surfaces would be able to let heat escape, including the floor (this allowed for a more conservative calculation, because only the side walls and roof will be exposed to the 40 degree Fahrenheit temperature of the heat retention booth.
3. All surfaces have the same insulation (either all R-tech insulation or all Reflectix).
4. U-value from heat transfer equation is constant over time, so U was only calculated to be 1/R.
5. Density of air stays constant, even with the changing temperature.
6. Heat transfer coefficients were ignored to allow for a simpler calculation.

The following Table 10 summarizes the results from the calculations.

Table 10. Summary of Heat Calculations.

Insulation	Heat Loss in 30 min	% of Heat Retained
Using Reflectix Insulation (R value of 3.0)	39.2ºF	56%
Using R-Tech Insulation (R value of 3.85)	30.55ºF	66%

Complete Project Budget

The spreadsheets of the breakdown of materials used in the prototype can be found in Appendix C3. The first spreadsheet is the bulk pricing used for San Jose, CA. The total cost for the materials is $1,138.55.

The second spreadsheet is a cost estimate of the labor to commercially manufacture and prefabricate the shelter according to the San Jose, CA labor average construction wages. The total cost for labor is $319.75

This brings the total cost of the entire shelter and labor to $1458.3. At the current cost, it would cost roughly $1,885,375 for a camp plan of 1250 shelters.

The cost of the shelter could be reduced by using less wood members, most efficiently packaging the materials, and getting lump costs for the exterior skin.

Also included is a spreadsheet showing the actual purchase prices of the materials. This total cost was $1,381.22.

Cultural Appropriateness

This shelter was designed and constructed as a home for those who have fled conflict or disaster. Cultural aesthetics are vital to a shelter because people's well being and health are directly linked to how they feel about their home and space. As designers and builders, cultural appropriation is one of the most important aspects of a shelter. The group, throughout the design phase, constantly evaluated the cultural appropriateness of the shelter. Knowing that this building would become a home and not a housing unit, the prototype was designed with the Syrian family in mind. Syrian houses in an urban setting are small and comfortable. They focus on a tight enclosed family community, as traditional rural housing in Syrian focuses on self-contained family units, symbolized by closed fronts to the outside world. Syrian building materials vary but many of the homes in the region are built with brick and stone, as well as mud houses in smaller villages. Specifically, the description of Syrian houses can be broken down, as traditional rural houses in the northwest are mud structures that are shaped like beehives; while in the south and east, most houses are made of stone.

This shelter had an exposed internal wood frame, resembling a home with semi-hard walls. Although wood is not a typical building material in Syria, it provided the best strength and durability. The wood frame gave a sense of comfort and safety to the occupants of the shelter. With the exposed members, the occupants will be able to see and understand the strength and redundancy of their home. Additionally, the wood internal structure allows for easy repairs to the structure. If the exterior facade gets damaged, the panel can be replaced without changing the internal wood frame. Using wood as the main building component was a better alternative to assimilate to rather than materials such as steel, aluminium and PVC because of the natural aesthetic wood provides.

Along with the privacy, the shelter exceeds the 8’ requirement and provided a tall roof for the occupants. The higher roof made the shelter feel more spacious despite the small footprint. Using wood as a building material allowed for the high roof. The high ceilings and exterior framing made the shelter a home and not a dignified tent.

Figure 15. Current Syrian refugee camp (Denselow).

Another aspect of the shelter that provides a home environment is shelter's privacy. The shelter was completely enclosed on all sides by panels, which give the the shelter a closed off and private ambiance. As the research states above, the Syrian refugees value a tight family community. The shelter, having semi-hard non-transparent walls, as well as a sturdy roof and floor, resembles a home to refugees.

The shelter also allowed for customization. With the open floor plan, families will be able to divide up the space in their own way. With the availability of internal customization, families have more pride and feelings of individuality towards their home. The family will have the freedom to control their ventilation atmosphere by attaching or breaking down the wood members below the roof and opening the doors and windows as needed. The floor can also be detached and laid flat on the ground on a hot day to allow for more airflow throughout the shelter. This will provide more airflow in the shelter and provide the necessary thermal comfort throughout the year.

In conclusion, our shelter brings safety, privacy, and a feeling of strength in a time of great turmoil. The hope is that this shelter will one day be a real home for a family in need.

Camp Plan

Overview

To create the draft camp plan, the standards given in the Sphere Handbook for Minimum Standards in Humanitarian Relief were followed closely to ensure the safety, comfort, and health of the refugees living in our proposed camp. Each section of the handbook was analyzed for standards that would affect the layout of the camp to create the draft camp plan. The overall camp asks for 1250 shelters, four people per shelter for a total of 5,000 residents.

The attached drawings for the camp plan show a zoomed-in setup of 100 shelters with a men's and women's bathroom and shower unit, one sink unit, and one laundry unit. This accounts for the minimum standards listed below that are outlined in the Sphere Handbook. The same setup was repeated to make larger groups of communities with roads connecting them. In the space between each half of the camp, directly off of the main roads that lead from the entrance of the camp, are the central community, dining, education, and gym facilities designed using the Sphere standard of 30 square meters (~322.9 square feet) per person for communal areas. Since square footage would have to be massive for 5,000 people to be able to dine or meet all at once, one-quarter of the population using these facilities at one time, at a maximum, was used for the design.

On either side of the camp, one wastewater storage tank was placed to which all wastewater can be diverted to using pipes. This can be emptied by trucks once weekly and taken to a municipal treatment plant. On the two opposite sides of the camp from the wastewater storage tanks were placed the three potable water storage tanks. They were separated from wastewater storage so as to eliminate the possibility of contamination of potable water, which can rapidly spread disease.

Minimum Standards in Shelter Layout

The Sphere Handbook states that shelters must be safe, secure, all-weather dwellings with access to communal facilities. The layout of the shelters should provide privacy for each group or family, and open onto a common space for the use of the household. It also specifies a minimum space of 45 square meters per person, including household plots. For a four-person shelter, as we are designing for in this competition, the area minimum per shelter and surrounding land plot, converted into US Customary units, is 485 square feet.

As the team's shelter was 12.5 ft x 12.5 ft, the inside square footage was 156.25 square feet, so an additional 328.75 was needed in surrounding land per shelter. For fire protection, the Sphere Handbook states that a minimum of two meters (~6.56ft) must be between every two shelters, but the preferred amount is twice the maximum building height. In this case, the highest end of the shelter was nine feet tall, so the minimum space between each shelter should be between 6.56 and 18 feet. 17 feet was chosen as the space between shelters on each side, which gave a total square footage of over 500 square feet, more than the minimum of 485 asked for.

The shower, sink, and laundry units described in the next section are eight feet tall and must be placed at least 16 feet apart to allow for twice the height of clear space for fire protection. Any extra will be additional safety space.

Minimum Standards in Water Supply, Sanitation, and Hygiene

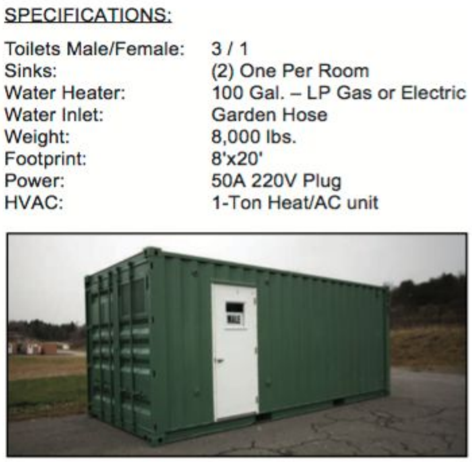
Basic Minimum Requirements

In regards to water supply and sanitation, the Sphere Handbook lays out minimum standards for toilet, shower, and water supply facilities. There must be one bathing and laundry facility per 100 people, (50 bathing and laundry facilities total). Toilet facilities must be one per 20 people (250 toilet facilities total) and each facility must be a maximum of 50 meters (~164 feet) from any shelter. Wastewater removal must occur at least 30 meters (~ 98.4 ft) away from drinking water sources or storage. Each household must also be able to access a water source no more than 500m (~1640.4 feet) away from their shelter and there must be one tap per 250 people with a wait time of less than 30 minutes for water.

These are all minimum standards from the Sphere Handbook which may be exceeded if thought necessary for the layout and success of the refugee camp during planning.

Sanitation Facilities

After doing research on commonly used portable bathroom, shower, and laundry units, the team decided to use the containerized toilet, shower, and laundry units from the US Army's Deployed Resources for emergency camps and disaster response because the camp allows for materials to be shipped from the United States. The containerized toilet, shower, and laundry units from Deployed Resources are shown below in Figures 16, 17, and 18, respectively, and are shown on the plan as an 8 ft x 20 ft footprint, which are the sizes for all three units as listed in the specifications.



SPECIFICATIONS:

Toilets Male/Female:	3 / 1
Sinks:	(2) One Per Room
Water Heater:	100 Gal. – LP Gas or Electric
Water Inlet:	Garden Hose
Weight:	8,000 lbs.
Footprint:	8'x20'
Power:	50A 220V Plug
HVAC:	1-Ton Heat/AC unit

Figure 16. Containerized Toilet Unit, Deployed Resources.

Containerized for durability, each shower unit provides 6 individual shower stalls, 2 lavatory sinks, hot and cold water, climate control and interior lighting. Designed from the ground up with field conditions in mind, these units are plug-and-play and can easily adapt to existing municipal water and sewer systems. In areas without utilities, temporary water and wastewater systems can be provided. Units can be positioned on the ground or left on the chassis trailer for immediate mobility and flexibility.

SPECIFICATIONS:

Showers / Sinks:	6 / 2
Water Heater:	100 Gal. - LP Gas or Electric
Water Inlet:	Garden Hose
Weight:	8,000 lbs
Footprint:	8' x 20'
Power:	50A 220V Plug
HVAC:	1-Ton Heat/AC unit

SPECIFICATIONS:

Showers / Sinks:	6 / 2
Water Heater:	100 Gal. - LP Gas or Electric
Water Inlet:	Garden Hose
Weight:	8,000 lbs
Footprint:	8' x 20'
Power:	50A 220V Plug
HVAC:	1-Ton Heat/AC unit

Figure 17. Containerized Shower Unit, Deployed Resources.

SPECIFICATIONS:

Washers/Dryers:	6 / 6
Water Heater:	100 Gal. - LP Gas or Electric
Water Inlet:	Garden Hose
Weight:	8,000 lbs
Footprint:	8' x 20'
Power:	50A 220V Plug
HVAC:	1-Ton Heat/AC unit

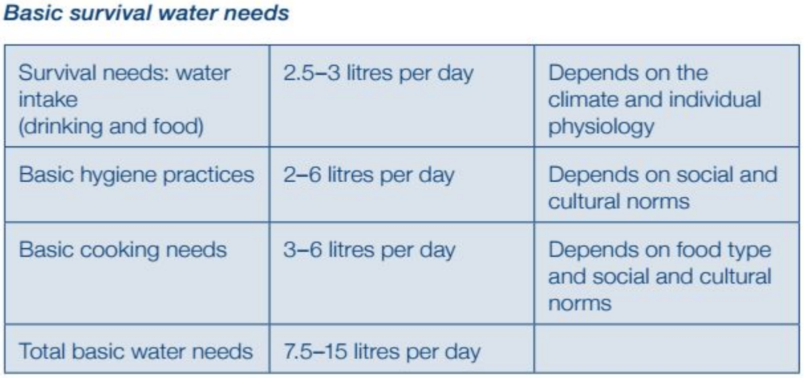
Figure 18. Containerized Laundry Unit, Deployed Resources.

These shower, toilet, and laundry units are ideal for a refugee camp situation because they are compact, easily transportable, and can be used independently or combined with other units. The toilet unit has flushing toilets, eliminating the need for trench latrines, and the laundry units can use both hot and cold water. According to Sphere standards, toilet units will be segregated by sex and each toilet facility has sinks in the unit for sanitary handwashing.

Water Supply Needs and Storage Facilities

For water supply, the Sphere Handbook provides the chart shown below in Table 11, which states that each person needs 7.5 to 15 liters per day minimum for survival, hygiene, cooking, and other basic needs. Since the camp the team designed held 5,000 people, this means that 75,000 liters of water needed to be available on site per day. Each household was placed within the standard of no more than 500 m from a water source.

Table 11. Basic Survival Water Needs, Sphere Handbook.



Basic survival water needs

Survival needs: water intake (drinking and food)	2.5–3 litres per day	Depends on the climate and individual physiology
Basic hygiene practices	2–6 litres per day	Depends on social and cultural norms
Basic cooking needs	3–6 litres per day	Depends on food type and social and cultural norms
Total basic water needs	7.5–15 litres per day	

For a consistent look and setup, the water source used was the Containerized Sink Unit from Deployed Resources, which has 16 hot and cold water sinks as shown below in Figure 19. The residents can use these sinks to fill up their water storage for their homes.

SPECIFICATIONS:

Sinks:	16
Water Heater:	100 Gal. - LP Gas or Electric
Water Inlet:	Garden Hose
Weight:	8,000 lbs
Footprint:	8' x 20'
Power:	50A 220V Plug
HVAC:	1-Ton Heat/AC unit

Figure 19. Containerized Sink Unit, Deployed Resources.

To fulfill the needed 75,000 liters of water per day, water may be transported on site by trucks and stored in durable, re-useable containers. There are many options available for water storage, including those that can be installed underground with concrete backfill, collapsible water storage "bladders," and above ground, standing water tanks.

Based on researching the materials of some different options found online and considering the climate of Greece, the team decided to use the durable, collapsible bladders for water storage on site. Greece's climate is mildly rainy winters, warm and dry summers, and extended periods of sunshine, so no extreme weather conditions need to be taken into consideration because they are very unlikely (hail, lightning, hurricanes, tornadoes, etc). With low danger of puncture, the bladders provided the most cost-effective method and are extremely easy to transport and ship as when empty they simply fold or roll up. While standing tanks may not be stable enough to withstand the wind and earthquake loads the shelters were designed for, the bladders are flexible and lay on the ground and should be able to move around without breaking in these situations. Figure 20 below shows a picture of the bladder that will be used, from Portable Tanks, a division of GEI Works, Inc.

Figure 20. Bladder Potable Water Storage Tank for Camp, Portable Tank Group.

The company has bladders ranging in sizes from 94 to 794,936 liters. With a need of 75,000 liters per day (525,000 liters per week), the team decided to use three of the largest size bladders, which will provide about enough water to last the camp a month (2,378,808 liters or 31.7 days at 75,000 liters/day). With these three large bladders, water will only have to be shipped in to refill the storage once a month. The bladders have two-inch connections that will allow for domestic hoses to attach to each and connect the water to the shower, bathroom, and sink units.

The fabric of the tanks can vary depending on the desired lifespan of one to seven years and are durable for temperature changes, sunlight, and weather. They are safe for drinking water and meet FDA standards for drinking water storage. The dimensions of each bladder are 75 ft x 73 ft x 6 ft (22.8 m x 22.5 m x 1.8 m) and were placed at the North end of the camp.

Wastewater Removal & Treatment

Removing human waste and wastewater from toilet, shower, sink, and laundry units is a huge consideration in a scenario where there is no municipal underground wastewater system to tie into that will transport the waste to a treatment facility. Because the toilet units used are flushing, there was no need for trench latrines at the toilet site, which would cause unpleasant odors for the users. Instead, in the team's design, water from flushing would be carried in pipes to a wastewater storage tank which was transported out of the camp for proper disposal at a municipal wastewater treatment plant every week. In the camp plan, the wastewater storage tanks were at least 30 meters (~ 98.4 feet) away from the potable water tanks to avoid contamination of drinking water and health concerns. The same company that sells the bladders for potable water, the Portable Water division of GEI Works, has bladder storage for greywater and wastewater, which are durable enough for extended exposure to wastewater and the elements. They are manufactured from heavy-duty coated fabrics, which can function for one to seven years depending on thickness and fabric choice. A photo of the bladders is shown below in Figure 21.

Figure 21. Grey and Waste Water Portable Bladder Tanks, Portable Tanks.

The largest size bladder they carry holds up to 794,936 liters and the dimensions are 75 ft x 73 ft x 6 ft. Due to the large volume of people in the camp, surplus room for a week's worth of wastewater was accounted for. Two of the largest bladder storage tanks would provide 1,589,872 liters of storage, which was enough for each of the 5,000 residents to use the toilet over five times per day at 7.5 liters per flush. Four additional bladders were used as storage of greywater from laundry, sink, and shower units. In total, three bladders were placed on the West and East sides of the camp, one for blackwater and two for greywater.

Electricity

Light and electricity are vital for creating a comfortable, safe home and refugee camp. It was decided that each shelter would contain one seven-Watt LED dimmable lightbulb and, as known from Deployed Resource's specifications, each of the containerized units runs on 220 Volts of power. This totals to 11,000 Watts. Solar street lamps, as shown in Figure 50 below, were placed along main roads every 50 m (~165 ft) and along small roads every 100 m (~328 ft) on alternating sides of the road.

Figure 22. Solar Street Lamps.

In order to provide a power source for the entire camp, the total wattage demand was determined. To summarize the power requirements for the camp, the summary in Table 12 was created estimating the electricity demand the community, medical, and education facilities and using specifications from light fixtures and containerized units from Deployed Resources.

Table 12. Summary of Electricity Demand.

Item	**Quantity**	**Wattage per Unit**	**Total Wattage (kW)**
LED Lightbulb	2500	7	0.1750
LED Street Light	106	11	1.17
Toilet Unit	96	11,000	1,056
Laundry Unit	24	11,000	264
Shower Unit	96	11,000	1,056
Sink Unit	24	11,000	264
Medical Center	6,250 sq ft	~70 W per 100 sq ft	4.375
Community Center	150,000 sq ft	~50 W per 120 sq ft	62.5
Education Center	40,000 sq ft	~70 W per 100 sq ft	28
Total	**-**	**-**	**4056.22 kW**

Because the climate in Greece is very sunny, it was decided that solar power would be a an available and sustainable source of power, however there needed to be a backup source of power for when sun is not shining, especially during long storm periods. For solar power, military grade solar transportable modular power units are available in the United States and Europe and provide about 34 kW of power per day given five hours of sunlight. The generator, shown below in Figure 23, was designed to withstand harsh environments and can be easily set up in five minutes by one person. It can be used to provide refrigeration for medical supplies, operate water filtration systems, and power communication equipment to aid refugees. The team planned on using these to provide solar power for the camp as much as possible.

Figure 23. Military Grade Solar Transportable Modular Power Unit, OkSolar.com.

Because highest demand for electricity tends to be after sunset and because over 120 solar units would be needed to meet the estimated demand, it was decided that the solar units would be supplemented with diesel generators, which can provide up to 600 kW in a single unit, although larger.

Roads & Walkways

The Sphere Handbook states that the camp and any primary storage facilities should have safe, all-weather accessible roads leading into it which can be used by all size vehicles and trucks. For this purpose, two-way asphalt roads were designed to run up either side of the main facilities (community, medical, education, and gym). The handbook also states that other facilities should be accessible by light vehicles, so secondary two-way asphalt roads with 10-foot lanes were designed to branch off from the main circle road on either side to run through the camps and end at the water or wastewater storage tanks. A 10-foot lane can still easily be accessible by larger trucks, so the storage facilities would have all-weather access by a range of vehicle sizes. Lastly, the handbook states that roads to individual dwellings should also be safe and all-weather accessible by residents. Leading off of the secondary roads, 10-foot wide one-way asphalt roads were designed to enter each cluster of 25 shelters. All roads were connected by a circular, two-way road surrounding the entire camp. This way, vehicles can enter any part of the camp or simply go around the edges to pick up wastewater and potable water and deliver more water.

John Brown University Competition Results

Shelter Building and Testing

Building Time and Success

Figure 24. The team builds the shelter during the timed setup

The shelter was estimated to take 110 minutes to build, as it was timed in a practice run through on campus at Santa Clara University. The practice run through was recorded on camera to help with efficiency. The timed construction test at the competition came out to be 99 minutes, which satisfied the requirement of the shelter needing to be built under two hours. The total time could have been even less than 99 minutes but it was constructed in stormy conditions which caused some delays. The assembly time at the competition was faster most likely due to the additional practice and familiarity the team had with the shelter. The construction process could be more efficient with four step ladders instead of two. This would allow for a quicker roof setup as all four corners could then be lined up at once. Additionally, bolting down the roof and adding the strips of tarp for waterproofing would all be quicker with the two additional stepladders. Other factors that could make a significant impact to the success and speed of the construction would be to have the wood members more visibly colored, in order to match members much faster.

Wind Test Results

The shelter was designed to withstand wind loading of 46.6 mph sustained for five minutes as specified in the competition guidelines. As shown in the calculations above, the required strength in the tension cables was 612 lbs, using a load factor of 1.6. The structure was expected to be able to withstand more than 46.6mph because the tension cables were rated for 750lbs of force. The shelter was able to easily withstand five minutes of wind loading at 50 mph and actually went on to withstand more force. The shelter finally failed due to uplift and torsion at 90 mph and the wind-loading machine was shut off at 110 mph. The structure was still standing at the end of the test but was damaged beyond repair due to the deformation in the wood members. Although these results are exceptionally good, the team felt that the structure would have been able to withstand even more load if it was anchored to the ground. In addition, the shelter was at a disadvantage from the beginning of the test because the testing of an adjacent shelter had deflected 120 mph wind into the door and blew it away prior to the start of our test. One way the team felt results could have been improved was if the wall panels were better supported, since they were the weakest part of the structure and were among the first elements to fail. The following figure shows the prototype at its failure point during the wind test.

Figure 25. Prototype at failure during wind test

Earthquake Shake Table Test Results

The following picture shows the team's prototype shelter on the shake table at the competition.

Figure 26. Prototype on Shake Table

As the John Brown University competition guidelines specified, the shelter was required to withstand sustained shaking for 1 minute for a simulated magnitude 7 earthquake. There was also a range of frequencies (1 Hz - 2.5 Hz) that the shelter underwent during this minute. After the shelter was completed, there was minimal damage and the shelter remained standing. The only noticeable damage to the structure was the loosening of the tension cables and the loss of one roof bolt that was believed to not be secured properly. Since this damage was easily fixable, the structures integrity was not compromised and the structure met the required specifications. The tension cables would be more effective if a mechanical means was implemented to tighten the tension cables, or by using a simpler cable such as come-alongs.

Rain Test Results

The shelter was tested before the competition for water proofing in the SCU engineering quad. The team assembled the shelter during the rainy weeks in March and April. The rain provided the team with periodic tests for overall shelter waterproofing. The shelter was waterproofed using the corrugated plastic roof, the side panels, and flooring. The predicted result of the competition rain test was that the three-part system would protect the shelter from any water leaks from vertical rainfall.

The competition rain test that was originally scheduled was cancelled because of the weather in Arkansas. On the day of the timed assembly and rain test, Arkansas experienced well above the target design water load for the competition. The judges decided that the rain outdoors would be suitable enough to do a thorough assessment of the waterproofing of the structures.
The results of the rain test were that the shelter did have small leaks between the top of the walls

and the roof. The small slits that existed between the roof panels allowed for rain that was coming in sideways due to the high winds to get into the structure. Additionally, some roof bolts appeared to have leaked overnight.

The shelter waterproofing could be improved through more continuous waterproofing between the roof panels and the side walls. The gaps that existed for ease of assembly eventually provided routes for water to enter the inside of the shelter. This problem could be addressed by using continuous flashing around the top and bottom of the walls, creating a waterproofing barrier from the roof to the top wood beam, and fabricating and continuous roof panel.

Heat Retention Test Results

The temperature change and heat retention calculations predicted an expected heat loss of 30.5 degrees Fahrenheit. These calculations assumed that heat loss was constant over time and that floor temperature remained constant. However, in the competition, the shelter had a temperature loss of 60 degrees Fahrenheit before finding equilibrium in the thermal booth. The judges commented that the heat retention tests are typically the most challenging for the shelter competition, and this was the case for the team. The biggest improvement that could be implemented to the shelter for insulation and heat retention would be to have the floor sealed to the walls. Additionally, foam boards used on the walls could prove to be more effective if boards that are more expensive were bought with higher “R” or thermal values.

The following graph shows the data taken from the heat retention test of the shelter.

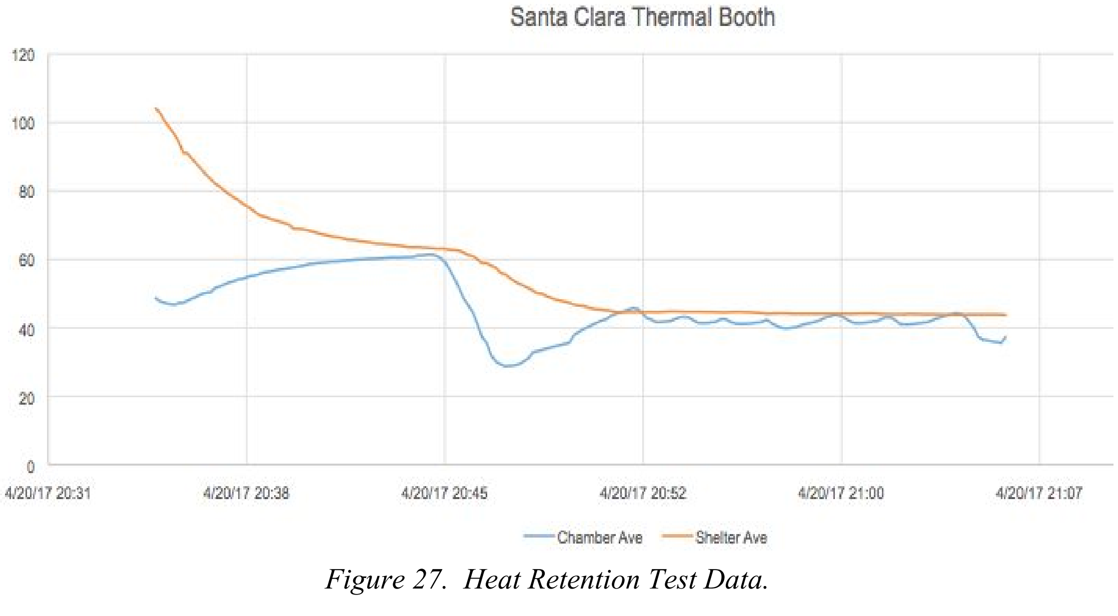
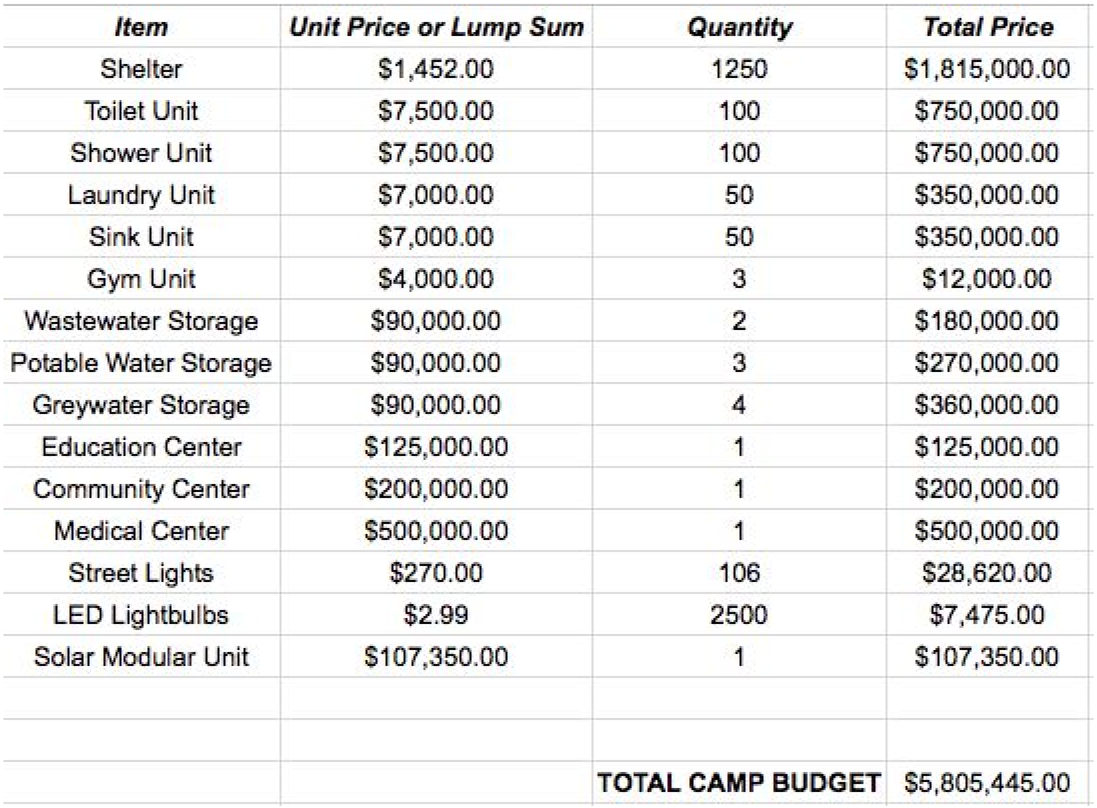


Figure 27. Heat Retention Test Data.

Camp Plan Feedback

In the competition, the camp plan won the award for “Best Camp Plan” and judges commented that the plan was many levels more in-depth than other teams. The team was recognized for their thorough planning and hitting every aspect of the camp plan, from electricity to lighting to sanitation to safety to water supply, and much more. While the camp plan was very detailed based on the information given, there were a few judge comments that led the team to identify improvements that could have been made. First of all, a cost estimate of the entire refugee camp was not estimated, and judges indicated that this would have been a helpful parameter by which to evaluate the feasibility of the camp. While this would have been very difficult due to the fact that the costs of labor and construction of community facilities (such as the medical, education, and community centers) were unknown and many products used (such as containerized units, water storage bladders, etc.) did not have prices listed online, after the judge's comment a rough estimate was attempted. The manufacturers for the storage bladders, containerized units from Deployed Resources, and solar electricity generators were contacted for quotes. Although not all manufacturers responded to the quote requests, a rough budget was put together using the prices given in quotes as well as estimates. For construction estimates, a contact who does construction in Nicaragua and is familiar with building medical centers and the like in poor countries was able to give an estimated lump sum value to use in the budget. While inaccurate due to not considering pipes and fittings as well as possible errors in the estimates, a rough estimate of about 5.8 million dollars resulted from the budget and gives an idea of how much it would cost to put together a safe, clean, and thorough refugee camp. The budget estimate can be seen below in Table 13.

Table 13. Total Camp Plan Budget Estimate.



Item	*Unit Price or Lump Sum*	*Quantity*	*Total Price*
Shelter	$1,452.00	1250	$1,815,000.00
Toilet Unit	$7,500.00	100	$750,000.00
Shower Unit	$7,500.00	100	$750,000.00
Laundry Unit	$7,000.00	50	$350,000.00
Sink Unit	$7,000.00	50	$350,000.00
Gym Unit	$4,000.00	3	$12,000.00
Wastewater Storage	$90,000.00	2	$180,000.00
Potable Water Storage	$90,000.00	3	$270,000.00
Greywater Storage	$90,000.00	4	$360,000.00
Education Center	$125,000.00	1	$125,000.00
Community Center	$200,000.00	1	$200,000.00
Medical Center	$500,000.00	1	$500,000.00
Street Lights	$270.00	106	$28,620.00
LED Lightbulbs	$2.99	2500	$7,475.00
Solar Modular Unit	$107,350.00	1	$107,350.00
		TOTAL CAMP BUDGET	$5,805,445.00

Suggested Modifications or Improvements

Upon returning from the competition in Arkansas, the team brainstormed on ways that the shelter could have been improved to perform better at the competition. The following sections detail the main improvements that would have lead to greater success.

Shelter Structure

The disaster shelter designed for the competition was quite heavy due to the wood framed members. An improvement that would help the shelter weight would be to use lighter and higher quality wood or change to lightweight still but that would increase the cost significantly. The reason why higher quality wood was not originally used was because of budget constraints.

The wood used for the frame of the shelter went through the entire design phase of the project. Due to this, the wood was bolted and unbolted a vast amount of times and saw some wear and tear that led to multiple cracks. While the wood was very sturdy and did hold up effectively in the competition, the shelter could be improved with newly bought wood that had not gone through the wear and tear.

Connections

The shelter consisted of numerous amounts of connections, generally bolted, in order to allow for the shelter to be assembled and disassembled. With all the connections, the assembly process was at times tedious and time consuming. An improvement to have less connections could be to have pre-assembled pieces for the roof, walls and frame that would reduce the amount of connections done on site. A constraint that made the team choose to individual members instead of pre-assembled sections was shipping considerations. Having larger pieces of the shelter would make it harder to move the materials to the competition since our group had a considerable distance to come from Santa Clara, California to Arkansas and would have increased our cost exponentially.

Walls

An improvement to the walls of the shelter that could of been made was to use panels or plywood that give the shelter more structure as well as help insulate and seal more effectively. The tarp and foam insulation boards used in the shelter were less expensive and lighter but were susceptible to bending in the wind. This issue caused wear and tear as well as making the occupants uncomfortable inside when the walls are to be blown inward. A more sturdy siding would help prevent this except that this method would have been a considerable amount of weight and cost that would have exceeded the shelter requirements.

Tension Cables

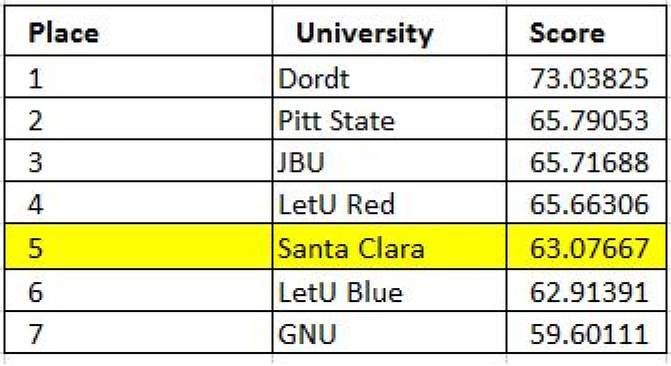
The tension cables were used in order to provide more lateral support to the frame of the shelter. Each individual tension cable was permanently attached to an eye hook at one corner of the frame while the other end had a hook. This way the cables could be taken on and off easily. At first, the tension cables were used with turnbuckles in order to have a mechanical way to tighten the cables. The turnbuckles though, proved to be difficult to work with without any advanced equipment and would wind and twist the wire until the turnbuckles would unwind itself. As a second alternative the team tried nylon come-along straps instead of using steel wire. While the nylon straps proved much easier to work with than the turnbuckles as they were easier to tighten, there were concerns over the longevity of the straps. The nylon straps had to be hand cranked and the team was concerned of them loosening as well as the fact that the straps are not meant to be tensioned for long periods of time. Therefore, steel tension wire was revisited, using clamps that could be pulled to the tautness needed to provide ample structural support. The tension cables would be improved with an easier system for tensioning them.

Project Conclusion

Figure 28. The team holding their awards with a Samaritan's Purse Representative

Overall in the competition the team placed 5th out of the seven teams that participated in the competition. Three of the teams failed to make it to Arkansas with a testable shelter. Santa Clara won two awards in the competition for Best Report/Presentation and Best Camp Plan. See Appendix F for complete scoring breakdown.

Table 14. John Brown University 2017 Competition Results



Place	University	Score
1	Dordt	73.03825
2	Pitt State	65.79053
3	JBU	65.71688
4	LetU Red	65.66306
5	Santa Clara	63.07667
6	LetU Blue	62.91391
7	GNU	59.60111

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APPENDIX A:
Prototype and Process Photos

Prototype and Process Photos

The following photos were taken throughout the design, building, and testing process of the prototype. AutoCAD drawings of the prototype can be found in Appendix D.

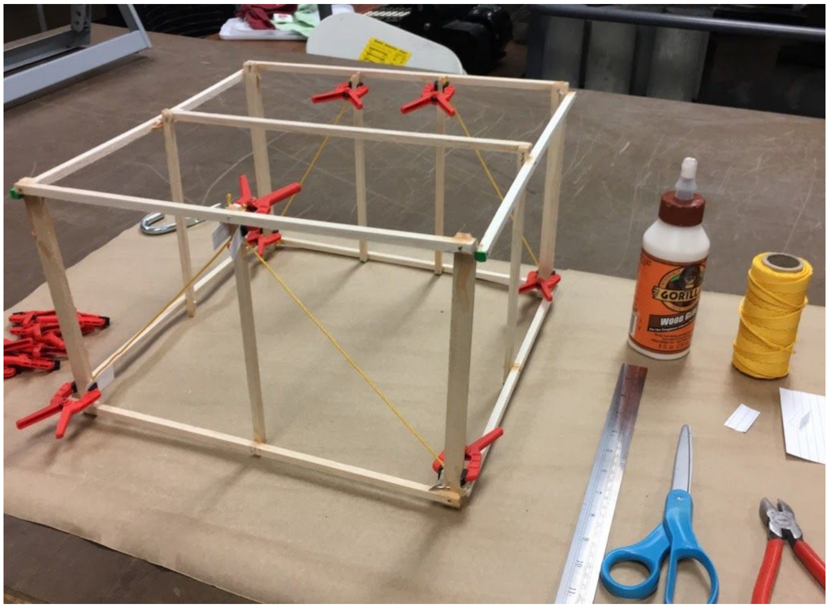


Figure 29. Shelter Prototype: shows layout of all the wood connections and tension cables

Figure 30. Roof and Frame: Finished framing with completed roof

Figure 31. Frame to Roof: Corner roof connection with eyebolt and tension cable

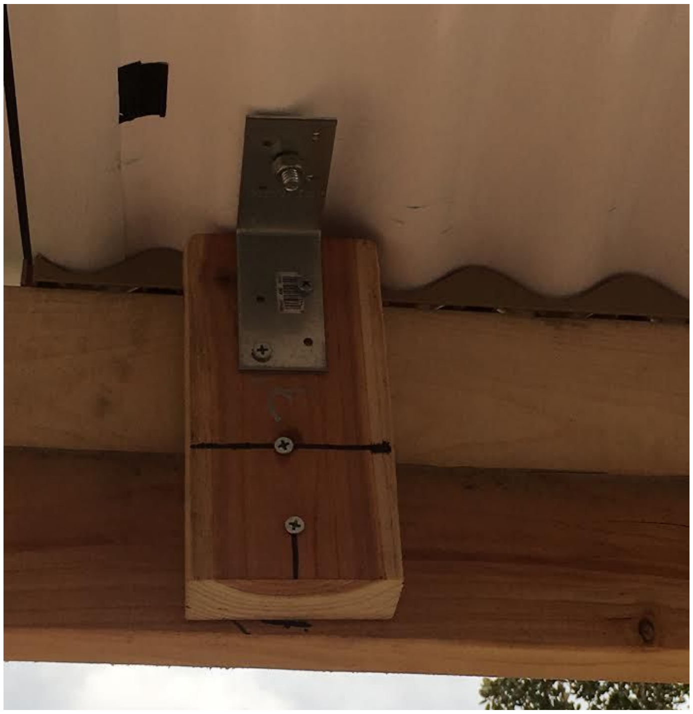


Figure 32. Frame to Roof: Typical connection

Figure 33. Frame to Roof: Midsection connection

Figure 34. Roof Cross Bracing: Typical connection

Figure 35. Typical Wall: Connection & Insulation

Figure 36. Typical Wall: Front View with Insulation and Waterproofing

Figure 37. Typical Wall: Inside View with Insulation

Figure 38. PVC Roof Panel : Panel to panel gorilla tape connections

Figure 39. Typical Bolt Hole: Drilling

Figure 40. Typical Bolt and Framing Connection

APPENDIX B:
Existing Shelter Design Review

Existing Shelter Designs Review

This section reviews existing disaster shelter designs that are already in use. Each shelter was evaluated on the materials used, locations of current use, sustainability, ease of assembly, cost efficiency, durability and adaptability, overall structural success and how it influenced the new prototype design. This evaluation was performed to aid in the design of the prototype shelter for the competition.

List of Shelters Reviewed:

1. "Better Shelter" by UNHCR and IKEA Foundation
2. Nader Khalili Built Earth Buildings
3. Stackable Exo Emergency Shelters
4. Collapsible Woven Shelters

"Better Shelter" by UNHCR and IKEA Foundation

Figure 41. Better Shelter Finished Exterior.

Shelter Description

This shelter, as pictured in Figure 41, above, is made up of four walls and a high dual sloped roof which are all made from semi-hard, non-transparent polyolefin panels that are connected to a lightweight galvanized steel framing system. The shelter has an area of 17.5 square meters and houses five people comfortably. The framing system, shown in Figure 42, below, includes diagonal steel tension cables that add to the structural strength of the shelter. The shelter can also be anchored to the ground for further strength against wind, rain, and snow loads.

The shelter is completely modular so various shapes and sizes can be built for different needs. There is one door that is lockable from both the inside and outside, as well as a solar powered lamp that illuminates the interior.

Figure 42. Steel framing system with steel tension cables.

Locations of Current Use

Iraq

More than 250 Better Shelters were ordered to be used for refugees in the Baghdad area in 2015, and there are plans to order 250 more once more funds are acquired. Also in 2015, over 3500 shelters were delivered throughout Iraq to different refugee relief programs. A photo of their construction in Iraq is shown below in Figure 43.

Figure 43. Better Shelters under construction in Iraq.

Greece

In September of 2016, 520 Better Shelter Units were delivered to UNHCR in Greece to the Karatepe transit camp. Also, 220 shelters were assembled in October of 2016 in Mytilini for refugees. The majority of these refugees are from Syria, and refugees of other nationalities are directed to the Moria transit camp. A photo of the Better Shelters in Greece is shown below in Figure 44.

Figure 44. Better Shelters used in Greece.

Sustainability and Durability

Both the lightweight steel frame components and polymer plastic panels can be recycled after the shelter has been used. All of the shelter parts can fit into two cardboard boxes which fit into a regular sized shipping container for transport. Because of the lightweight materials and compact storage, one 40 foot long "High Cube Container" shipping truck can contain 48 shelters. Thus, money is saved on shipping the shelters to the area in need. The modular constructability of the shelter allows it to be easily repaired if an area is damaged, so an entire new shelter does not need to be constructed. The Better Shelter is expected to last for at least three years in moderate climates, after which the materials will be recycled or used in other shelters. The shelter also includes a solar panel that can be used to power an interior lamp and various other electronic devices.

Ease of Assembly

The Better Shelter can be constructed by a team of four people in four hours without tools. One cardboard Box A contains the steel foundation, roof frame, roof panels, and solar panel. Box B contains the wall frames, wall panels, windows and door. These boxes are packed in the order of which the components should be built. Included in the boxes are instruction manuals and all necessary tools.

The shelter can be constructed easily in three stages:

1 – Steel Foundation
2 – Roof with ventilation and solar panel
3 – Walls with windows and door

Cost Efficiency

The shelters are shipped from the Better Shelter warehouse, located in Gdansk, Poland. The overall cost of the Better Shelter varies depending on how many are ordered and where they need to be shipped to. The cost of materials and building the shelter, however, are estimated to be approximately $1,150. For a refugee camp housing 5000 people, the overall cost would be around $1,150,000 because each Better Shelter can house up to 5 people.

Adaptability

The Better Shelter is easy to adapt to different needs because of the modular design of the walls and roof, which can be placed into any section of the framing system. More frame sections can also be added to increase the size of the shelter to suit different uses. This shelter can also be used for different applications, such as an emergency medical tent.

Structural Success

This shelter is extremely successful according to UNHCR because its design allows it to be easily adapted while still being structurally sound. The prototype shelters have been evaluated by UNHCR regarding the environmental, logistic, and financial framework that the shelter is designed for. The designers also considered the personal, social, and cultural expectations of the inhabitants the shelter will have. Hundreds of Better Shelters have been used in multiple camps in Greece and thousands have been used globally due to the successful design. Figure 45, below, shows the Better Shelter being used in a refugee camp in Baghdad, Iraq.

Figure 45. Better Shelter in a Refugee Camp in Baghdad, Iraq.

Connection to the Prototype

Researching this shelter was very helpful because it was very similar to the team's original design idea. This shelter was also under the $1,500 budget limit for the competition, so it was very helpful to see what kinds of materials were used. Better Shelter units were also used for refugee camps in Greece to house for Syrian refugees, so the team was very interested in this shelter because of the similarity with the competition situation and its elements aided in the design stage of the team's prototype.

Nader Khalili Built Earth Buildings

Figure 46. Built Earth Buildings Exterior in the Baninajar Refugee Camp in 1994.

Shelter Description

The Built Earth Building shelters, shown above in Figure 46, are made up of various sized sandbags that are filled with moistened earth so that the sand is more easily compatible. The sandbags are arranged in layers or long coils as shown below in Figure 47 and wrapped with barbed wire and a stabilizer, such as cement, lime, or asphalt emulsion.

Figure 47. Shelter Sandbag Arrangements.

Various Locations of Use

Haiti

These shelters were used in Port-au-Prince and surrounding cities after the devastating earthquake in 2010, as shown below in Figure 48. These structures included a 10-foot main dome with three small apses for sleeping, cooking, and storage. A door was built out of recycled pallets, and small air vents were made using PVC pipes.

Figure 48. Built Earth Building in Haiti after the 2010 earthquake.
source: http://www.calearth.org/relief-initiatives/

Pakistan

These shelters were also used in northern Pakistan after the October 2005 earthquake, as seen below in Figure 49. The sandbags were distributed and hundreds of refugees were trained to build the shelters.

Figure 49. Built Earth Building used in Pakistan after the 2005 earthquake.
source: http://www.calearth.org/relief-initiatives/

Nepal

Over 40 domes were built in 2006 for children and their caretakers in the Pegasus Children's Project in Nepal, as seen below in Figure 50. These domes later survived the magnitude 7.6

earthquake in 2015 and all the inhabitants were safe and could continue living in the domes after the earthquake.

Figure 50. Built Earth Buildings in Nepal.

Sustainability

These shelters are extremely sustainable because they use mainly earthen materials and require no power tools or transportation. The sand bags used are synthetic low UV resistant and bio-degradable, so they will cause no harm to the environment after their use is up. The barbed wire that is used can come from a recycled source and can be recycled again if the shelter is ever demolished. Since the bags are most often filled with sand and dirt that are close to the site, there is no need to transport heavy building materials.

Ease of Assembly

The domes can be built in one day with five to seven builders that were trained on site. These shelters can be covered with plaster for more long-term uses, or be left uncovered for temporary uses, such as a disaster situation. The only tools needed to construct one of these shelters are shovels and tampers, and the only materials needed are sandbags, soil, galvanized barbed wire, and water.

Cost Efficiency

Since the shelters use local soils and recycled materials, the cost of building one shelter is approximately $625. For a refugee camp housing 5000 people, the overall cost would be approximately $781,250 because each shelter can house four people.

Durability and Adaptability

The sandbags are made of bio-degradable material, so the shelter can only be used temporarily if it is not covered with plaster. Covering the shelters will provide more insulation, fireproofing, waterproofing, and a longer lifetime. The sandbag building system can also be used for architectural structures such as arches, domes, and vaults, as well as for landscape purposes such as stabilizing slopes and building dams.

Structural Success

These structures passed severe earthquake code tests in California and have been endorsed by the UN, so they will continue to be employed for many uses worldwide. Compressive forces are taken by the long coils of sandbags, and tensile forces are taken by the reinforcing barbed wire. Waterproofing, insulation, and fireproofing are also provided by the sandbags and possible plaster covering.

Connection to the Prototype

Conducting research on this shelter helped the team understand how they could integrate architecture and functionality into the design of their prototype. The design of these shelters also focused on incorporating temporary global safety requirements with the traditional earth architecture. After researching these shelters, the team put more of a focus on safety by emphasizing the prototypes core strength through the frame design. The team also began brainstorming how our shelter could resemble the traditional architecture of Syria.

Stackable Exo Emergency Shelters

Figure 51. Exo Emergency Shelters Stacked for Transportation.

Shelter Description

The Stackable Exo emergency shelter is an 80 square foot, lightweight stackable shelter that was inspired by a coffee cup. As seen above in Figure 51, the rigid shell has a lockable door built into it and a skylight on the roof. The floor is hollow so that it can be filled with up to 1000 lbs of water to secure it to the ground. The lightweight walls and the floor snap together to create resistance against wind loads, and the interior is climate controlled. Each shelter sleeps four adults, and beds can be attached to the walls. These characteristics are summarized by Figure 51, below.

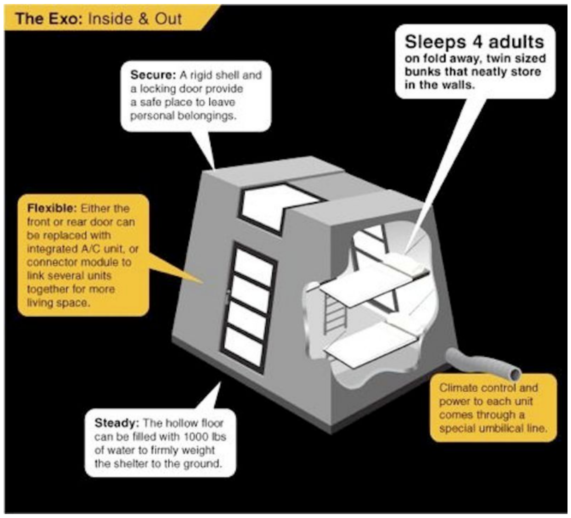


Figure 51. Description of Exo Shelter.

Locations of Current Use

Currently, the creators of the Exo Shelter are trying to attain funding to pay for the testing of five prototypes for refugee families in Syria, but no shelters are currently in use.

Sustainability

The walls of the Exo Emergency Shelter consist of Tegris, which is a durable aircraft-grade aluminum composite material. Tegris has similar properties to carbon fiber but is 100% recyclable and is much cheaper to make. It is also extremely lightweight and durable, so cost is reduced in transportation and maintenance. The hollow bottom is made up of birch and steel, which are also both recyclable.

Ease of Assembly

The shelters are stackable so they can be easily transported in large quantities. They are also extremely lightweight, at 400 pounds each, and can be set up easily in minutes by four people without any equipment. Because of the stackability and lightweight materials, the shelters can be quickly deployed in disaster situations.

Cost Efficiency

Each shelter costs approximately $5,000. For a refugee camp housing 5000 people, the overall cost would be approximately $6,250,000 because each shelter can house four people.

Durability and Adaptability

The shelters are extremely durable due to the Tegris material. They are also adaptable because the units can be connected through the door slot, so many can be put in a cluster to accommodate larger families and neighborhood units, as seen in Figure 52, below.

Figure 52. Exo Emergency Shelters in Possible Camp Plan Layout.

Structural Success

These shelters have not been previously used in a disaster situation, but will no doubt be extremely successful because of the extensive research and engineering completed in the prototype design.

Connection to the Prototype

Researching this shelter gave the team the idea to use translucent panels on the roof to allow for daylight. The team also liked the idea of having the walls and floor snap together, so various ways to achieve something similar were discussed.

Collapsible Woven Shelters

Figure 53. Collapsible Woven Shelter Design.

Shelter Description

This shelter is an entirely conceptual design, as shown in Figure 53, above. It is made of a structural woven fabric that blends aesthetics and function. The fabric is waterproof and helps to store water and electricity, as shown in Figure 54, below. The shelter expands to create the enclosure and can contract again for transportation.

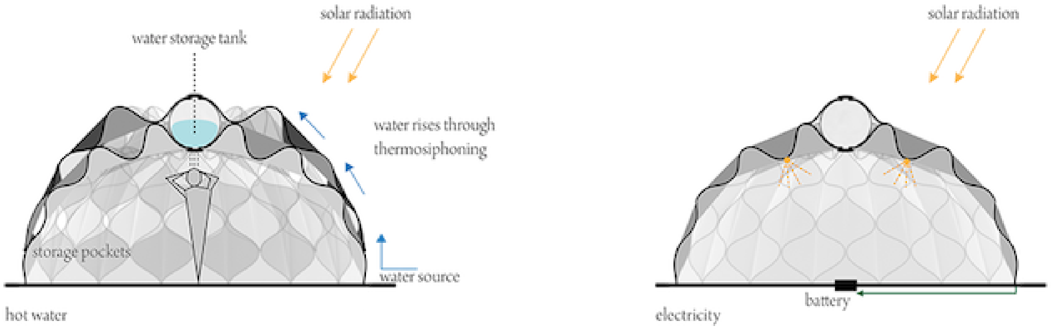


Figure 54. Description of Collapsible Woven Shelters.

Locations of Current Use

Since this is still a conceptual idea, there are no current prototypes being used.

Figure 55. Collapsible Woven Shelter Conceptual Interior.

Sustainability

The exact materials of the shelter are not known, so the sustainability of this structure cannot be discussed, however, the structure appears to be lightweight and compactable, so transportation costs and environmental impacts would be low. The conceptual drawings also show that the structure would collect water and create electricity, both of which would help reduce environmental impacts and provide a more liveable environment for the refugees.

Ease of Assembly

This structure is extremely easy to construct, since a simple expansion of the fabric is needed, however, no information on the foundation support could be found.

Cost Efficiency

The cost of one Collapsible Woven Shelter is not known because the design is only in the conceptual stage.

Durability and Adaptability

This shelter does not seem very durable because it is simply made out of fabric and easily collapses from an external force pushing in. The shelter is also not very adaptable because of the organic shape and lack of modularity.

Structural Success

There is no proof of any structural successes of this concept because there are no prototypes. This structure will likely not be successful because it can easily collapse inwards and has no connection to the ground. The structure also seems to be lightweight because of the canvas materials, so it will blow over in large wind forces if it is not secured to the ground.

Connection to the Prototype

This shelter was researched even though there are no prototypes in use because the team wanted to research various waterproof canvas materials. This shelter was helpful to the team because it added more in depth thinking about using a canvas material. The team was also intrigued by the collapsible nature of this structure and it the team to think of a way that a wooden frame system could be partly collapsible.

APPENDIX C1:
Wind Calculations

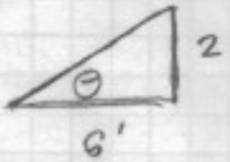
Mean roof height = 8 + 1 = 9 ft

$q_z = 0.00256 K_z K_{zt} K_d V^2 I$

V = 75 km/hr = 46.6 mph

Length = 14 ft

Width = 12 ft



$\theta = 18.4^\circ$

Roof slope = 18.4°

No overhang

K_{zt} = 1.0 (assume flat surface) Exposure B

↳ numerous closely spaced obstructions having the size of single family dwellings

Category IV building → emergency shelter

I = 1.15 from table 6-1 ASCE 7

K_d = 0.85 for MWFRS components and cladding

Assume structure is at Ground level

$K_z = K_h = 0.7$ from ASCE table 6-3

$q_z = 0.00256(0.7)(1.0)(0.85)(46.6)^2(1.15)$

$\boxed{q_z = 3.80 \text{ psf}}$

Internal Pressure Coefficient

$GC_{pi} = \pm 0.18$ from ASCE 7 Figure 6-5

External pressure coefficient

L = 12 ft B = 14 ft

	Direction	L/B	Cp	
windward wall	n/a	All values	0.8	q_z
Leeward Wall		0.857	-0.5	q_h
Side Wall		All values	-0.7	q_h

External Roof Pressure Coeffcients

Wall	h/L	Cp
windward	10/12 = 0.83	-0.4
Leeward	10/12 - 0.83	-0.4

θ = 18.4°

} In use 20° for conservative design

From ASCE Figure 6-6

$p = qGC_p - q_iGC_{pi}$

Since effective area is less than 700 sf

$p = q \times GC_p$ $G = 0.85$ for rigid

Surface	Design Wind Pressure Calcs	pressure (psf)
windward wall	p= 3.80 (0.8) (0.85)	2.584 psf
Leeward wall	p= 3.80 (0.85) (-0.5)	-1.615 psf
Side Wall	p= 3.80 (0.85) (-0.7)	-2.261 psf
windward roof	p= 3.80 (0.85) (-0.4)	-1.292 psf
Leeward roof	p= 3.80 (0.85) (-0.4)	-1.292 psf

★ Assumes Rigid Structure, G= 0.85

Questions: Do we need to consider flexible structure meaning the natural frequency of the building < 1Hz? If so, how?

↓ use huge safety factor!

The basic pressure equation (ASCE 7 6-17), which includes the internal pressure coefficient is as follows:

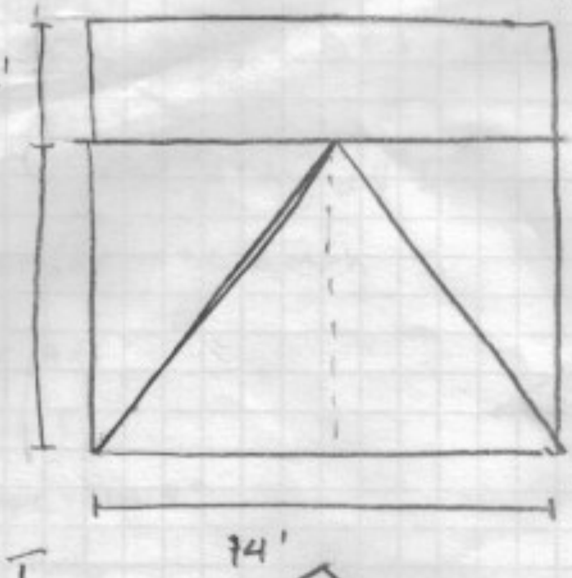
$$p = qGC_p - q_i(GC_{pi})$$

However, this would only be used if designing individual components whose effective tributary area is equal to or greater than 700 sf (ASCE 7-05 6.5.12.1.3 and IBC 2006 1607.11.2.1). When determining loads on the global structure (i.e., shear walls or foundation design), the internal pressure components will act in equal and opposite directions on the roof/floor and the leeward/windward walls, thereby algebraically canceling each other. The resulting simplified form of the pressure equation is:

$$p = q \text{ x } GC_p$$

Table F-3 summarizes the design pressures calculated using this simplified wind design pressure equation. Figure F-2 shows the application of these design pressures on the structure. For foundation design, internal pressures need not be considered since internal pressure on windward walls, leeward walls, floors, and roofs cancel each other. For example, internal pressures acting on a windward wall are equal and opposite to those acting on a leeward wall and the net force on the foundation from internal pressures is zero.

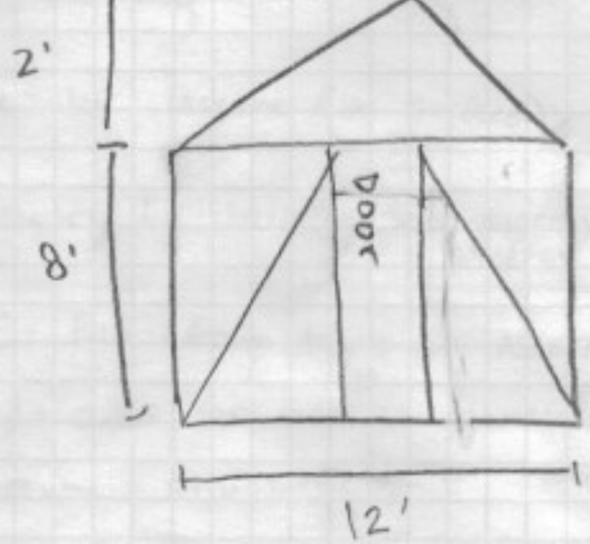
Laakea Warren | Senior Design | Sketches (Aluminum)



Side

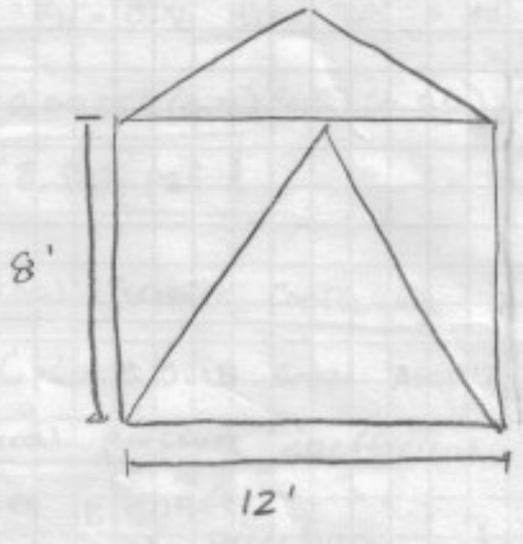
bending

uniform loads



Front

* Braces may not be required!



Back

Lateral

La'akea, Colin, Antonio   Tension Cable Calcs   Pg 1

Windward wall pressure = 2.584 psf

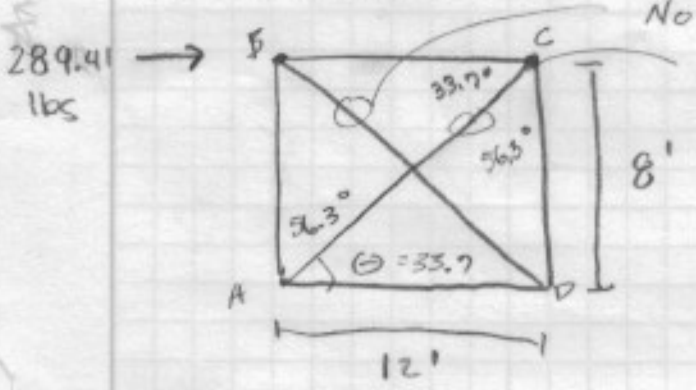
Area = $112\ ft^2$

$F = 2.584\,(2)\,(112\ ft^2) = 578.82\ lbs$

Assume side walls take ½ of F, F.S. = 2

$F_s = 289.411\ lbs$

AMPAD



No compression only tension pins

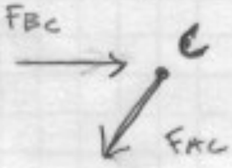
$\theta = \tan^{-1}\left(\frac{8}{12}\right) = 33.7^0$

Factored Load

use 1.6W for LRFD

$F = 1.6\,(289.41) = 463.1\ lbs$

Joint C



$\sum F_x = 0 = F_{BC} - F_{AC}\left(\cos 33.7^\circ\right)$

$0 = 463.1\ lbs - F_{AC}\left(\cos 33.7\right)$

$F_{AC} = \frac{463.1\ lbs}{\cos 33^\circ}$

$\boxed{F_{AC} = 556.64\ lbs}$

windward pressure + leeword pressure = 2.584 + 1.615 psf

$P = 4.199$ psf

$F = 2(4.199\,\text{psf})(112\,\text{ft}^2) = 940.576$ lbs

$\frac{F}{2} = F_{side} = 470.288$ lbs

$F = 1.6\,F_s = 752.46$ lbs

$F = 752.46$ lbs

$F_{AC} = \frac{752.46\,\text{lbs}}{\cos 33°}$

$F_{AC} = 904.45$ lbs

$\boxed{F_{AC} = 904.45\ \text{lbs}}$

Only LRFD (No Factor of Safety)

$F = 1.6(4.199)(112)$

$F = 752.4608$

$F_s = 376.23$

$F_{AC} = \frac{376.23}{\cos 33.7}$

$\boxed{F_{AC} = 452.2\ \text{lbs}}$

use F.S of 2 and 1.6W from LRFD

* 3/16" tension cable 125ft → Max load = 750 lbs
(Home depot)

APPENDIX C2:
Heat Calculations

5/17 | Katie Bipes

THERMAL BRIDGING CALCS

SHELTER DIMENSIONS

TO CALCULATE HEAT LOSS FOR THE GIVEN SCENARIO:

see pages 12-15 from polydynamics.com attached

SCENARIO:

- air surrounding shelter cooled to 40°F
- air inside shelter heated to 80-100°F
- temp decrease over 30 mins calculated

KNOWN:

- T_1 = 80-100°F ⇒ use avg of 90°F = 305.4 K
- T_2 = 40°F = 277.6 K
- R_1 = 3 (using Reflectix insulation - see spec sheet attached)
- R_2 = 3.85 (using R-Tech insulating sheathing specs attatchd)

HEAT LOSS SURFACE AREA

⚠ assume all surface areas can lose heat and have same insulation

$A_{roof} = 12.54' \times 12.5' = 156.75\ ft^2$
$A_{floor} = 12.5' \times 12.5' = 156.25\ ft^2$
$A_{walls\ L\&R} = 12.5' \times 8.5' = 106.25\ ft^2$
$A_{back\ wall} = 12.5 \times 8' = 100\ ft^2$
$A_{front\ wall} = 12.5 \times 9' = 112.05\ ft^2$

$\Sigma A = 661.30\ ft^2$
$= 61.44\ m^2$

2/1

TOTAL HEAT TRANSFER: (IN WATTS)

$Q = UA\,\Delta T$ (from pg. 13 of polydynamics com) see attached

$\hookrightarrow U = \frac{1}{R}\ [W/m^2K]$

Using Reflectix: $Q_{Ref} = \left(\frac{1}{3}\ W/m^2K\right)(61.44\,m^2)(305.4K - 277.6K)$

$$\boxed{Q_{Ref} = 569.3 \text{ Watts}}$$

Using R-tech: $Q_{R\text{-}tech} = \left(\frac{1}{3.85}\ W/m^2K\right)(61.44\,m^2)(305.4K - 277.6K)$

$$\boxed{Q_{R\text{-}tech} = 443.64 \text{ Watts}}$$

see pages 4-5 from polydynamics.com attached →

CONVERSION TO TEMPERATURE DECREASE IN 30 MIN

- 1 Watt = 1 Joule/second = 3.412 BTU/hr

$\therefore\ Q_{ref} = 569.3\,W \times \frac{3.412\ BTU/hr}{1\ watt} = 1942.5\ BTU/hr$

$Q_{r\text{-}tech} = 443.64\,W \times \frac{3.412\ BTU/hr}{1\ Watt} = 1513.7\ BTU/hr$

FOR REFLECTIX: $(R = 3)$

$\left(\frac{1942.5\ BTU}{1\ hour}\right)\cdot\left(\frac{1\ hour}{60\ mins}\right)(30\ mins) = 971.25\ BTU$ in 30 minutes

- from first law of thermodynamics:

$Q + W = \Delta E$

- since no work done, $Q = \Delta E = m\,c_p\,\Delta t$
- m = mass of air in room = $\rho \cdot V$

changes w/temp & elevation

★ $\rho_{air} = 1.24\ kg/m^3$

$V = 12.5' \times 12.5' \times 8.5' = 1328.12\ ft^3$

$\Rightarrow V = 37.61\ m^3$

$m = (1.24\ kg/m^3) \times (37.61\ m^3) = 46.63\ kg = 102.8\ lb$

- C_p = heat capacity of air = 0.24 BTU/lb °F

KNOWN FROM ABOVE: $Q = m c_p \Delta t$

- $Q_{total} = 971.25$ BTU in 30 mins
- $m = 102.8$ lbs
- $C_p = 0.241$ BTU/lb °F

SOLVING FOR Δt:

$$\Delta t = \frac{Q}{m \cdot C_p} = \frac{971.25 \text{ BTU}}{(102.8 \text{ lbs})(0.241 \text{ BTU/lb}\cdot°\text{F})}$$

$$\Rightarrow \boxed{\Delta t = 39.2\,°\text{F loss in 30 minutes}}$$

FOR R-TECH: (R = 3.85)

$$\left(\frac{1513.7 \text{ BTU}}{1 \text{ hour}}\right)\left(\frac{1 \text{ hour}}{60 \text{ mins}}\right)(30 \text{ mins}) = 756.85 \text{ BTU in 30 mins}$$

$$\Delta t = \frac{Q}{m \cdot C_p} = \frac{756.85 \text{ BTU}}{(102.8 \text{ lbs})(0.241 \text{ BTU/lb°F})}$$

$$\Rightarrow \boxed{\Delta t = 30.55°\text{ F loss in 30 minutes}}$$

USED FOR PART 1

CONVECTION

In most heat transfer problems, we are concerned with solid walls separating liquids or gases from each other. In such cases we usually do not know the temperatures on the wall surfaces, but rather the temperatures of the bulk of fluids on both sides. Careful experiments supported also by theoretical considerations, have shown that the greatest temperature drop is confined within a thin fluid layer attached to a solid surface, as shown in Fig. 6.

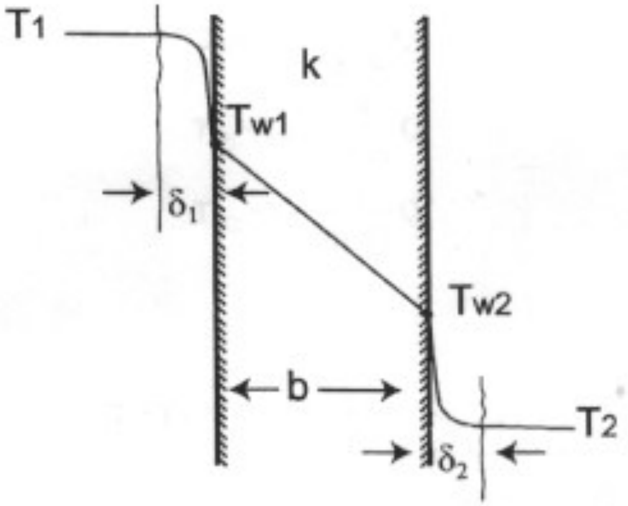


Figure 6
Heat transfer through a wall separating two fluids.

To explain this observation, we may assume that a thin film, of thickness δ, adheres to the wall, whereas outside this film all temperature differences vanish as a result of mixing motions. Within the film heat flow takes place by conduction, as in a solid wall. Thus, in general, we may write

$$Q = \frac{k}{\delta} A(T - T_w)$$

The quantity $k/\delta = h$ is called the <u>heat transfer coefficient</u> and it is an extremely important concept in heat transfer. This simplified model is very useful for practical applications, because the calculation of heat transfer can be made in terms of the heat transfer coefficient:

$$Q = h A (T - T_w)$$

At this point it suffices to say that the heat transfer coefficient depends on the flow conditions and fluid properties. Typical values are given in Table 2. In the next section we will present some correlations that can be used for the more accurate determination of this coefficient.

For the wall separating the two fluids of Fig. 6, we have

5/μ

$$Q = h_1 A\ (T_1 - T_{w1})$$
$$Q = \frac{k}{b} A\ (T_{w1} - T_{w2})$$
$$Q = h_2 A\ (T_{w2} - T_2)$$

or

$$T_1 - T_{w1} = \frac{1}{h_1 A} Q$$
$$T_{w1} - T_{w2} = \frac{b}{k A} Q$$
$$T_{w2} - T_2 = \frac{1}{h_2 A} Q$$

By summing up

$$T_1 - T_2 = \left(\frac{1}{h_1 A} + \frac{b}{kA} + \frac{1}{h_2 A}\right) Q$$

or

$$T_1 - T_2 = \frac{1}{A}\left(\frac{1}{h_1} + \frac{b}{k} + \frac{1}{h_2}\right) Q$$

The quantity in the brackets is called the <u>total thermal resistance</u>. A more useful concept, however, is the <u>overall heat transfer coefficient</u>, which is defined as follows

$$\frac{1}{U} = \frac{1}{h_1} + \overset{\Delta R}{\boxed{\frac{b}{k}}} + \frac{1}{h_2}$$

For a composite wall separating two fluids (a and b), we have

$$\frac{1}{U} = \frac{1}{h_a} + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \ldots + \frac{1}{h_b}$$

Then, in general, we have:

$$T_1 - T_2 = \frac{1}{A}\,\frac{1}{U}\ Q$$

and

$$\boxed{Q = U\ A\ \Delta T}$$

6/1

The significance of the overall heat transfer coefficient is that it permits the calculation of the rate of heat flow by multiplying this quantity by the heat exchange area (perpendicular to the heat flow direction) and the temperature difference.

Example

Determine the heat loss through an 8-ft by 4-ft glass window of 4 mm thickness. The inside temperature is assumed to be 24°C (75°F) and the outside temperature is –10°C (14°F). The inside heat transfer coefficient is 5 W/m°C and the outside about 20 W/m°C (due to moderate wind). The thermal conductivity of window glass is 0.78 W/m°C.

Solution

The overall heat transfer coefficient is

$$\frac{1}{U}=\frac{1}{h_1}+\frac{b}{k}+\frac{1}{h_2}=\frac{1}{5\ W/m^2\,{}^\circ C}+\frac{0.004\ m}{0.78\ W/m^2\,{}^\circ C}+\frac{1}{20\ W/m^2\,{}^\circ C}$$
$$=0.2+0.005+0.05=0.255\ m^2\,{}^\circ C/W$$

$$U=3.92\ W/m^2{}^\circ C$$

The rate of heat flow is

$$Q=U\ A\ (T\ -T_2)$$
$$=3.92\ W/m^2{}^\circ C\times(2.44\times1.22\,m^2)\ (24^\circ C-(-10^\circ C))$$
$$=3.92\times2.98\times34=397\ W$$
$$=1355\ Btu/hr$$

Convection Heat Transfer Coefficient Calculation

The most important step in heat convection calculations is the determination of the appropriate heat transfer coefficient. The higher the fluid velocity is, the higher the heat transfer coefficient will be. Numerous correlations have been developed for the calculation of the heat transfer coefficient in terms of dimensionless groups:

Nusselt number is the dimensionless heat transfer coefficient defined as

$$Nu=\frac{h\ D}{k}$$

$$Q = \frac{T_1 - T_n}{\frac{b_1}{k_1 A} + \frac{b_2}{k_2 A} + \ldots \frac{b_n}{k_n A}}$$

Table 1

Some typical values of thermal conductivity (k)

	W/m°C	Btu/hr ft°F
Copper	380	220
Aluminum	204	118
Carbon Steel	43	25
Glass	0.78	0.45
Polymer	0.2	0.115
Water	0.6	0.347
Air	0.025	0.0144

Table 2

Typical values of convection heat transfer coefficients

Mode	$W/m^2\,°C$	$Btu/hr\ ft^2\,°F$
AIR, Free Convection	4 - 28	0.7 - 5
AIR, Forced Convection	4 - 570	0.7 - 100
WATER, Free Convection	284 - 1500	50 - 265
WATER, Forced Convection	284 - 17,000	50 - 3,000
WATER, Boiling	2840 - 57,000	500 - 10,000
STEAM, Condensing	5680 - 113,000	1,000 - 20,000

interpolate: $\frac{4}{0.7} = \frac{28}{5} = \frac{5}{?} \Rightarrow ? = \frac{(5 \times 5)}{28} = 0.89$ BTU/hr ft^{2}°F

6/1

The significance of the overall heat transfer coefficient is that it permits the calculation of the rate of heat flow by multiplying this quantity by the heat exchange area (perpendicular to the heat flow direction) and the temperature difference.

Example

Determine the heat loss through an 8-ft by 4-ft glass window of 4 mm thickness. The inside temperature is assumed to be 24°C (75°F) and the outside temperature is –10°C (14°F). The inside heat transfer coefficient is 5 W/m°C and the outside about 20 W/m°C (due to moderate wind). The thermal conductivity of window glass is 0.78 W/m°C.

Solution

The overall heat transfer coefficient is

$$\frac{1}{U}=\frac{1}{h_1}+\frac{b}{k}+\frac{1}{h_2}=\frac{1}{5\ \mathrm{W/m^2\,°C}}+\frac{0.004\ \mathrm{m}}{0.78\ \mathrm{W/m^2\,°C}}+\frac{1}{20\ \mathrm{W/m^2\,°C}}$$
$$=0.2+0.005+0.05=0.255\ \mathrm{m^2\,°C/W}$$

$$U=3.92\ \mathrm{W/m^2°C}$$

The rate of heat flow is

$$Q=U\ A\ (T\ -T_2)$$
$$=3.92\ \mathrm{W/m^2°C}\times(2.44\times1.22\ \mathrm{m^2})\ (24°\mathrm{C}-(-10°\mathrm{C}))$$
$$=3.92\times2.98\times34=397\ \mathrm{W}$$
$$=1355\ \mathrm{Btu/hr}$$

Convection Heat Transfer Coefficient Calculation

The most important step in heat convection calculations is the determination of the appropriate heat transfer coefficient. The higher the fluid velocity is, the higher the heat transfer coefficient will be. Numerous correlations have been developed for the calculation of the heat transfer coefficient in terms of dimensionless groups:

Nusselt number is the dimensionless heat transfer coefficient defined as

$$Nu=\frac{h\ D}{k}$$

USED FOR PART TWO

7/1

$$\text{Thermal efficiency } \eta = \frac{\text{W(energy sought)}}{\text{Q (energy that costs)}}$$

The efficiency of heat engines is higher if the heat source has higher temperature. However, all such actual devices have low efficiencies (e.g. combustion engines for cars, no more than 35%). In other words, only about 1/3 of the energy in gasoline goes to useful work (motion of the car). The rest is wasted due to thermodynamic implications. This is the reason why there is so much research on fuel cells nowadays, in which fuels react with oxygen to produce electricity, at higher efficiencies (50–60%).

For more information on the thermodynamic laws and their implications the reader is referred to more specialized textbooks [1-3].

Example 1

Thirty people gather for a cocktail party in a basement room that can be assumed completely sealed off and insulated. The room dimensions are 24 ft × 28 ft with 8 ft ceiling. Calculate the temperature rise in 30 minutes.

Solution

We apply the first law of thermodynamics

$$Q + W = \Delta E$$

Since there is no work being added to the air in the room

$$\Delta E = Q$$

We will assume that each person gives off approximately 2500 kcal/day (equal to the average metabolic energy consumption for light activity, like talking and walking around the room)

$$\begin{aligned} \Delta E &= Q = 30 \times 2500 = 75{,}000 \text{ kcal/day} = 3125 \text{ kcal/hour} \\ &= 52 \text{ kcal/min} \end{aligned}$$

This amount of energy goes to the air inside the room which is roughly

$$\text{Air volume} = 24 \text{ ft} \times 28 \text{ ft} \times 8 \text{ ft} = 5376 \text{ ft}^3 = 152.25 \text{ m}^3$$

We neglect the volume occupied by the people.

The density of air is about 1.24 kg/m^3. So the total mass of air in the room is

$$m = 1.24 \times 152.25 = 188.79 \text{ kg.}$$

The internal energy change will be

$$\Delta E = m\,C_p\,\Delta T$$

where C_p is the heat capacity of air (0.239 kcal/°C).

$$\Delta T = \frac{\Delta E}{m\,C_p} = \frac{52\ \text{kcal/min}}{188.79\ \text{kg} \times 0.239\ \text{kcal/kg}\,^\circ\text{C}} = 1.15^\circ\text{C / min} = 2.07^\circ\text{F / min}$$

So, in 30 minutes the temperature would rise by 30 × 1.15°C/min = 34.5°C (62.1°F)! This means that even a cold room would become quickly very hot, if the assumption of complete insulation is valid. In reality, there would be considerable heat losses to the surroundings that will slow down the temperature rise.

Example 2

In an injection molding machine 20 kg of LDPE are molded per hour. The melt temperature entering the mold is 180°C and the mold temperature is maintained at 40°C by a cooling water system. Determine the amount of water required to cool the plastic and keep the mold at 40°C, if the difference in input-output temperatures of the water is not to exceed 5°C.

Solution

This is a straightforward application of the first law of thermodynamics, that is the principle of conservation of energy. The heat for coming off the solidifying plastic in the mold must be taken away by the water.

$$Q_{\text{plastic}} = Q_{\text{water}}$$

The heat removed from the plastic is equal to the heat given off as the plastic temperature drops from 180°C to 40°C plus the heat of solidification which is equal to the heat of fusion but opposite in sign. As the plastic solidifies and the molecules stop moving randomly, heat is liberated.

$$Q_{\text{plastic}} = \dot{m}\,c_p\,\Delta T + \dot{m}\,\Delta H_f$$

$\dot{m}$ is amount of material molded per hour, C_p its heat capacity and ΔH_f the heat of solidification (200,000 J/kg for LDPE which solidifies around 106°C).

$$\begin{aligned} Q_{\text{plastic}} &= 20\,\frac{\text{kg}}{\text{hr}}\,\frac{\text{hr}}{3600\,\text{s}} \times 2300\,\frac{\text{J}}{\text{kg}\,^\circ\text{C}} \times (180^\circ - 40^\circ\text{C}) \\ &\quad + 20\,\frac{\text{kg}}{\text{hr}}\,\frac{\text{hr}}{3600\,\text{s}} \times 200{,}000\ \text{J/kg} \\ &= 1789 + 1111 = 2900\,\frac{\text{J}}{\text{s}} \end{aligned}$$

The heat taken up by the water undergoing a 5°C temperature change is

9/1

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Reflectix 50-sq ft Reflective Roll Insulation (24-in W x 25-ft L)

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Product Information

Description

- An easy-to-handle double reflective, double bubble insulation designed where a 24-in width makes for a quicker install
- R-values range from R-3.0 to R-21 depending on the applications
- Energy-saving residential applications include: cathedral ceiling, crawl space, radiant floor, wall, HVAC duct, water pipe, garage door, knee wall and water heater
- A tape measure, staple gun, utility knife and safety glasses are all you need for installation (not included)
- A fiber and itch free insulation product
- Class A/Class 1 fire rating
- Inhibits condensation and resists growth of fungi, mold and mildew
- No nesting characteristics for birds, insects or rodents
- Made at an ISO 9001:2008 manufacturing location

Based on our application,
assumed R-value = 3

Specifications

Series Name	N/A	**Sound Barrier**	×
Width (Inches)	24	**Insulation Type**	Reflective
Length (Feet)	25	**Faced/Unfaced**	Unfaced
Thickness (Inches)	0.3125	**Fits 2 x 4 Walls**	✓
Package Weight (lbs.)	3	**Fits 2 x 6 Walls**	✓
Coverage Area (Sq. Feet)	50	**For Use in Attics**	✓
Vapor Retardant	✓	**For Use in Basements**	✓
Formaldehyde Free	✓	**For Use in Ceilings**	✓
Warranty	15-year limited	**For Use in Crawlspaces**	✓

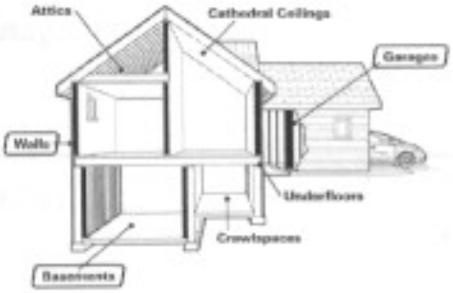
11/1

Reflective	Double
Maximum R-Value	21
R-Value per Inch	3
ENERGY STAR Certified	×
For Use in Doors	×
For Use in Electrical	×
For Use in Vents	×

For Use in Duct	✓
For Use in Floors	✓
For Use in Garage Doors	✓
For Use in Masonry	✓
For Use in Plumbing	✓
For Use in Walls	✓
For Use in Windows	✓

Projects, Tips & Services

Insulation Buying Guide



How to Install Insulation

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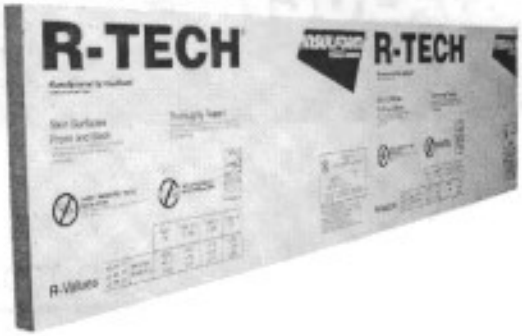

R-Tech

1 in. x 4 ft. x 8 ft. R-3.85 Insulating Sheathing

★★★★★ (12) Write a Review Questions & Answers (49)

- Numerous household, hobby and construction uses
- Easy to cut-to-size and to install
- Poly-facer provides excellent durability & flexibility

$10.48 /each

Quantity - 1 +

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Product Overview

R-Tech 1 in. x 4 ft. x 8 ft. Insulation Sheathing cuts easily to size. Facilitating its installation as wall sheathing, basement and foundation insulation or siding underlayment. This product meets federal guidelines for energy efficiency.

- Designed for use as wall sheathing, basement and foundation insulation or siding underlayment
- Energy Star qualified to meet or exceed federal guidelines for energy efficiency for year-round energy and money savings
- Cuts easily to size to make installation a snap
- Poly-facer on both sides for flexibility and durability
- Moisture-resistant design to help maintain a water-tight seal

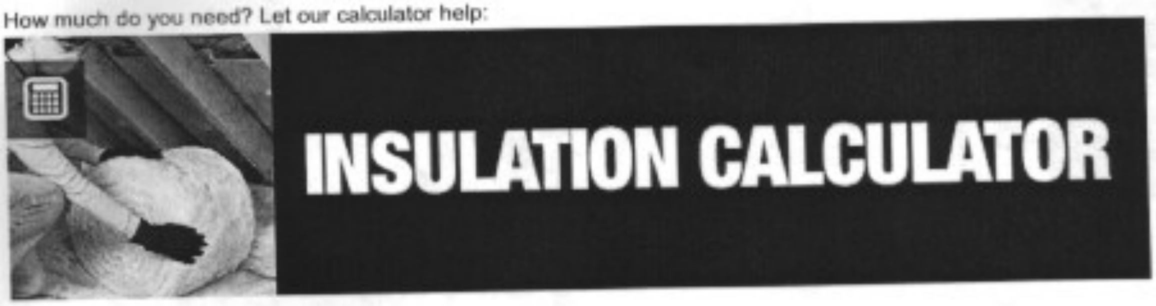
Info & Guides

Installation Guide

Specification

You will need Adobe® Acrobat® Reader to view PDF documents. Download a free copy from the Adobe Web site.

- Note: Product may vary by store
- How much do you need? Let our calculator help:



Specifications

Dimensions

Product Depth (in.)	1	Product Thickness (in.)	1 in
Product Height (in.)	96	Product Width (in.)	48
Product Length (ft.)	8 ft		

Details

Faced or Unfaced	Faced	Interior/Exterior	Interior/Exterior
Insulation Application Type	2x4 Walls,2x6 Walls,Attics,Basements,Crawlspaces,Exterior Sheathing,Exterior Wall Foundation,Garage,Under Slab	Product Weight (lb.)	2.7lb
Insulation R-Value	3.85	Sheathing Type	EPS
Insulation Type	Sheathing	Structural	Yes

Warranty / Certifications

ENERGY STAR Certified	Yes	Warranty Information	N/A

How can we improve our product information? Provide feedback.

APPENDIX C3:
Budget

Bureau of Labor Stats San Jose Construction 29.86

	TASK	EQUIPMENT	HOURS	Persons	Cost	Total	
DRILLING	BOLT HOLES IN FRAME	DRILL	1.5	2	28	84	
	BOLT HOLES IN PVC PANELS	DRILL	0.5	2	28	28	
	METAL CHANNELS	DRILL	0.5	1.5	28	21	
							133
TAPING	COVER TARP AROUND FOAM BOARD	TAPE, SCISSORS	1	2	28	56	
	BUBBLE WRAP	TAPE, SCISSORS	0.25	2	28	14	
	PVC PANELS	TAPE, SCISSORS	0.5	1	28	14	
							84
CUTTING	FRAME MEMBERS	SAW	1	1.5	28	42	
	STUDS	SAW	0.25	1	28	7	
	PVC PANELS	SAW	0.5	2	28	28	
	TARP	BOX CUTTER	0.25	1.5	28	10.5	
	FOAM BOARDS	BOX CUTTER	0.5	1	28	14	
							101.5
	GRAND TOTAL				319		

	Item	Receipt Term	Receipt Unit Cost	Unit	Quantity	Cost	Total					
WOOD MEMBERS	4x4 (9')	4x4 10' DF #1 S4S 100% FDHC	913.0/MBF	ea	2		0				LF	18
	4x4 (8')	4x4 8' DF #1 S4S 100% FDHC	913.0/MBF	ea	2		0				LF	16
	2x4 (12.5')	2x4 14' DF S4S STD & BTR GRN	589.0/MBF	ea	9		0				LF	112.5
	2x4 (8')	2x4 10' DF S4S STD & BTR GRN	619.0/MBF	ea	1		0				LF	8
	2x4 (9')	2x4 10' DF S4S STD & BTR GRN	619.0/MBF	ea	4		0				LF	36
	2x4 (6.5')			ea	4		0				LF	26
	Wood			LS	1	140	140	Total	140		total	216.5
BOLTS	1/2" Bolts	1/2-IN X 6-IN ZN HEX BOLT	1.68	ea	22	1.68	36.96					
	1/2" Eye Bolts	1/2" X 8" EYE BOLT W/NUT ZP	2.67	ea	8	2.67	21.36			40		
	1/2" washers	Everbilt 1/2 in. Hot Dipped Galvanized Cut Washer	0.33	ea	30	0.33	9.9					
	1/2" nuts	HM 1-CT 1/2-IN 13 HEX LOC	0.2	ea	30	0.2	6					
	3/8" Eye Bolts	Everbilt 3/8 in x 6in zinc plated eye bolt	1.11	ea	4	1.11	4.44					
	3/8" bolts	HM 1-CT 3/8-IN X 6-IN GAL	1.77	ea	6	1.77	10.62					
	3/8" wahsers	Everbilt 3/8 in x 1-1/2 in zinc plated washer	0.25	ea	10	0.25	2.5					
	3/8" nuts	HM 1-CT 3/8-IN 16 HEX LOC	0.18	ea	10	0.18	1.8	Total	93.58			
STEEL CABLE	Wire Rope	WIRE ROPE STAINLESS 3/16"	0.5	LF	102	0.5	51					
	Wire Hook 1/4"	1/4" CLV HK	4.26	ea	8	4.26	34.08					
	Wire clamp	CLAMP SET 3/16 ZINC 4 PK	2.58	ea	12	2.58	30.96					
	Electric Tape	3/4in x 30ft vinyl carder electric tape	1.97	ea	1	1.97	1.97	Total	118.01			
ROOFING	PVC roof panels	8ft PVC PANEL WHITE/OPAQUE	12.47	ea	16	14.97	239.52					
	Gorilla Tape	1.88-in x 30yd Gorilla	8.98	LF	210	0.09	18.9				LF	210
	Shear Hanger	LUS24Z 2"x4" 18GA DBL Shear Hanger	0.78	ea	8	0.78	6.24					
	Framing Anchor	3inx3in Angle Framing Anchor	2.67	ea	16	2.67	42.72					
	bolts and nuts	1/4in x 3in hex bolt	0.48	ea	30	0.48	14.4					
	screws	External Hex flange connector screw (100)	12.37	ea	48	0.13	6.24					
	Plastic Washers	Neoprene Washer 3/8x2	0.97	ea	25	0.97	24.25	Total	352.27			
ROOFING INSULATION	Reflectix Insulation	48-in x 25-ft Foil Bubble	43.25	SF	156	0.43	67.08					
	Reflectix Tape	2-INx30FT Reflective F	3.35	LF	50	0.12	6					
	strong velcro			ea	4	10	40					
	Velcro	4in x 2in industrial strength strips (2pack)	2.97	ea	8	2.97	23.76	Total	136.84			
WALLS	Tarp	40'X60' GEN PURPOSE BLUE TARP	194.22	SF	425	0.08	34					
	R-tech Foam Board (8'x4')	1inx4ftx8ft polystyrene	10.48	ea	11	11	121					
	Flashing	(25 CT)3 in X 5 in X 8 in STP Flash	18.07	ea	32	0.7	22.4					
	screws	External Hex flange connector screw (100)	12.37	ea	64	0.13	8.32					
	Gorilla Tape	1.88-in x 30yd Gorilla	8.98	LF	350	0.09	31.5					
	Blue Duct Tape	55-yd Blue Duct Tape	6.98	LF	64	0.04	2.56					
	Reflect Tape						20					
	Space Blankets			ea	11	0.5	5.5	Total	245.28			
FLOOR	Grommets			ea	15		10					
	Hooks			ea	9	5	45					
	Screws			ea	18		0					
	tape						20					
	Rope			LF	75		12					
	Tarp	40'X60' GEN PURPOSE BLUE TARP	194.22	SF	350	0.08	28					
	Insulation (bubble wrap)	48-in x 25-ft Foil Bubble	43.25	SF	160	0.43	68.8	Total	183.8			
WATERPROOFING	Tarp			SF			10					
	Velcro			ea			40					
	Epoxy			ea			5					
	bungees			ea			15					
							0					
DOOR	Velcro			ea			20					
	Zipper			ea			7					
	Epoxy			ea			5					
	Tarp			SF			5					
	reflect tape			LF			5					
	Reflectix Insulation	48-in x 25-ft Foil Bubble	43.25	SF	25	0.43	5					
	GRAND TOTAL					1386.78						

	Item	Receipt Term	Receipt Unit Cost	Unit	Quantity	Bulk Pricing	Total		
WOOD MEMBERS	4x4 (9')	4x4 10' DF #1 S4S 100% FDHC	913.0/MBF	ea	2	0	0		
	4x4 (8')	4x4 8' DF #1 S4S 100% FDHC	913.0/MBF	ea	2	0	0		
	2x4 (12.5')	2x4 14' DF S4S STD & BTR GRN	589.0/MBF	ea	9	0	0		
	2x4 (8')	2x4 10' DF S4S STD & BTR GRN	619.0/MBF	ea	1	0	0		
	2x4 (9')	2x4 10' DF S4S STD & BTR GRN	619.0/MBF	ea	4	0	0		
	2x4 (6.5')			ea	4	0	0		
	Wood			LS	1	121.2	121.2	Total	121.2
BOLTS	1/2" Bolts	1/2-IN X 6-IN ZN HEX BOLT	1.68	ea	22	1.065	23.43		
	1/2" Eye Bolts	1/2" X 8" EYE BOLT W/NUT ZP	2.67	ea	8	2.3496	18.7968		
	1/2" washers	Everbilt 1/2 in. Hot Dipped Galvanized Cut Washer	0.33	ea	30	0.2904	8.712		
	1/2" nuts	HM 1-CT 1/2-IN 13 HEX LOC	0.2	ea	30	0.176	5.28		
	3/8" Eye Bolts	Everbilt 3/8 in x 6in zinc plated eye bolt	1.11	ea	4	0.9768	3.9072		
	3/8" bolts	HM 1-CT 3/8-IN X 6-IN GAL	1.77	ea	6	1.5576	9.3456		
	3/8" wahsers	Everbilt 3/8 in x 1-1/2 in zinc plated washer	0.25	ea	10	0.22	2.2		
	3/8" nuts	HM 1-CT 3/8-IN 16 HEX LOC	0.18	ea	10	0.1584	1.584	Total	73.26
STEEL CABLE	Wire Rope	WIRE ROPE STAINLESS 3/16"	0.5	LF	102	0.37	37.74		
	Wire Hook 1/4"	1/4" CLV HK	4.26	ea	8	3.7488	29.9904		
	Wire clamp	CLAMP SET 3/16 ZINC 4 PK	2.58	ea	12	1.96	23.52		
	Electric Tape	3/4in x 30ft vinyl carder electric tape	1.97	ea	1	1.6898	1.6898	Total	92.94
ROOFING	PVC roof panels	8ft PVC PANEL WHITE/OPAQUE	12.47	ea	16	12.56	200.96		
	Gorilla Tape	1.88-in x 30yd Gorilla	8.98	LF	210	0.0792	16.632		
	Shear Hanger	LUS24Z 2"x4" 18GA DBL Shear Hanger	0.78	ea	8	0.6864	5.4912		
	Framing Anchor	3inx3in Angle Framing Anchor	2.67	ea	16	1.8876	30.2016		
	bolts and nuts	1/4in x 3in hex bolt	0.48	ea	30	0.333	9.99		
	screws	External Hex flange connector screw (100)	12.37	ea	48	0.1144	5.4912		
	Plastic Washers	Neoprene Washer 3/8x2	0.97	ea	25	0.8536	21.34	Total	290.1
ROOFING INSULATION	Reflectix Insulation	48-in x 25-ft Foil Bubble	43.25	SF	156	0.8215	128.154		
	Reflectix Tape	2-INx30FT Reflective F	3.35	LF	50	0.1056	5.28		
	Velcro	4in x 2in industrial strength strips (2pack)	2.97	ea	8	2.6136	20.9088	Total	154.3
WALLS	Tarp	40'X60' GEN PURPOSE BLUE TARP	194.22	SF	425	0.0704	29.92		
	R-tech Foam Board (8'x4')	1inx4ftx8ft polystyrene	10.48	ea	12	8.975	107.7		
	Flashing	(25 CT)3 in X 5 in X 8 in STP Flash	18.07	ea	32	0.545	17.44		
	screws	External Hex flange connector screw (100)	12.37	ea	64	0.1144	7.3216		
	Gorilla Tape	1.88-in x 30yd Gorilla	8.98	LF	350	0.0792	27.72		
	Blue Duct Tape	55-yd Blue Duct Tape	6.98	LF	64	0.0352	2.2528		
	Channels	3-in x 3-in x 10ft Galv	8.74	ea	4	7.6912	30.7648	Total	223.1
FLOOR	Plywood	7/16in x 48in x 8ft. Oriented strand board	11.66	SF	156	0.2987	46.5972		
	Staples	T50 3/8in Leg x 3/8in. Gal steel staples (1250pack)	3.22	LS	1	2.8336	2.8336		
	Tarp	40'X60' GEN PURPOSE BLUE TARP	194.22	SF	160	0.062	9.92		
	Insulation (bubble wrap)	48-in x 25-ft Foil Bubble	43.25	SF	160	0.7765	124.24	Total	183.6
	GRAND TOTAL					1138.5546			

APPENDIX D:
AutoCAD Drawings

Santa Clara University

DEPARTMENT OF CIVIL ENGINEERING

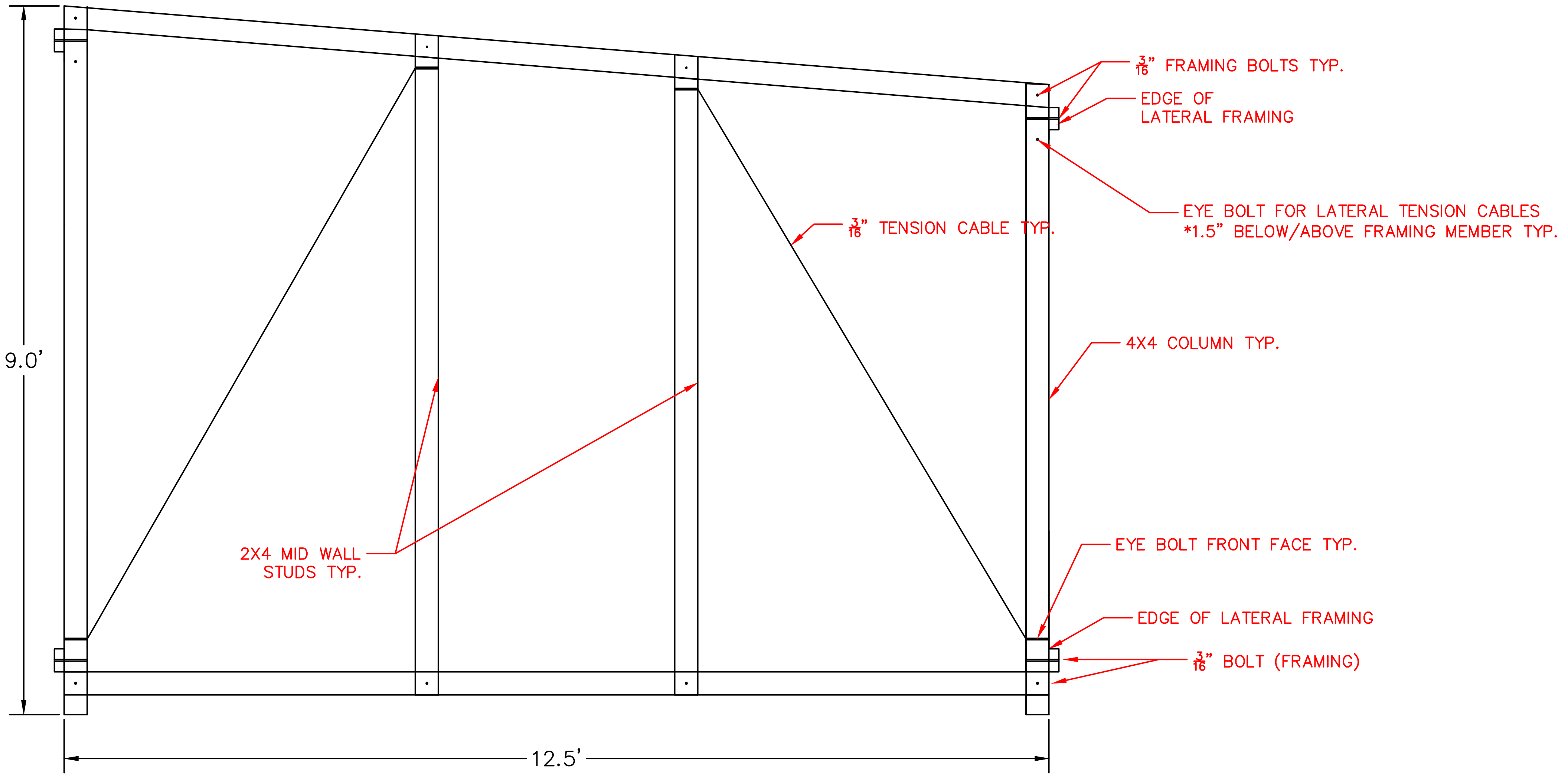
PROJECT TITLE: DISASTER SHELTER DESIGN

DESIGNED BY: LA'AKEA WARREN A. GONZALEZ
COLIN SKAGGS DANNY O'MALLEY

INSTRUCTOR: ZIAD DWEIRI

DATE: 2/20/17 SCALE: 0.5":1'

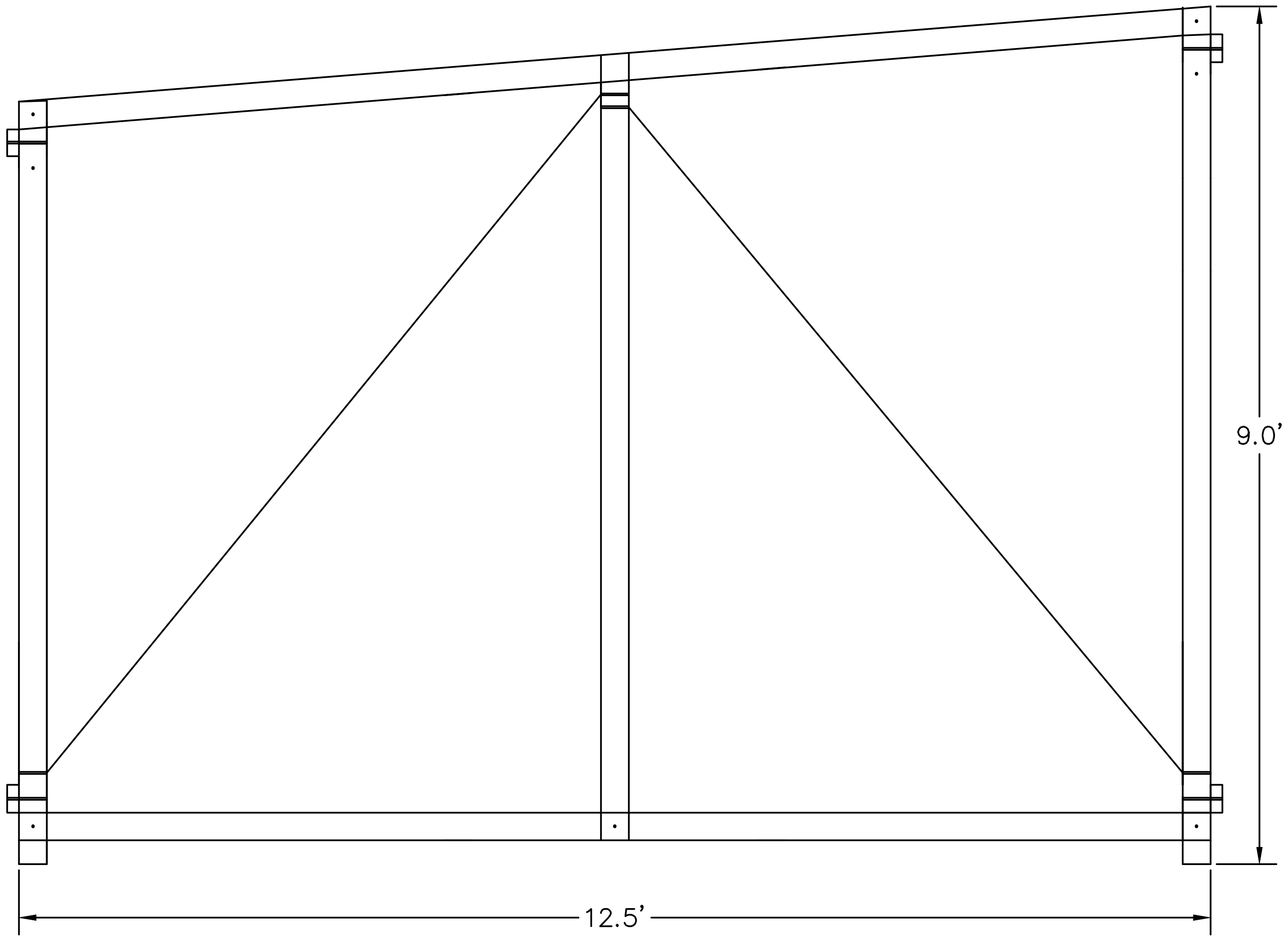
SHEET NAME: FRONT VIEW SHEET NO.: 1 OF:



FRONT VIEW

LAST REVISION

S
TYP.



BACK VIEW

Santa Clara University
DEPARTMENT OF CIVIL ENGINEERING
PROJECT TITLE: DISASTER SHELTER DESIGN
DESIGNED BY: LA'AKEA WARREN A. GONZALEZ
COLIN SKAGGS DANNY O'MALLEY
INSTRUCTOR: ZIAD DWEIRI
DATE: 3/15/17 SCALE: 0.5":1'
SHEET NAME: BACK VIEW SHEET NO.: 2 OF:

LAST REVISION

Santa Clara University

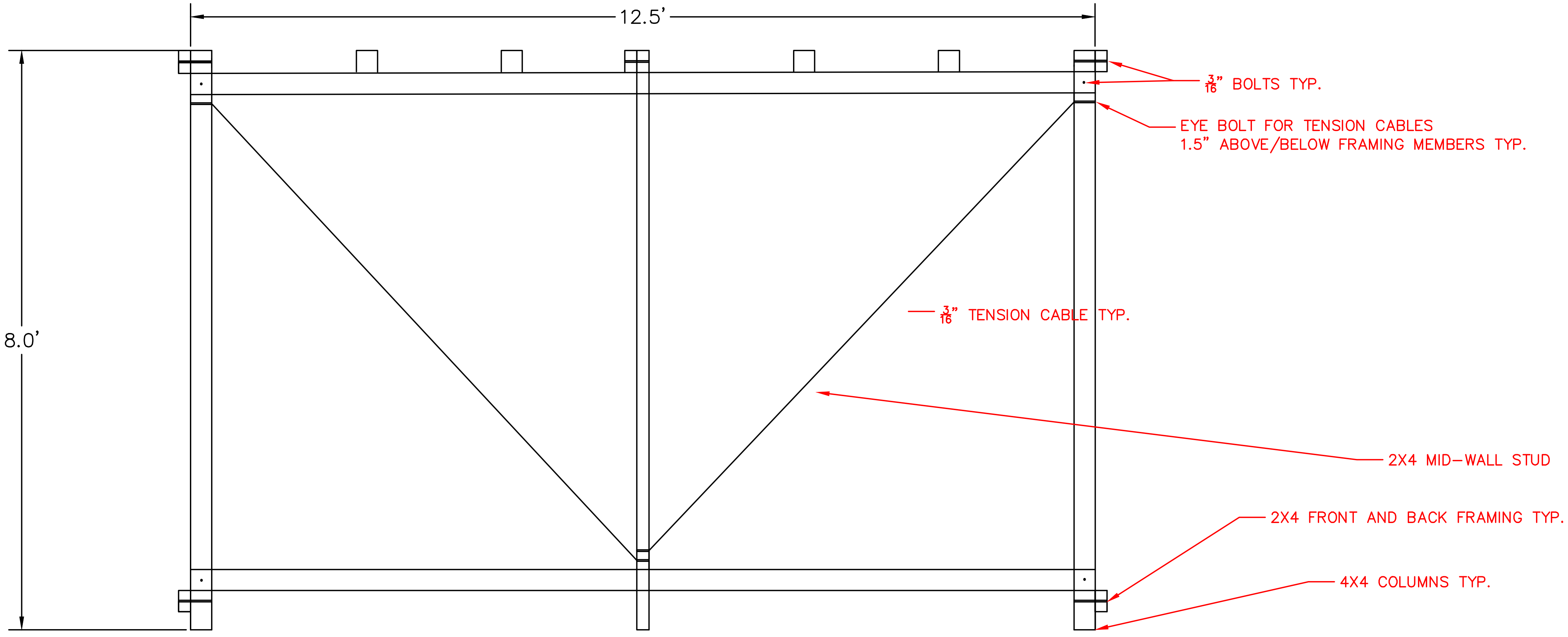
DEPARTMENT OF CIVIL ENGINEERING

PROJECT TITLE: DISASTER SHELTER DESIGN

DESIGNED BY:	LA'AKEA WARREN	A. GONZALEZ
	COLIN SKAGGS	DANNY O'MALLEY

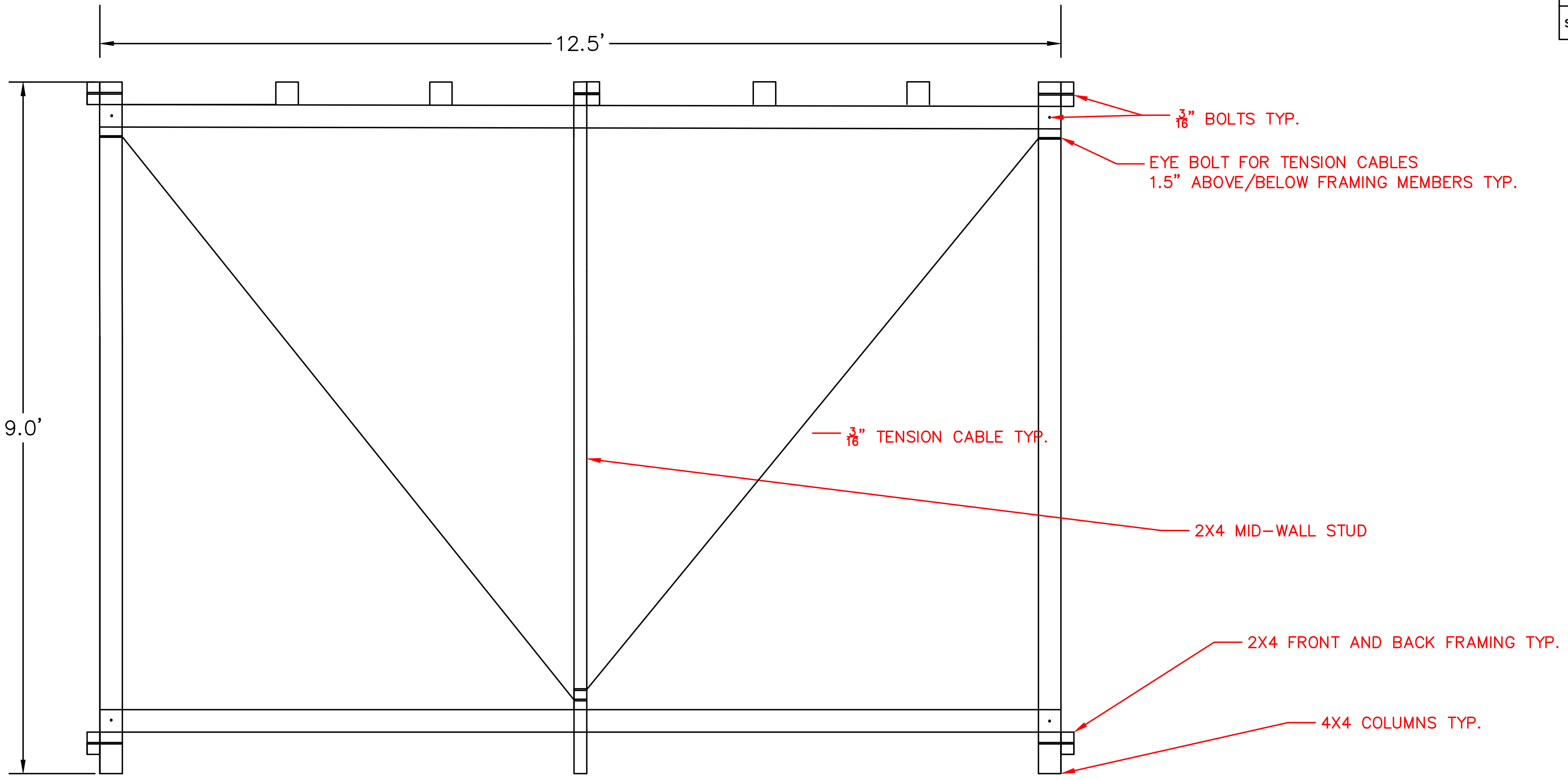
INSTRUCTOR: ZIAD DWEIRI

DATE: 3/15/17	SCALE: 0.5":1'
SHEET NAME: RIGHT VIEW	SHEET NO.: 3 OF:



RIGHT LATERAL VIEW

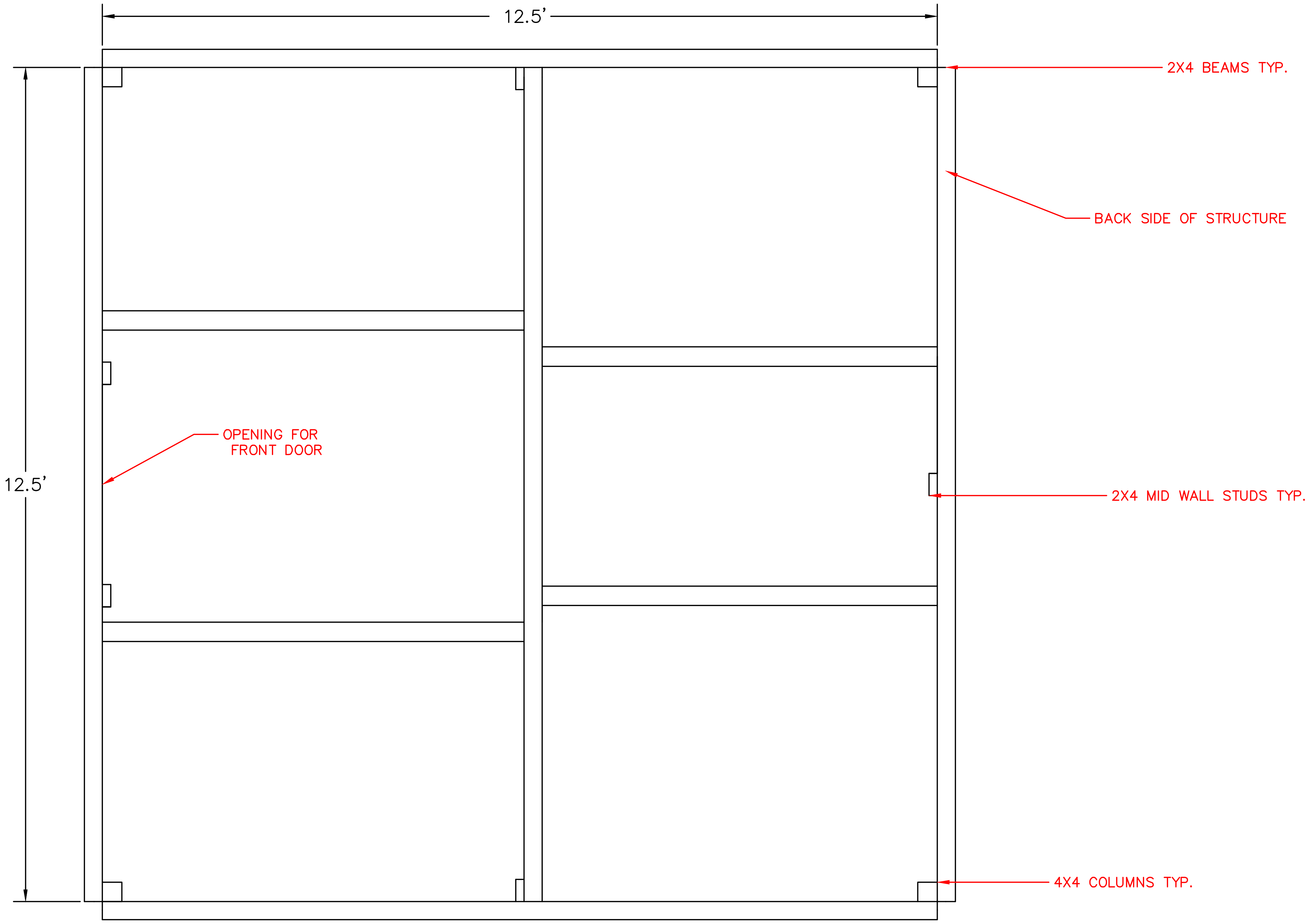
LAST REVISION



LEFT LATERAL VIEW

Santa Clara University
DEPARTMENT OF CIVIL ENGINEERING
PROJECT TITLE: DISASTER SHELTER DESIGN
DESIGNED BY: LA'AKEA WARREN | A. GONZALEZ
COLIN SKAGGS | DANNY O'MALLEY
INSTRUCTOR: ZIAD DWEIRI
DATE: 3/15/17 | SCALE: 0.5":1'
SHEET NAME: LEFT VIEW | SHEET NO.: 4 | OF:

LAST REVISION

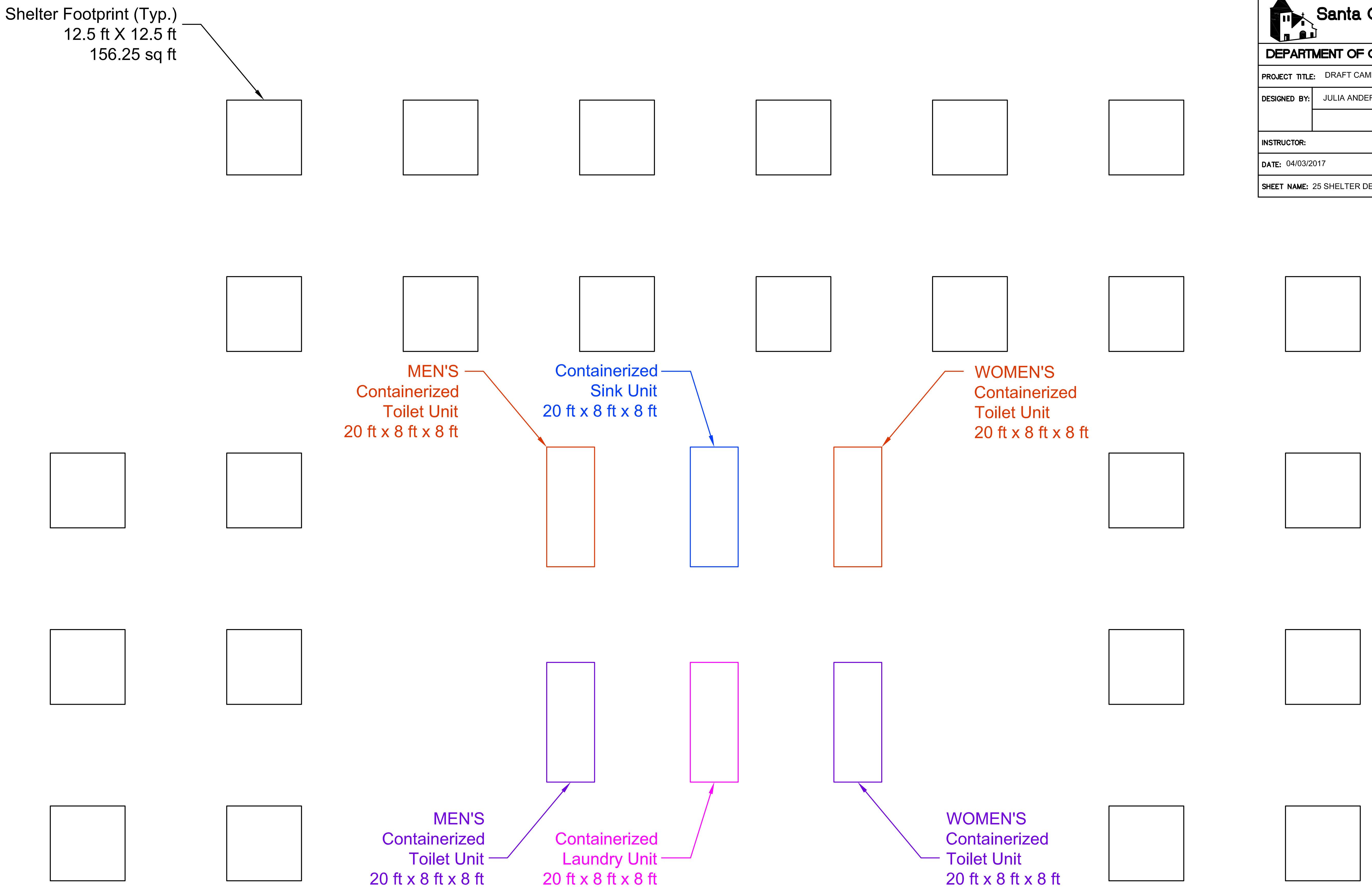


TOP VIEW

Santa Clara University
DEPARTMENT OF CIVIL ENGINEERING
PROJECT TITLE: DISASTER SHELTER DESIGN
DESIGNED BY: LA'AKEA WARREN, COLIN SKAGGS, A. GONZALEZ, DANNY O'MALLEY
INSTRUCTOR: ZIAD DWEIRI
DATE: 3/15/17
SCALE: 0.5":1'
SHEET NAME: TOP VIEW
SHEET NO.: 5
OF:

LAST REVISION

APPENDIX E:
Camp Plan Layout



Santa Clara University

DEPARTMENT OF CIVIL ENGINEERING

PROJECT TITLE: DRAFT CAMP PLAN

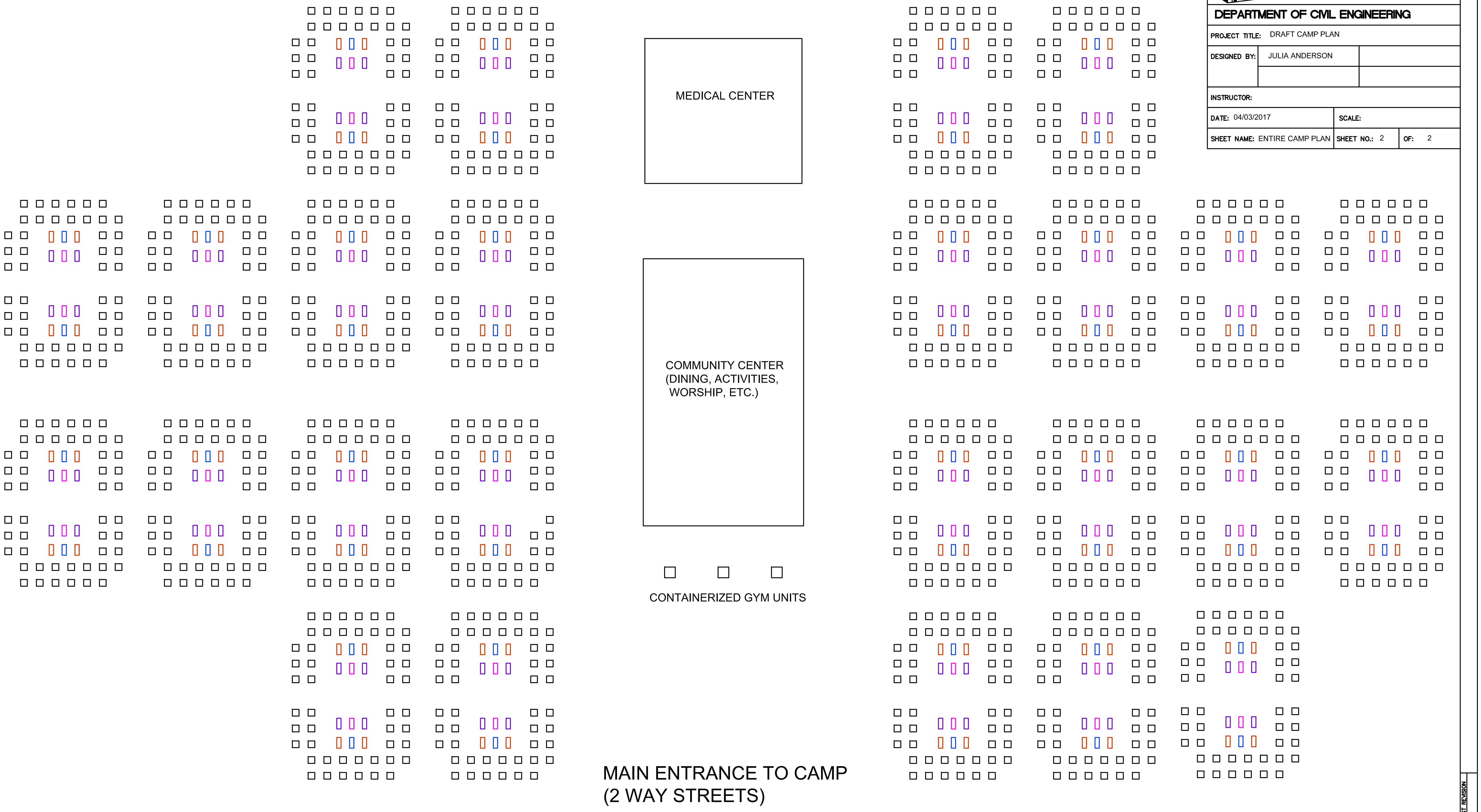
DESIGNED BY: JULIA ANDERSON

INSTRUCTOR:

DATE: 04/03/2017 SCALE:

SHEET NAME: 25 SHELTER DETAIL SHEET NO.: 1 OF: 2

LAST REVISION



Santa Clara University

DEPARTMENT OF CIVIL ENGINEERING

PROJECT TITLE: DRAFT CAMP PLAN

DESIGNED BY: JULIA ANDERSON

INSTRUCTOR:

DATE: 04/03/2017

SCALE:

SHEET NAME: ENTIRE CAMP PLAN

SHEET NO.: 2

OF: 2

APPENDIX F:
Competition Scoring Matrix

Samaritan's Purse - Emergency Shelter Competition **SCORING SHEET**
April 20 - 22, 2017

Item:	Target Value	Actual	AVERAGE Raw Score	% Weight	Dordt	LetU Blue	LetU Red	Pitt State	GNU	Santa Clara	JBU	Notes
Design Report	100 pts			5%	76.36	76.98	73.22	51.91	53.16	77.63	60.72	Judges score this; 100 pts possible
Team Presentation	100 pts			5%	84.48	70.71	72.58	63.81	58.19	78.88	63.22	Judges score this; 100 pts possible
- Content/Quality of Presentation												
- Presentation Skills												
Camp Plan				7%	70.10	72.78	69.16	54.03	61.28	79.50	61.96	Judges rank all entries; Best is 100 pts, then reduce incrementally
Physical Parameters (Tested):												
Size, Footprint	14 m2 (Note 1)			5%	83.25	81.38	76.00	72.63	78.88	71.38	71.38	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
- Actual footprint												
- Head clearance												
Height	2 m			5%	70.13	74.35	72.88	84.47	79.50	78.00	69.48	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
Weight	200 kg			5%	66.36	41.33	78.25	53.23	31.30	45.06	47.59	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
Wind Loading	75 km/hr			5%	81.36	45.04	37.54	80.11	60.66	57.56	70.09	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
Seismic Loading	No Damage			5%	73.85	53.84	60.09	75.11	64.46	70.09	66.34	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
Heat Retention	100 pts			5%	70.36	66.61	83.74	78.50	53.95	55.59	85.12	Judges rank all entries; Best is 100 pts, then reduce incrementally
Rain Resistance	No Leaks/Damage			5%	85.75	40.66	44.45	87.00	44.41	56.59	65.11	Judges rank all entries; Best is 100 pts, then reduce incrementally
Functionality:												
Timed setup	120 Minutes			5%	83.25	72.33	73.21	73.35	70.31	60.68	79.99	100 pts possible; Judges rank all entries; meeting criteria = 70 points; Judges determine additional/reduction.
Ventilation	100 pts			5%	75.09	62.00	59.44	66.28	55.69	63.84	72.59	Judges rank all entries; Best is 100 pts, then reduce incrementally
Security and Privacy	100 pts			5%	73.70	67.99	63.70	57.96	77.99	50.11	77.27	Judges rank all entries; Best is 100 pts, then reduce incrementally
Durabilty	100 pts			5%	65.09	59.38	49.38	65.72	74.50	58.50	74.47	Judges rank all entries; Best is 100 pts, then reduce incrementally
- Projected life span												
- Resistance to elements												
- Resistance to fire												
- UV Resistance												
Ease of Assembly	100 pts			4%	85.13	70.69	69.50	77.56	70.91	58.22	75.09	Judges rank all entries; Best is 100 pts, then reduce incrementally
- Number of people required												
- Type of tools required												
- No power tools												
- Assembly Instructions												
Packing Ease and Size	100 pts			4%	68.23	50.09	58.21	79.48	72.59	51.99	55.06	Judges rank all entries; Best is 100 pts, then reduce incrementally
- Easily packaged												
- Fits in shipping container												
- Shipping container space utilitization												
- Number of units per containter												
Originality of Approach	100 pts			3%	70.11	71.35	81.38	63.16	64.83	64.97	76.36	Judges rank all entries; Best is 100 pts, then reduce incrementally
Livabiltiy (overnight)	100 pts			3%	85.75	38.13	41.25	70.11	55.11	58.24	74.49	'Victim' judges score this from ovenight stay
- Protection from cold												
- Protection from rain												
- Protection from wind												
Upgradability	100 pts			3%	70.00	58.75	62.53	47.56	53.13	63.75	63.81	Judges rank all entries; Best is 100 pts, then reduce incrementally
- Can be added on to												
- Compatible with local materials												
- Uses local materials												
Culturally Appropriate	100 pts			3%	77.38	63.75	76.50	62.50	65.13	57.00	72.50	Judges rank all entries; Best is 100 pts, then reduce incrementally
- Configuration												
- Access												
- Family/Gender												
Financial:												
Cost	$1,500			5%	67.46	66.33	76.38	56.94	43.79	63.21	46.30	100 pts possible; meeting criteria = 70 points. Judges determine additional/reduction.
- Cost to mass produce												
- Cost to transport												
Camp Cost Estimate	100 pts			3%	2.53	69.48	60.73	2.53	2.89	47.63	2.53	Judges rank all entries; Best is 100 pts, then reduce incrementally
				100%	73.04	62.91	65.66	65.79	59.60	63.08	65.72	**FINAL SHELTER SCORE**
				Rank	**1**	**6**	**4**	**2**	**7**	**5**	**3**	

Note 1: Shelter must fit on 16' X 20' shake table