Modular Housing

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Abstract

In 2012, 776,000 Americans and 32.4 million people worldwide were forced to evacuate their homes for extended periods of time due to emergency situations. In such situations, large groups of people are displaced at a single time, which puts an excessive amount of strain on the surrounding areas ability to house them. In addition, the costs associated with housing and providing for these individuals contributes a considerable amount to the aid required by relief efforts. The purpose of the Modular Housing Project is to design low-cost, temporary, semi-portable housing for up to four people, per unit, in the event of a disaster. The modular housing project is run by four students as a senior design project. The main focus is creating low-cost, portable, and durable emergency shelters, which can be shipped quickly and in large quantities. These units will provide occupants with the most basic necessities required for day-to-day life. The interior design of the house will provide the occupants with necessities such as water and electricity, two functions not always available to disaster relief currently. Each housing unit will be able to be unloaded and constructed without the assistance of machinery. With the Lego®-like assembly, the construction of the units will be quick and easy. In the event of a disaster, those affected are in need of a safe and comfortable place to stay, the modular housing units will provide this for them.

1. Introduction

There are many different types of natural disasters that happen year-to-year. According to World Vision, in 2013, the top five natural disasters include: Typhoon Haiyan (Philippines), Typhoon Phailin (India), Hurricanes Manuel and Ingrid (Mexico), Earthquake (Central Visayas, Philippines), and Tornadoes (Unites States) [1]. Each and every one of these disasters displaced thousands of people from their homes. Whenever events like this occur, different disaster relief organizations come together with the community in order to find shelter for all affected. The idea of modular housing is semi-portable, durable and reliable housing units that can be shipped in large quantities to areas in need. These units will house up to four people at a time, providing them with the basic necessities such as water and electricity. Each unit will be furnished with four beds, a sink, and storage space. This will eliminate the need for finding big open buildings to house the people. The group of four individuals that will occupy a unit will be able to choose where they will set up their modular house. This allows families and friends to stay close, with the comfort of having someplace safe and warm to stay.

Currently, there are a few companies making competitive products similar to the modular housing project. Some of these products include the Prefab Modular Housing Design by Garrison Architects. These units are designed for a city block and are built three units high. These units contain a first floor 480-square-foot bedroom as well as two more 822-square-foot bedrooms as the second and third floor [2]. The problem with this design arises because the units must be craned into place. This doesn't allow for easy assembly or flexibility of placement. Also, the cost of the unit would not be realistic when trying to provide for thousands of displaced people. The next existing product that was researched was Foldable Housing by the University of Buenos Aires in partner with 2M Arquitectos Design Firm. This half-foldable design allows six to seven units to fit onto one truck trailer. These units contain the basic wiring and LED lighting as well as the ability to connect to other units [3]. Problems arise due to the 1000 pounds per unit, causing each unit to be moved with a forklift. Another design that was researched was the SpaceMax Foldable Buildings by ModSpace Team. This design incorporated aluminum, insulated walls, WIFI, plumbing, as well as 115- and 220- amp electricity [4]. These units must also be moved with a forklift, again making them not ideal in disaster relief efforts. The cost of each unit, similar to the Prefab Modular Housing Design, would be too expensive. After researching the different designs already in existence, decisions were made as to what was most important to keep in mind when ensuring the Modular Housing Project would be the best option for disaster relief. The housing design will allow cheap, portable, accessible, durable, and comfortable living. The design chosen will allow for quick, large shipments into the affected areas. The design is lightweight, allowing the unit to be portable and easy to assemble, allowing for anyone to set up the unit. The upcoming sections will discuss the project in further detail.

2. Criteria and Constraints

In order for this project to address the problems it seeks to solve, several criteria must be met by the design. First, the design must be as light as possible. This is to ensure ease of shipping and assembly. Next, the design must be low cost and maximize living space. Last, the design must be comfortable to live in, as well as strong and durable. Meeting these basic requirements is the focus of the group, and will factor into how the final design is implemented.

With the criteria listed above in mind, the final structure is required to meet the following constraints in order to be considered a success. Those constraints are:

- Maximum dimensions of 12'x8'x9'
- Maximum weight of 2000 lbs
- Capacity of four people
- Structure strength – ability to withstand at least 30 MPH winds
- Reusable units with a lifetime of 5 years, with a max of 1-2 month use with proper maintenance and storage after each use
- Up to 3" Water resistant
- Functions: water, electricity
- Able to house up to four beds

Testing and analysis of these constraints must be done in order to determine success or failure. The specific analysis completed on the constraints can be seen in Sections 4 and 5.

3. Materials

In order to provide a comfortable environment for the occupants of the modular housing unit, a specific outer material must be chosen. When choosing a material for the shell of the unit, a material that is wind-resistant, water-resistant and durable must be found. The material chosen to provide these necessary characteristics was 12 oz. treated canvas tarps. The canvas tarp selections is heavy-duty and is designed specifically for outdoor use. The canvas is treated in order to be fire retardant, wind-resistant and water-resistant. The skeleton pole structure of the unit is one of the most important stabilizers. In order to make the structure stand up to the wind speeds needed, the tubes chosen need to be strong. The tubes chosen for the skeleton structure are one and a quarter inch diameter ASTM A53 steel. In order to secure the canvas to the pole structure, a slipcover design will be utilized. In order to connect each section of piping, steel joint-fittings will be used. The joint-fittings will be made of the same steel as used in the tubing. The purpose for the joint-fittings is to allow the total tubing assembly to be assembled and disassembled to allow for modularity of the housing units. In order to ensure water-resistance, five and a half inch tall polyethylene pallets will be used for the base of the structure. Each unit will need six pallets to complete the flooring assembly. Due to the height of the pallets, this will allow for the water resistance of the units.

4. Analysis

In order to analyze the structure used in each modular housing unit, a couple of different tests were performed. Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses different numerical methods and algorithms to solve and analyze problems that involve fluid flow. The calculations performed simulate different flow over a specified body. In order to analyze the forces on the house at different wind speeds, CFD analysis was performed. In order to determine the specifics of the simulation, PointWise [5] software was used. This software allows the formation of grid cells over a specific geometry. Once the grid is drawn, specific boundary conditions can be set to simulate specific situations. Cobalt [6] was then utilized in order to set up the correct boundary condition file to run the simulation on the Sun Microsystem. After the solution converged, the results could be analyzed. The simulation was performed to give forces in the x, y and z-directions at a given wind speed of 30 MPH. Also, the coefficient of drag can be determined based on the simulation.

Finite Element Analysis (FEA) is a technique that provides solutions to differential equation problems. Different structures can be analyzed to determine the effects of different forces at specified points on the given body. In order to simulate the 30 MPH effects on the modular housing unit, FEA through a 3D modeling program, SolidWorks [7], was used. In order to begin, the skeleton pole structure was modeled in SolidWorks. The specific pole dimensions were drawn to scale and each pole was fixed to the ground, using specific SolidWorks commands. Fixing the poles to the ground allowed the simulation to be consistent with what the prototype will experience once the poles are fixed into the base design. SolidWorks Simulation is the specific program used in order to run the FEA on the frame. The specific steel used for the poles was specified in the program to accurately simulate the housing unit. In SolidWorks, the specific pole connections were also chosen. In the prototype of the house, steel joint-fittings will be used in order to allow for assembly and disassembly, but there is not an option for that in SolidWorks. In order to simulate the FEA as closely to the prototype, welded joints were used for connection. In reality, these welded joints will not be as strong as the steel joint fitting that will actually be used. This allows an estimate for how strong the structure will be, but when the proper fittings are used, the structure will actually end up being stronger than what is simulated. Lastly, the specific force as well as where that force is located on the pole structure was specified. Once all of these things were complete, the FEA analysis could be run on the frame. The FEA analysis will provide specific values for the maximum stress experienced on the frame as well as the maximum deformation experienced on the frame.

5. Analysis Results

Once the CFD simulation was complete, the results were analyzed. It can be shown that when the simulation is run at 30 MPH and Mach number of 0.0394, the coefficient of drag is 1.0009. When analyzing the data given, the most important force direction to look at is the x-direction. Figure 1 shows in which direction each axis is in correspondence with the housing unit.

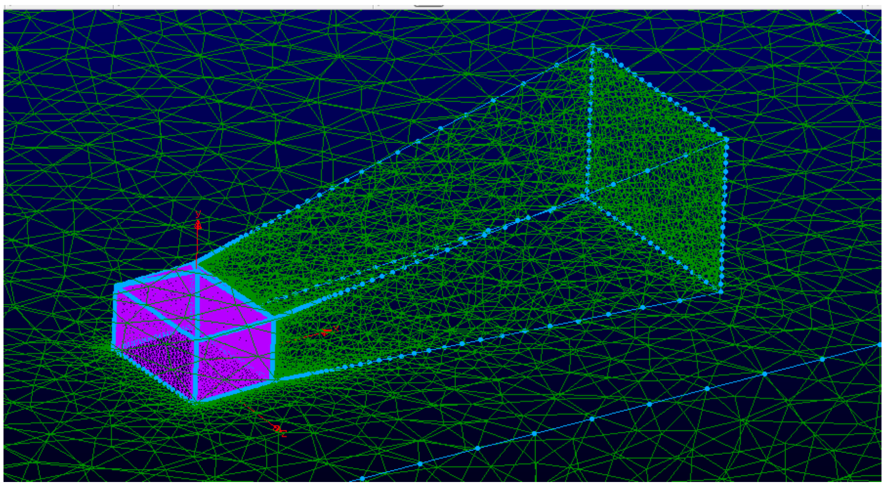

Figure 1: CFD Axis Specification

As you can see in Figure 1 above, the x-direction is in the direction of the biggest face of the housing unit. The housing unit has the largest frontal surface area in the x-direction. By looking at the forces in the x-direction, it allows the greatest force, at 30 MPH winds, on the house to be determined. Since the largest face will produce the biggest force, compared to the other faces, the simulation of 30 MPH winds is completed from left to right in the picture above. It can also been seen that a wake block was added to the backside of the housing unit. This block will allow the analysis of any other wind effects behind the house. It was determined that the maximum force applied on the house at the simulated wind speeds is around 210 N. With this force, the moments on the house can be calculated which will be used to determine the weight of the base needed to stabilize each unit.

Using the forces acquired in the CFD analysis, which were supported by basic calculations, the frame structure was analyzed in SolidWorks Simulation. To do this, the frame was modeled and fixed to the ground. In the real world, the frame would not be fixed, but the goal of this analysis was to check for deformation in the frame and potential failure, not whether it would be uplifted or not. After fixing the four corner poles, a force of 210N, which was calculated using the CFD model, was applied to the largest face of the house. The largest surface was chosen, with a perpendicular wind, because it would experience the most force out of all of other sides and angles. Figure 2 shows the model, force, and stress.

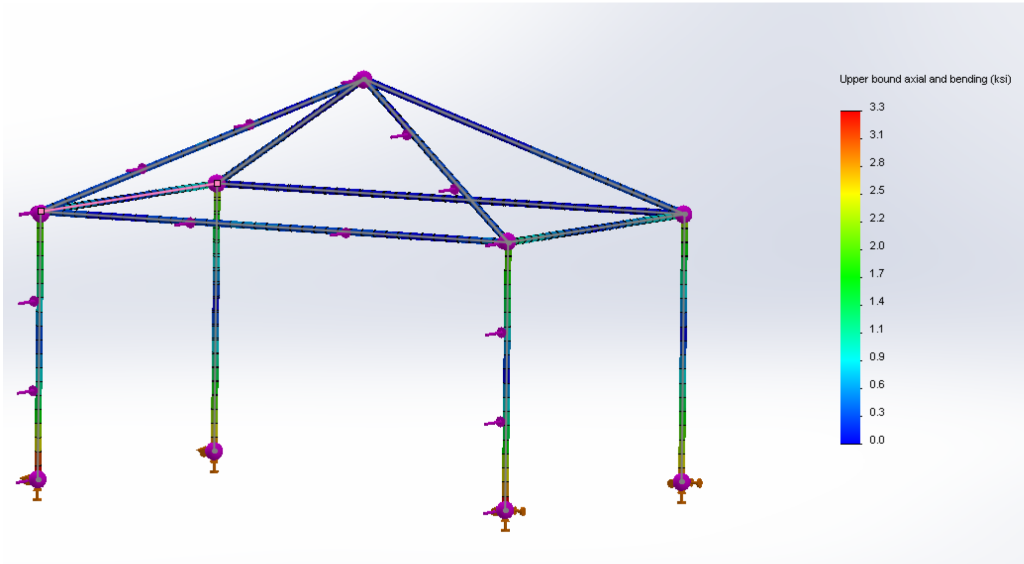

Figure 2: Frame Load and Stress

As can be seen in Figure 2, the maximum stress experienced by the frame is 3.3 ksi, significantly less than the yield strength of the steel. Additionally, the maximum deformation in the structure is approximately 3 mm in the front center tube. Both of these values are well within acceptable ranges.

In order to determine if the structure can withstand 30 MPH wind gusts, the following equation was used. This equation determines the amount of force the structure sees as a result of wind.

$$F = \frac{1}{2}\rho v^2 A C_d \quad (1)$$

Where F is the force due to wind, ρ is the density of the air, v is the velocity of the wind, A is the surface area of the structure the force is acting on, and C_d is the coefficient of drag of the structure.

The amount of force applied on the steel structure given a 30 MPH wind would be 405.8 lb_f. Given the FEA results, this is substantially less than the force the structure could withstand without failing.

6. Future Work

In order to complete the project there is a number of details that must be finalized. Now that all of the components have been ordered and received, the final building process can begin. Work will include piecing together the frame and securing it to the base. The base, made from six high-density polyethylene pallets, must be fixed firmly together into a single contiguous piece. The nine base foot-stands of each pallet are left hollow for the purpose of stacking. These hollow pockets, however, make the floor unsafe due to the non-solid walking surface and thus must be filled or covered in some manner. Once the frame and floor are constructed, the canvas shell must be cut, sewn, and fit to the frame. Furthermore, doors and windows must be made. There are no pictures of the complete assembly at this point. However, a SolidWorks model of the final housing unit can be seen in Figure 3.

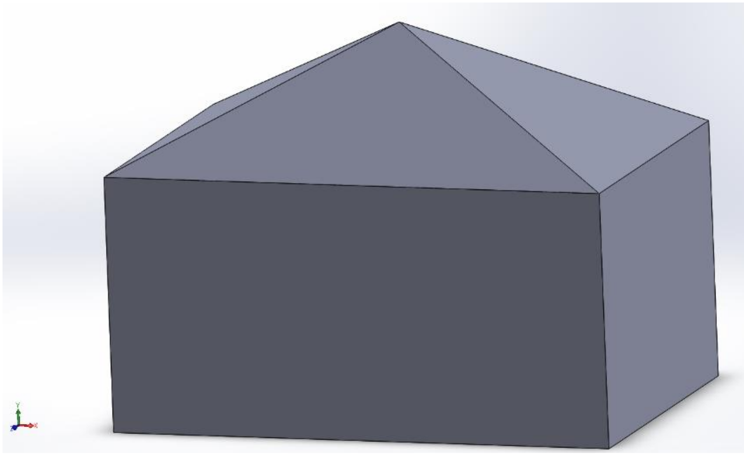

Figure 3: SolidWorks Model of Housing Unit

It can be seen in Figure 3 that the design will consist of a solid outer shell over the skeleton pole structure. As stated earlier, the outer shell will be made from water-resistant, wind-resistant and fire retardant heavy duty, treated canvas. Once all of the structural components are in place, the beds and other furnishings must be brought in and incorporated into the structure.

When construction is completed, the final stage of the project, testing, can begin. To test this design, a volunteer will live in the structure for an agreed upon length of time. They will comment and evaluate the structure on a number of different criteria including comfort and ease of use. With the acquired data and information the final tweaks will be made to the design and structure.

7. Conclusion

In this project, a modular housing unit is designed and built to shelter people during a disaster period. Based on the calculations and analysis, it can be concluded that the proposed design and materials will be both strong and durable enough to ensure the success of this project. With the FEA and CFD analysis, the pole structure and tarp shell will be able to withstand at least 30 MPH wind gusts while maintaining structural integrity and weatherproofing. Due to the height of the polyethylene pallets as well as their composition, the structure will be able to handle three inches of standing water at the base without suffering any internal or external damage. The canvas tarps comprising the outer shell of the structure provide wind and water protection for the occupants, while still allowing breathability and air movement.

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