MECH 4860
Team 20

Design Project Final Report

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Sponsoring Company: Composites Innovation Center

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Abstract

The objective of this project is to design a composite modular floor and wall panel system for Composite Innovation Center (CIC) to be implemented in a temporary disaster relief structure. CIC completed the design and prototyping of an open modular composite gazebo, consisting of a modular roof panel and supporting timber frame, and decided to expand the gazebo's functionality by enclosing it to serve as a temporary disaster relief structure in the tropical zone.

The completed design of the floor and wall systems consists of 9 uniquely designed components used in conjunction with pins, bolts, nuts, and washers. The geometry of the components allows for electrical routing and plumbing; and the ability to expand the structure by 4 ft. The intended joints make it easy for the assembler to locate and secure the components together. In addition, the components were designed to maximize the assembling efficiency.

While the design itself is not production ready, further stress analysis must be applied to finalize geometry, joints, and materials. However, it is recommended that pultrusion be used for all shelter parts. Core materials for floor and wall panels will depend on loading requirements and should attempt to utilize green materials in the final design.

1.0 Introduction

This section of the report will briefly highlight the scope of the modular temporary disaster relief structure design project. It will discuss the background behind both the Composite Innovation Center and the project, and the project objectives. The section will give a brief scope of the entire report.

1.1 CIC & Project Background

The Composites Innovation Center (CIC) is a not for profit organization jointly sponsored by the private sector and industry. Its mandate is to support and stimulate economic growth, innovative research, development and application of composite materials and technologies for manufacturing industries. The main role of the CIC is to provide project management, engineering consulting, process development and testing services to support industry in developing and commercializing composite materials, products and processes [1].

The modular temporary disaster relief structure design project began as a simple modular composite gazebo design. Mark J. Townsely C.E.T., a ground transportation manager at the CIC, was the first who thought of the design. The design was a response to issues dealing with the replacement of an entire gazebo tarp due to tears in the material. It was apparent to Mark that the use of modular pieces would allow for easy replacement of individual damaged pieces, making repair more convenient. Based on Mark's initial concept, CIC later completed the design and prototyping of an open modular composite gazebo, as pictured in Figure 1. The design comprised of composite modular roof panels supported by timber framing.

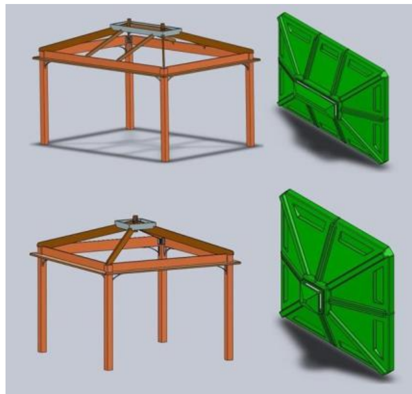

Figure 1. Original composite gazebo

CIC decided to expand the gazebo's functionality by enclosing it to serve as a temporary disaster relief structure. CIC recognized an absence of composite modular structures in the disaster relief market, as structures primarily were over-sized tents. CIC imagined that a composite modular structure would allow increase the potential for structure functionality, by being able to accommodate electrical routing and plumbing - allowing the structure to be used a support center, such as a medical facility, water treatment facility, or office facility. In addition, CIC believes that the modular composite temporary disaster relief structure would potentially stimulate the local Manitoba economy by manufacturing and distributing the structures, as well as taking advantage of local green materials. Thus, CIC tasked our team with the design a modular composite temporary disaster relief structure.

1.2 Project Objectives

The main focus of this project is to generate and refine conceptual designs for the modular composite temporary disaster relief structure's floor and wall panel system. Emphasis of the project is placed on generating floor and wall panel geometries, in order to achieve a repeating panel configuration (a modular panel), and panel joint configurations. Furthermore, the floor panel system must be designed to accommodate electrical routing and plumbing.

CIC originally intended the project to include composite laminate design and stress analysis, but later decided to focus on the structure geometry, joining methods and a limited amount of material selection. The customer expects a CAD model of the temporary disaster relief structure; detailing panel configuration and panel joint configuration. In addition, the customer hopes that a rapid prototype can be made. Ultimately, the final design is not required to be production ready. The final design should allow the customer to continue onto stress analysis, laminate design, and a more detailed design phase. In designing the structure's floor and wall, the following customer needs were taken into consideration as shown on Table 1 below [2].

TABLE I. CUSTOMER NEEDS

#	Need		Imp.
1	The Structure	must be enclosed	1
2	The Structure	must be easy to assemble	2
3	The Floor & Wall Panels	should be comprised of "green" materials	1
4	The Floor & Wall Panels	must be able to support amenities (modular beds and tables)	2
5	Panel Manufacturing	must be either pultrusion, compression moulding, or RTM to support high volume	1
6	The Structure	should be designed to minimize the number of fasteners	3
7	The Floor & Wall Panel Designs	should minimize panel geometry size to accommodate repeating units (modular)	1
8	The Wall Panels	must attach to the timber (of the roof structure)	1
9	The Structure	must include a door and window	1
10	Material Costs	should be minimized	3
11	Manufacturing Costs	should be minimized	3
12	The Floor	must be raised	1
13	The Structure	should accommodate a rain collection system	4
14	The Floor Design	must accommodate electrical routing, and plumbing	1
15	The Floor & Wall Panels	must be fire retardant	4
16	Panel Designs	must suit both foundation areas of 10 x 10 ft and 10 x 14 ft	1
17	The Structure	should be aesthically appealing	2
18	The Structure	should must snow loading requirements	1
19	The Structure	should must wind loading requirements	1
20	The Floor and Wall Panels	must avoid snap joints as panel joining methods	1

Using the customer needs, it was determined that the intent of the design was to make use of modular pieces to allow for both easy expansion of the structure and easy replacement of individual damaged parts. The modular parts would be designed to allow the structure to expand 4 ft, to satisfy both 10 ft by 10 ft and 10 ft by 14 ft structure surface areas. The design of individual components would need to be minimized (component types), to reduce the manufacturing of different parts. In terms of joining the components, the number of fasteners should be kept to a minimum. In addition, the design would need to accommodate both electrical routing and plumping. CIC also required that the wall system be able to accommodate for wall amenities.

1.3 Scope of Report

The report outlines the design of the floor and wall systems for the temporary disaster relief structure. The report includes a description of the individual parts that were designed, how the geometry and joints satisfy CIC requirements (customer needs), a recommendation of materials and manufacturing process, and the assembly of the individual parts into the entire structure. The report will also explain the necessary analysis to be taken into consideration to take the design into production, as the design is not production ready.

2.0 Design Detail

This section will describe in detail the floor and wall systems designed for the CIC's modular composite temporary disaster relief structure. The section is divided into 5 subsections, covering the individual designed components of the floor and wall system, the geometry and joints of the design components, the possible materials and manufacturing methods, and the assembly of the individual designed components into the complete structure.

2.1 Floor and Wall System Components

This subsection will highlight, primarily though Figures, the individual designed components of the wall and floor system for the modular composite temporary disaster relief structure. The individual components assemble together to form the composite temporary disaster relief structures. Please refer to Appendix D for full drawings of individual components.

There were nine components uniquely designed components for floor and wall systems of the structure. As shown in Figure 2, the components designed are: (A) modular floor lid panel, (B) modular floor storage panel, (C, D, E) modular floor extension panels, (F) dowel piece, (G) modular wall panel, (H) modular wall corner piece, and (I) wall clamp.

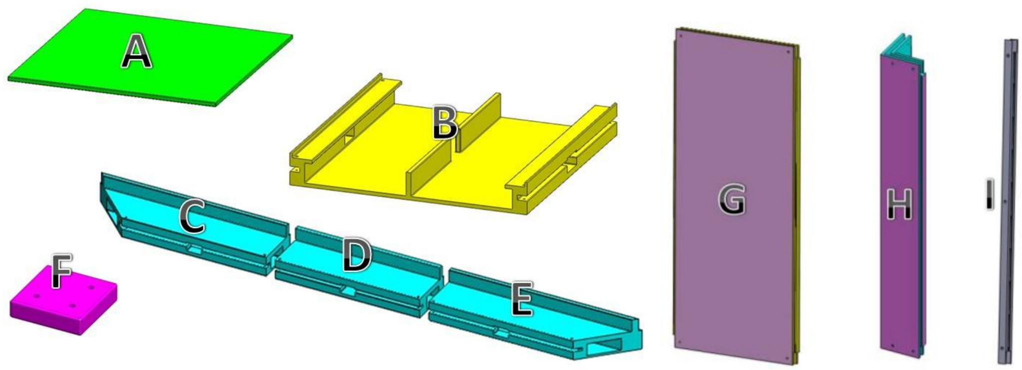

Figure 2. Wall and floor components

2.2 Geometry

This subsection will highlight some of the important geometrical features of the floor and wall systems. It will specifically detail the structure expansion and electrical routing and plumbing. For a more detailed account of the geometry design please refer to Appendix B.

2.2.1 Structure Expansion

The structure's ability to expand lies in the design of the geometry of both the floor and wall systems. Taking into account the 4 ft expansion requirement of the structure, select components were designed to be 4 ft (or 48 in). The center floor assembly, as later described in the section 2.6 of the report, expands from 10 ft to 14 ft through additional modular floor storage panels and modular extension panels, as shown in Figure 3.

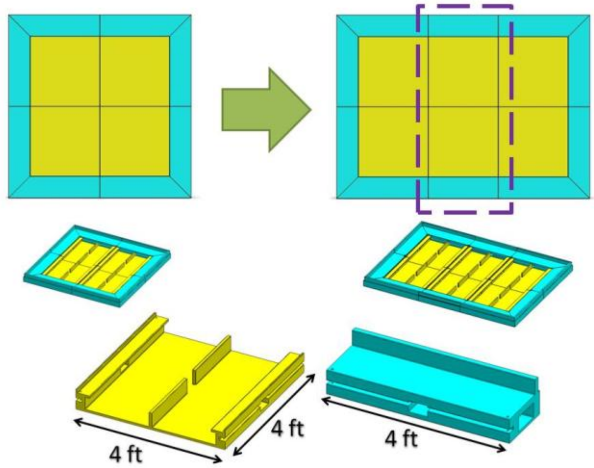

Figure 3. Floor expansion

The 4 ft expansion, as highlighted by the purple dashed line in Figure 3, is accomplished using 2 additional modular floor storage panels and 2 modular extension panels. The expansion is accommodated in the geometry of the two panels, as shown by the 4 ft length indication. As for the wall assembly, the expansion is accomplished through the addition of 2 extra modular wall panels and wall clamps shown in Figure 4. Just as the modular storage panels and modular extension panels were 4 ft in length, the modular wall panel and wall clamp together are as well to accommodate the 4 ft expansion.

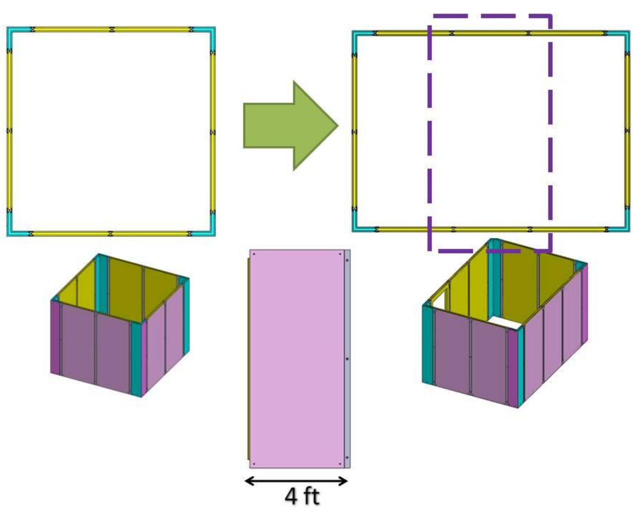

Figure 4. Wall expansion

The 4 ft expansion, as highlighted by the purple dashed line, is accomplished using 2 additional modular floor panels and 2 wall clamps. The expansion is accommodated in the geometry of the two panels, as shown by the 4 ft length indication.

2.2.2 Electrical Routing & Plumbing

One of the key features of the floor system is the accommodation of electrical routing and plumbing. Electrical routing and plumbing is accomplished through routing within the modular storage panels and modular extension panels. The modular storage panels feature a 'storage' design, enabling routing within the panel.

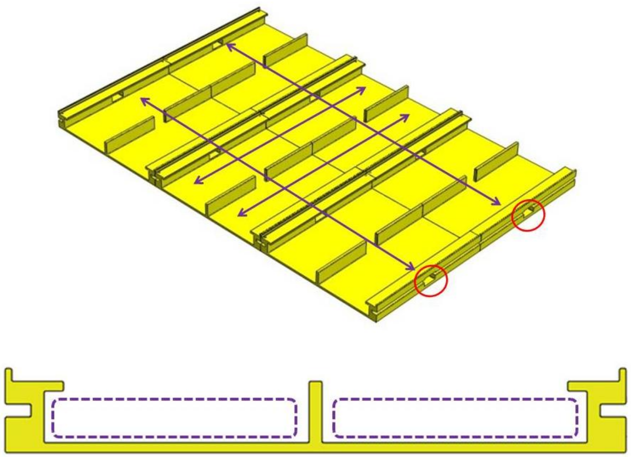

Figure 5. The modular floor storage panel

Routing is accomplished in both directions, as indicated by the purple arrows in Figure 5. The dashed purple area demonstrates the space in which routing can be placed. Cut out holes located on the side of the panel, as indicated by the red circles, allow for routing to the extension panel. The routing is left unexposed to the occupants through the modular floor storage lid, as shown in Figure 6, by placing the lid on top of the storage panel.

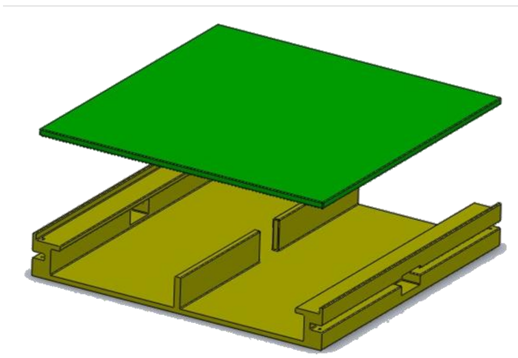

Figure 6. Modular lid

Routing through the extension panels was achieved by way cut-out holes, as indicated by the red arrows in Figure 7. In addition, the cross section of the extension panel allows for routing within itself, as shown by the dashed purple area. As the extension panels are hollow, the routing is able to travel around the perimeter of the floor structure. The purple dotted area in Figure 7 shows the hollow cross section of the extension panels.

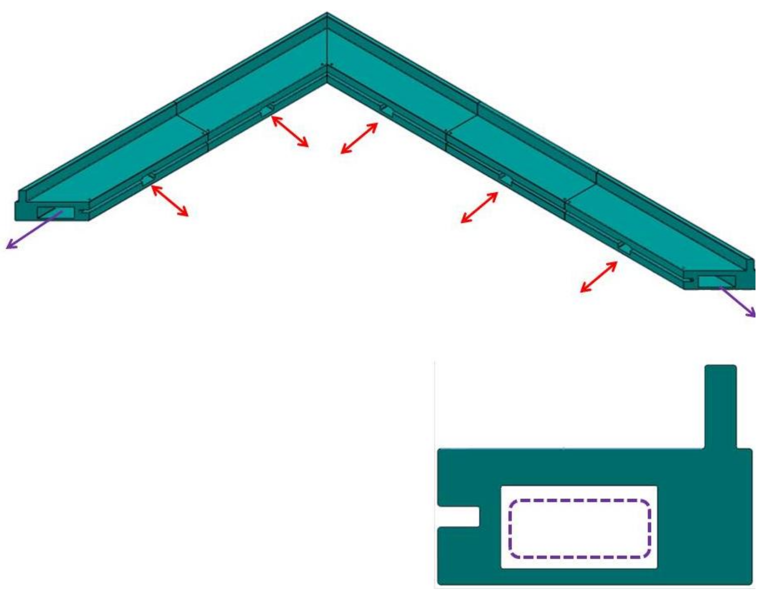

Figure 7. Routing through extension panels

Compared to the modular storage panel, the extension panel does not offer any type of easy access for the occupants by way of the floor lid. Please refer to section 2.6 for further detail on the electrical routing and plumbing.

2.3 Joining methods

This subsection will highlight the three joint mechanisms designed for the floor and wall systems of the composite modular temporary disaster relief structure, as pictured below. It will specifically discuss the joint mechanism of the walls, joint mechanism of the walls to floor, and joint mechanism of the floor. For a more detailed account of the joint mechanism design please refer to Appendix C.

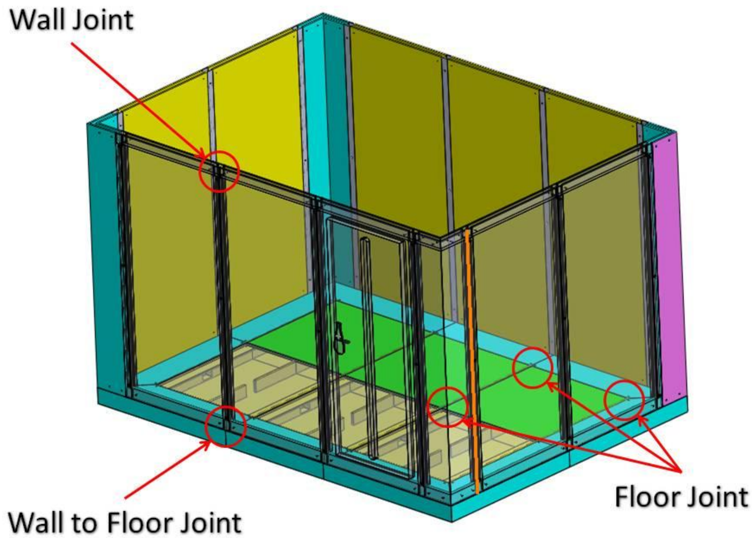

Figure 8. Perspective view of the structure with indicated joint locations.

2.3.1 Wall Joint

The wall joint consists of joining the modular wall panels and modular wall corner piece using a wall clamp, as pictured in Figure 9. As mentioned previously, the wall panels and corner pieces have male mating ends along both edges. In the same fashion, the wall clamp components contain a similar female mating geometry to suit the edges of the wall panels and corner pieces.

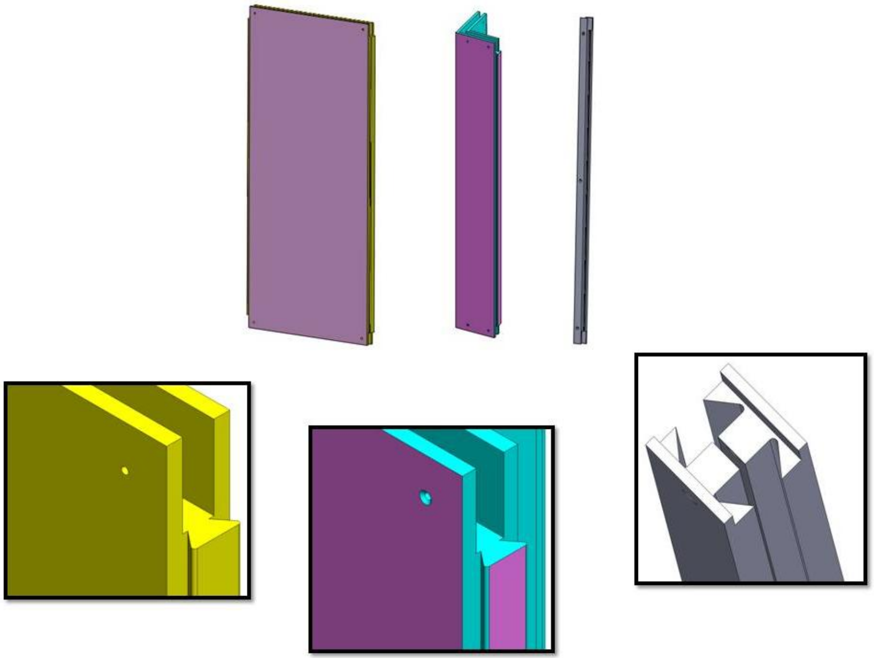

Figure 9. Wall components shown with their joining features

The wall joint connection is done by mating the ends of the wall panels and corner pieces with the two wall clamp components as pictured below. Using a bolt, washer, and nut in three hole locations along the wall clamp, the clamp is tightened. The wall clamp holes are not threaded, to prevent damage. As a result of the tightening, the wall panels and corner pieces are secured and joined together. The clamp connecting the 2 wall panels is shown in Figure 10.

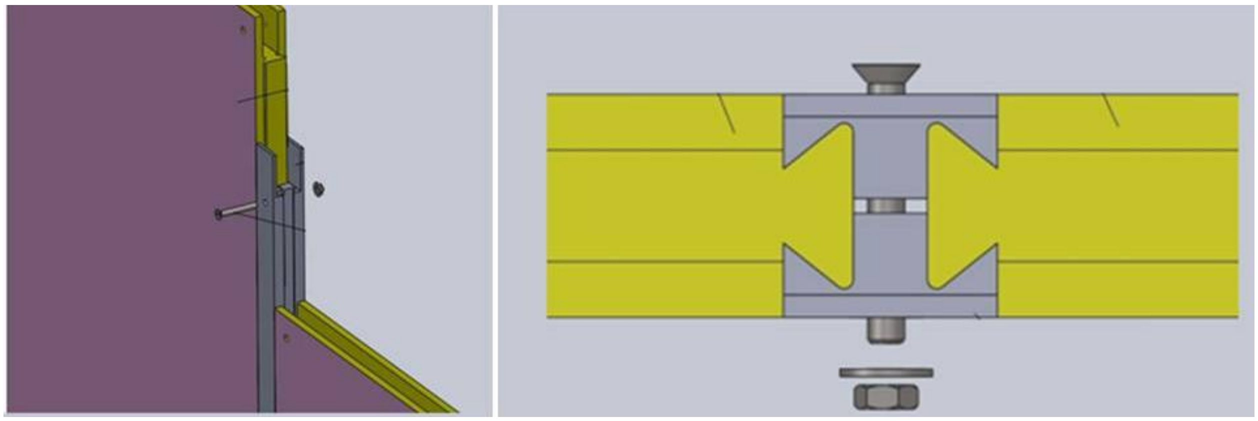

Figure 10. Wall clamp

2.3.2 Wall to Floor Joint

The wall to floor joint consists of placing the modular wall panel, or wall corner piece, over the extruded boss of the modular extension panel and securing using a bolt, nut, and washer as pictured in Figure 12. The modular wall panel contains an embedded U-channel that suits the extruded boss geometry. The panel, or corner piece, is properly located by matching the fastener holes and securing using a bolt, nut, and washer.

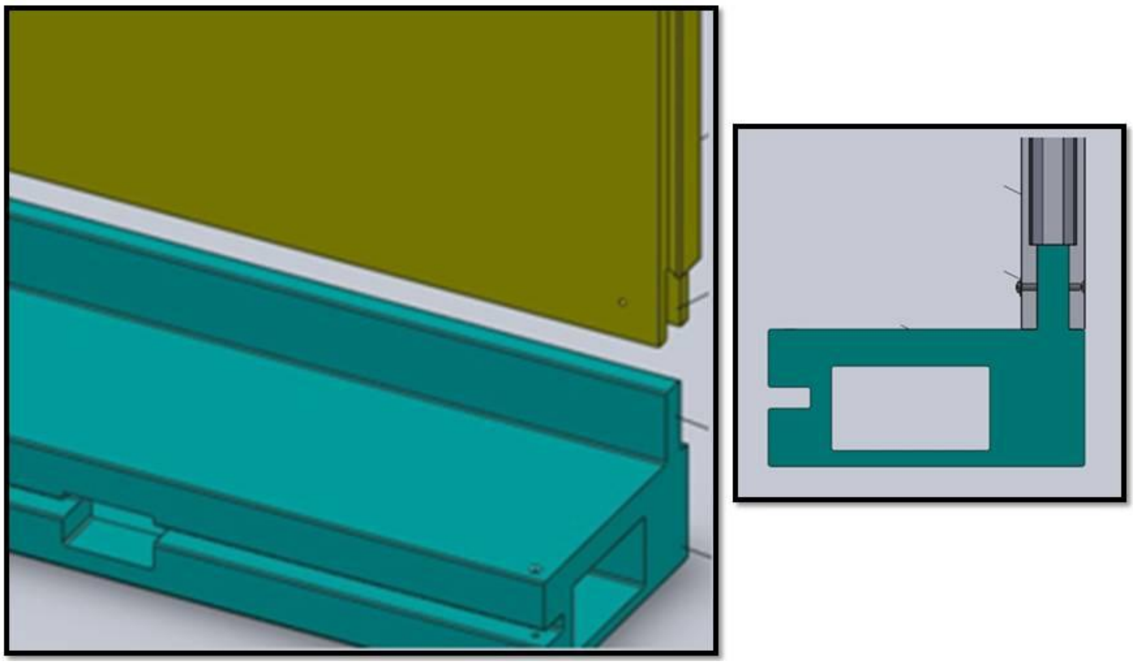

Figure 11. Wall to floor joint

2.3.3 Floor Joint

The floor joint consists of a dowel and a dowel cut-out along the edges of the modular floor storage panel and modular floor extension panels. The cut-out, as shown in Figure 12, is used to locate the panels together using the dowel by placing it in the cut-out. The panels are joined together by placing the dowel in the cut-out, mating holes of the dowel and the panels, and securing using a pin.

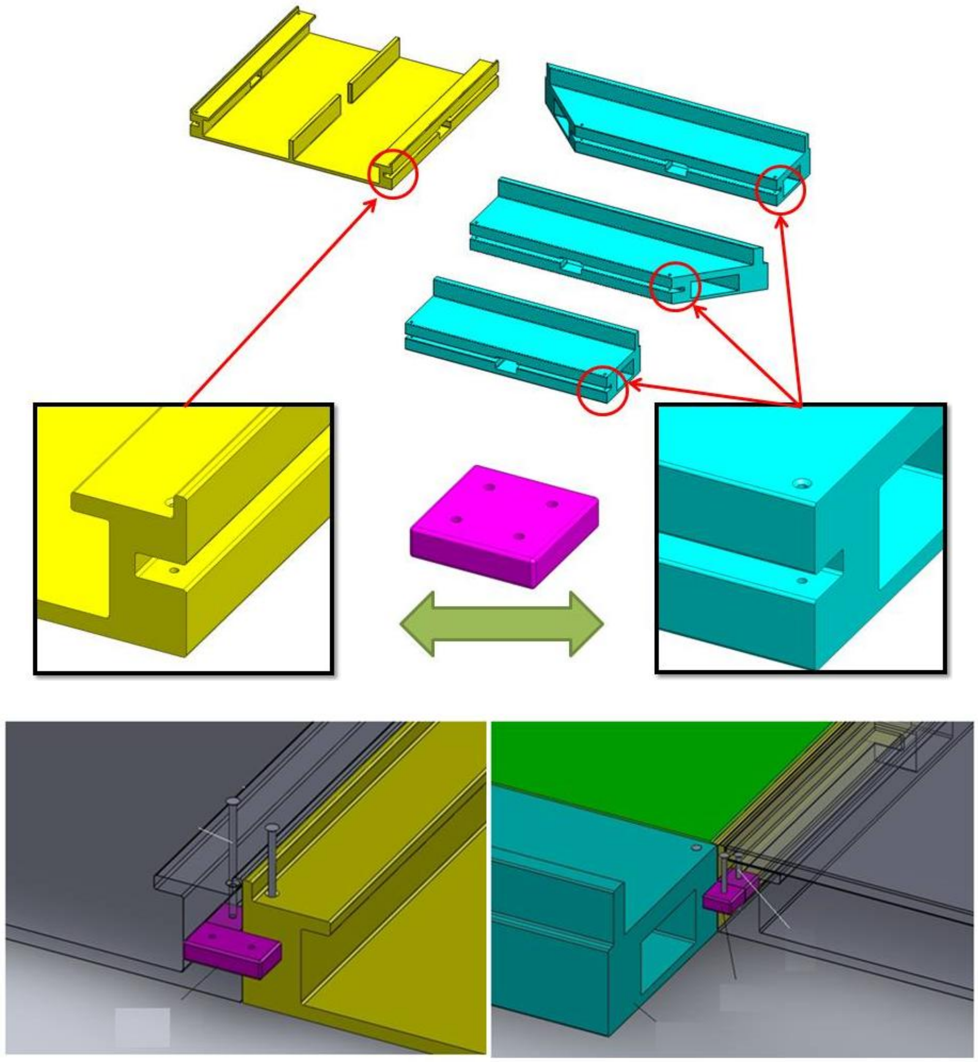

Figure 12. Floor joint

2.4 Structure Assembly

This subsection will demonstrate the needed steps in assembling the modular composite temporary disaster relief structure, as shown in Figure 13. As the focus of the project has been on the design of the floor and wall, this section will not include the assembly of the roof - as the roof design was finalized by the CIC prior to project definition. In addition, the section will demonstrate the assembly for a 10 ft by 10 ft and 10 ft by 14 ft structure.

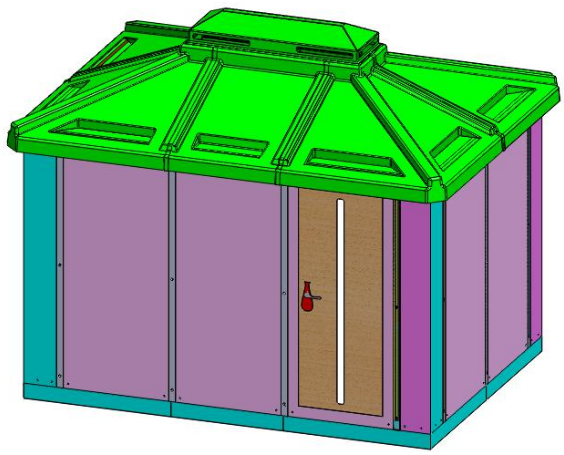

Figure 13. 10’ x 14’ structure

The assembly of the entire structure consists of 3 phases: Floor Assembly, Wall Assembly, and Roof Assembly. As mentioned previously, focus of the assembly will be on the floor and wall. The assembly makes use of nine unique parts, in conjunction with bolts, nuts, and pins, all described in the geometry and joint sections of the report.

2.4.1 Floor Assembly

The Floor assembly consists of six of the nine unique parts that were designed for the modular composite temporary disaster relief structure, as pictured in Figure 14. Shown parts are (A) modular floor lid panel, (B) modular floor storage panel, (C, D, E) modular floor extension panels, (F) dowel piece.

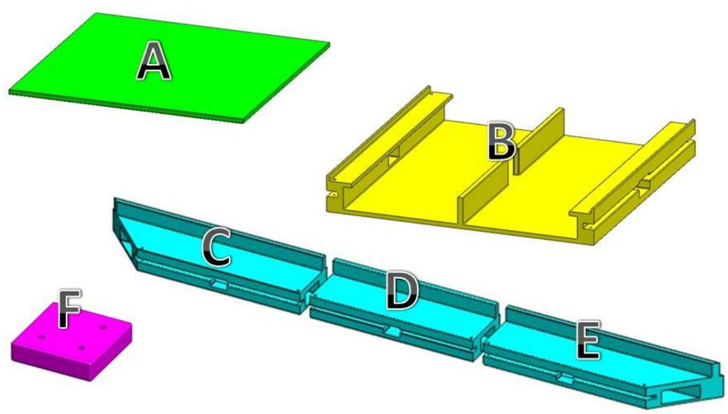

Figure 14. Floor parts

For the 10 ft by 10 ft structure, a total of 16 pieces and 32 pins are required, while the assembly of the 10 ft by 14 ft structure requires an additional 9 pieces and 12 pins. The assembly consists of 4 steps: center floor assembly, perimeter floor assembly, electrical routing and plumbing, and enclosing.

TABLE II. TABLE OF PIECES REQUIRED FOR FLOOR ASSEMBLY

	Floor Assembly Pieces							
Structure	A	B	C	D	E	F	Pins	Total Pieces
10 by 10	4	4	4	0	4	9	32	57
10 by 14	6	6	4	2	4	12	44	78

The center floor assembly consists of joining the required number of modular center floor storage panels together using dowels and pins. Figure 15 illustrate two how the two completely assembled center floor assemblies, for the 10 ft by 10 ft, and 10 ft by 14 ft structures, join together.

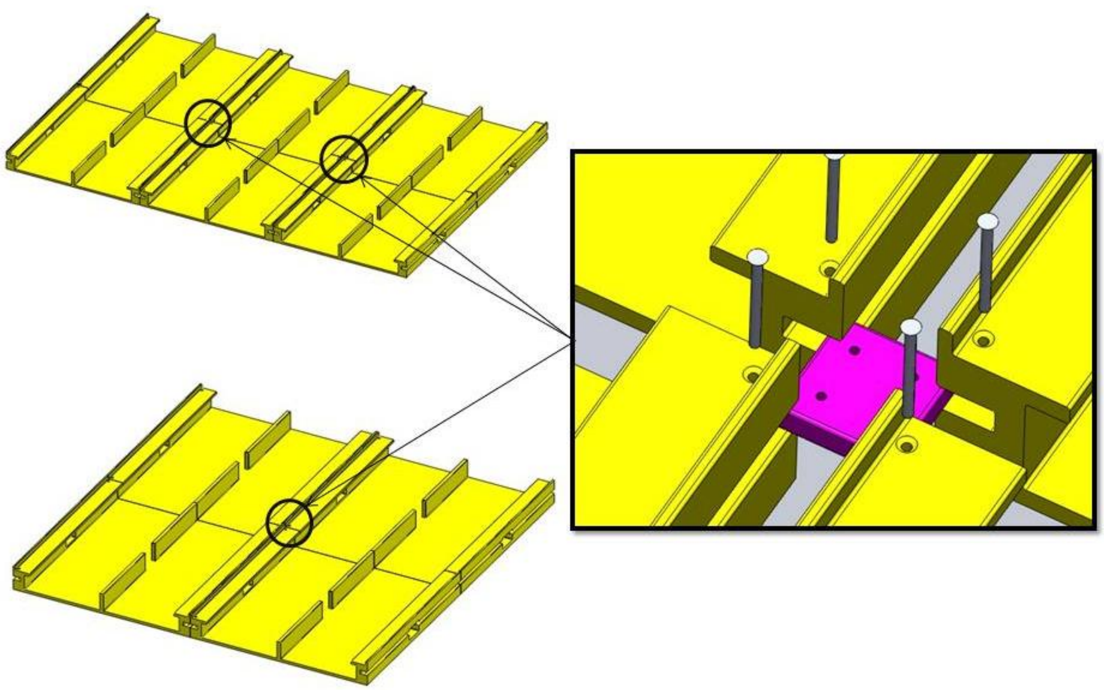

Figure 15. Dowel assembly

The center floor storage panels join together using a dowel to locate four panels together, with the dowel seated within the dowel cut-out of the center storage panel. Mating the four pin holes of the dowel with the pin holes of the storage panel, a pin is used per each hole to join the panels together. After the center floor assembly is complete, assembly of the perimeter floor assembly is required. The perimeter floor assembly consists of using the extension panels to perimeter the center floor assembly, as shown in Figure 16. The two joint locations are highlighted for corners (red) and straight (black).

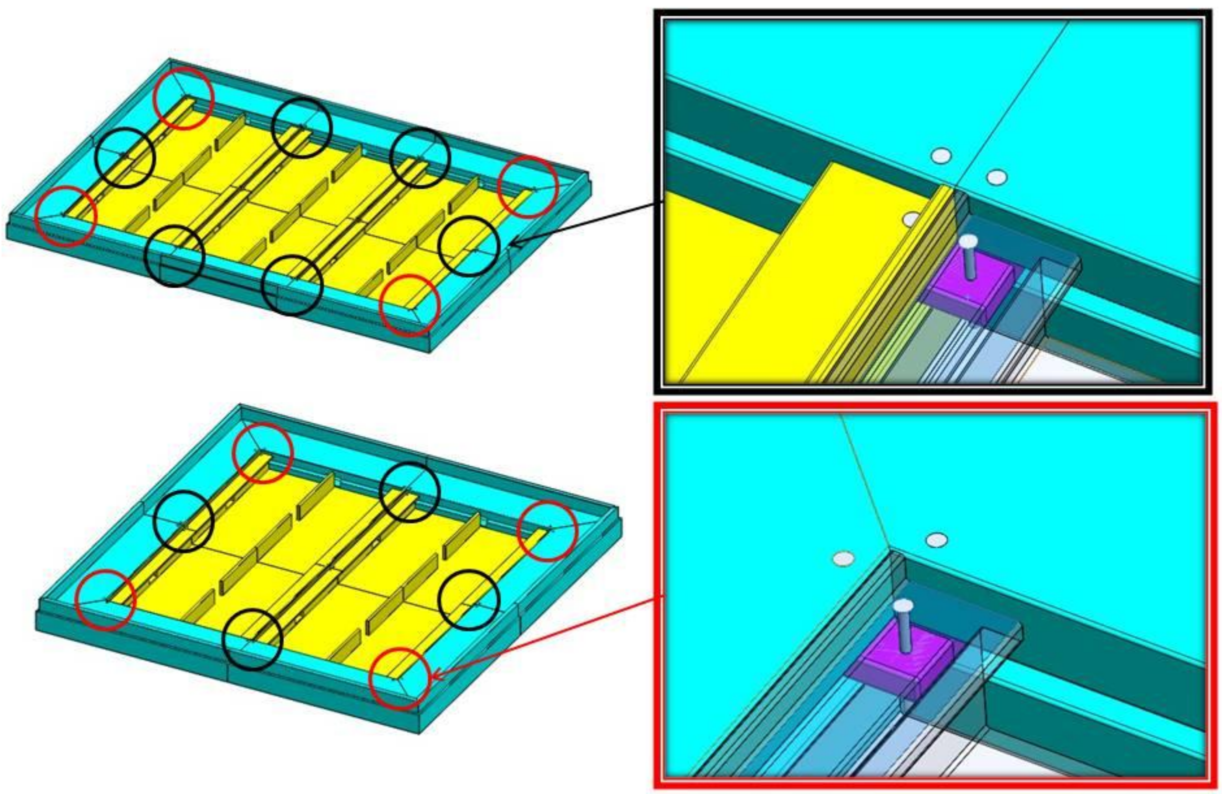

Figure 16. Perimeter floor assembly for 10' x 10' and 10' x 14'

The perimeter floor storage panels join together using a dowel to locate four panels together, with the dowel seated within the dowel cut-out of the center storage panel. Mating the four pin holes of the dowel with the pin holes of the storage panel, a pin is used per each hole to join the panels together. For the corners 3 pins are used, while for the straight portions of the assembly 4 pins.

After the completion of the perimeter floor storage, electrical routing and plumbing are then completed. We imagine that plumbing will be accomplished using flexible tubing, rather than standard PVC pipe, to allow for easy routing. Electrical routing and plumbing are done within the storage panel, as pictured in Figure 17. Electrical routing and plumbing directions within storage panel are shown with red arrows.

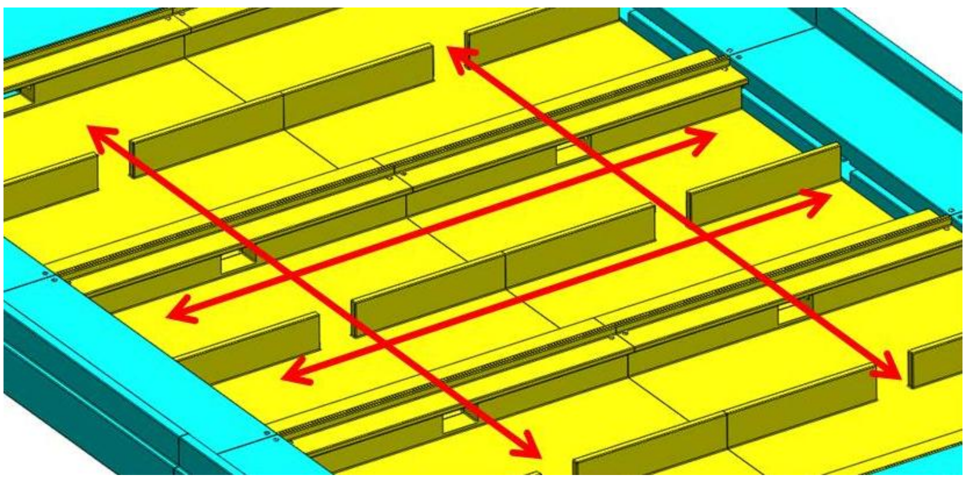

Figure 17. Floor routing

After completion of the electrical routing and plumbing, the floor assembly is finally completed by enclosing the center storage panels with the modular floor lid panel. As shown in Figure 18, the lid panel simple sits on top of the storage panel, creating a flush floor surface. As mentioned in the geometry section, the lid panel allows for quick and easy access to the routing when necessary.

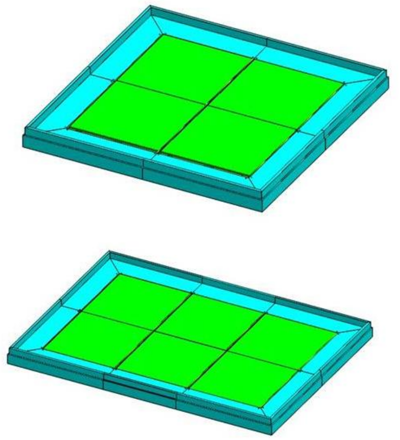

Figure 18. Completed floor assembly

2.4.2 Wall Assembly

The wall assembly consists of three of the nine unique parts that were designed for the modular composite temporary disaster relief structure. Shown in Figure 19 are the three unique parts used in the floor assembly: (G) modular wall panel, (H) modular wall corner piece, (I) wall clamp.

Figure 19. Wall components

For the 10 ft by 10 ft structure, a total of 324 pieces and 200 bolts, nuts and washers are required, while the assembly of the 10 ft by 14 ft structure requires an additional 4 pieces and 36 bolts, nuts and washers.

TABLE III. PIECES REQUIRED FOR WALL ASSEMBLY

	Wall Assembly Pieces						
Structure	G	H	I	Bolts	Nuts	Washer	Total Pieces
10 by 10	8	4	12	100	100	100	324
10 by 14	10	4	14	114	114	114	370

The wall assembly consists of simply installing each wall panel and wall corner piece individually to the floor assembly. The floor assembly contains an extruded boss, which mates with the embedded U-channel of the wall panel and wall corner piece. Sitting either the wall panel or wall corner piece on the extruded boss, the panel/piece is then secured to boss using a bolt, nut and washer. Ideally, the assembly should begin with the installation of the wall corner piece as shown in Figure 20.

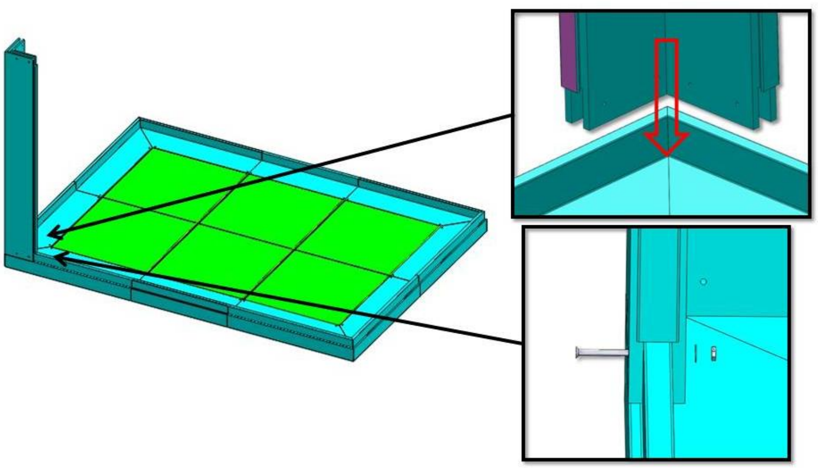

Figure 20. Installed corner piece

After the first wall corner piece is successfully installed, the rest of the wall panels and corner wall pieces can be installed. In the same fashion, the panels/pieces are slid onto the extruded boss of the floor assembly. The panels/pieces are then secured together using a wall clamp. The wall clamp, shown in Figure 21, clamp onto the tale mating ends of the two panels/pieces to be joined. The clamp is then tightened using a bolt, nut, and washer in 3 places along the length of the clamp. The wall assembly is complete when the entire perimeter is of the floor assembly is enclosed with the wall assembly as shown Figure 22.

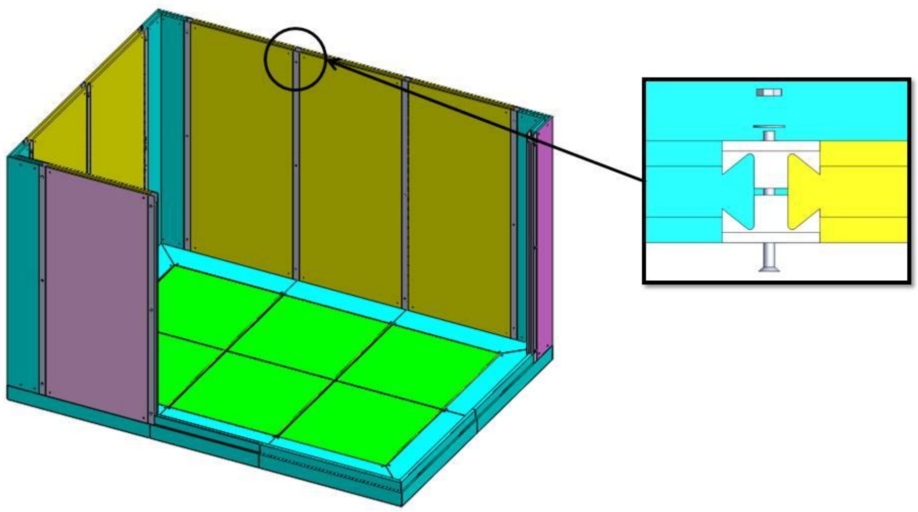

Figure 21. Wall structure installation

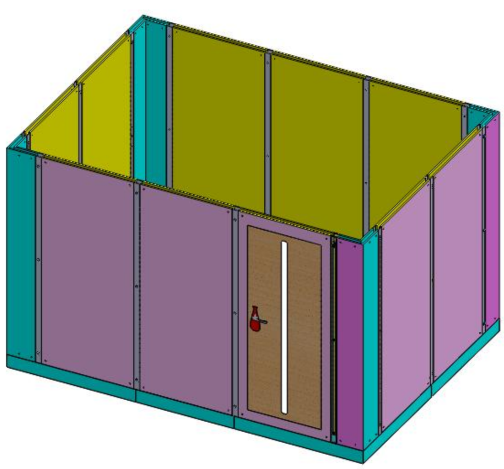

Figure 22. Completed wall assembly

2.4.3 Roof Assembly

As mentioned in the beginning of the assembly section, this section will not detail the exact installation of the modular roof panels. CIC completed the design and prototyping of the modular composite gazebo, as mentioned in the introduction section, and advised not to modify the roof design. However, in the design of the wall assembly, the installation of the roof was taken intro slight consideration.

The wall assembly was designed with an embedded U-channel, similar to that which connects the wall panels to the extruded boss of the floor assembly, for installation of a timber to support the roof as shown in Figure 23. We imagine that a perimeter joist would sit in the U-channel, and the subsequent roof would be installed. Again, because we were advised not to modify the roof design, the roof assembly will not go into any other detail.

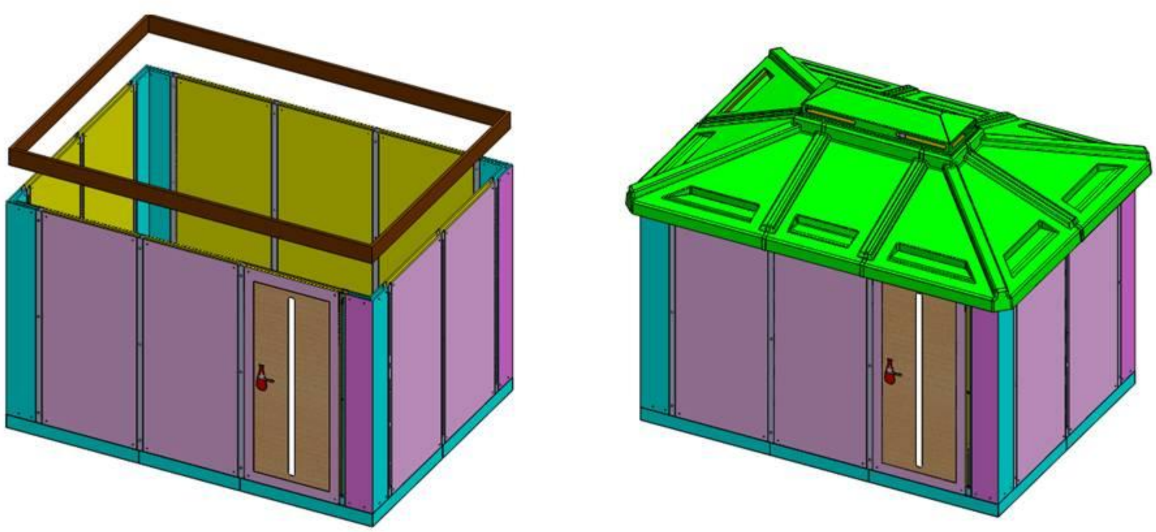

Figure 23. Structure shown with the perimeter joist and roof

2.5 Materials & Manufacturing

The selection of materials for the shelter can only be done in a limited capacity, as stress analysis was cut from the project requirements. If one knows the loads the shelter will encounter, stress analysis is performed and will drive the material selection. The materials and manufacturing section in this report will simply seek to compare available alternatives and to show the design intent.

Many manufacturing processes are available for composite parts. The team had the opportunity to see hand layup and RTM lite processes at the beginning of the project. Other manufacturing methods include compression molding, vacuum molding, and pultrusion, among others. The team considered several of these processes, but eventually decided that the best process for the shelter would be pultrusion. Pultrusion supports high volume production, which is a project requirement. Pultrusion is also highly automated, leading to lower labour costs. The main drawback of pultrusion is that parts must have a constant cross section. Intricate part details cannot be achieved in all directions. All work done on the shelter geometries was performed with the need for a constant cross section in mind, which made things more difficult. The pultrusion setup is shown in Figure 24.

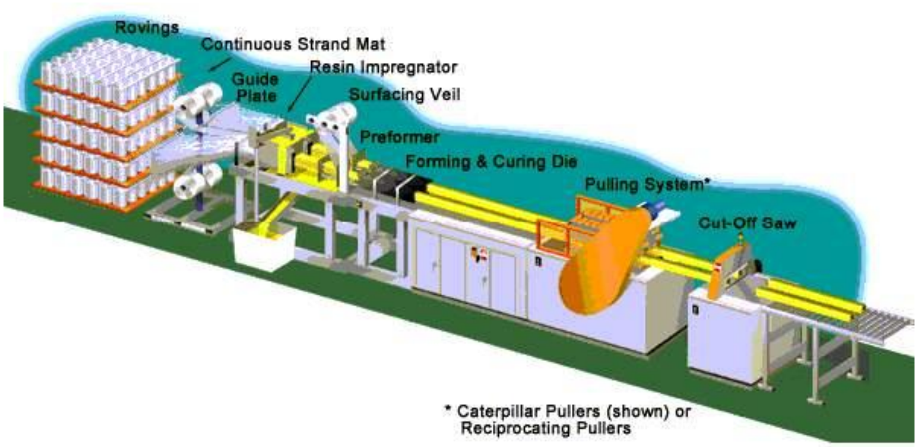

Figure 24. Pultrusion process [3]

Fortunately for the team, a company called Faroex in Gimli, Manitoba has pultrusion capability. Figure 24 below shows a pultruder. The pultruder at Faroex is capable of a maximum part cross section width of 48 inches. This maximum part width of 48 inches means that all shelter parts will have to be equal to or less than 48 inches. The most common materials used in the pultrusion process are glass fibers and a thermoset resin. Fibers are fed into the pultruder from spools, coated with the partially cured resin, and then cured in the die. In addition to making parts with glass and resin, a core material can be inserted into the die, creating a sandwich part. Faroex has experience with both Polyurethane and Balsa cores. The cores sheets they have used in the past are 5/8", but an employee at Faroex said they could do 2" core .

Composite sandwich construction is a very common way of increasing the bending stiffness of a part. The core or inner material can be a foam material such as polystyrene or polyethylene, balsa wood, or a honeycomb material. The outer material or skin is often a fibreglass laminate, but can also be a metal material. As the shelter walls must be designed to withstand high wind loads, a sandwich panel for the walls is the obvious choice. Along with the wall panels, the floor panels will also be sandwich panels to support the flexural loads from people in the shelter [4].

One of the requirements for the project laid out by the CIC in September was that the team would complete a detailed laminate design. As the project progresses, it became clear that the team would have to put more attention into the joints, with laminate design no longer being a requirement. The original schedule included 2 weeks devoted entirely to laminate design, with CIC members helping the group through the entire process. Though a detailed laminate design is not included in the project, a comparison and discussion of alternative materials can be done.

Carbon fiber can be used in pultrusion, but it is much less common than glass. Carbon fibers, while being much stronger than glass, are much more expensive. This is not to say that carbon fiber has no place in structural applications, indeed there are many companies that make carbon fiber pultrusions for use in structures. The ambiente home system, which can be seen in the alternative village near the U of M, can withstand winds up to 250 km/hr and is made completely from fiberglass parts. This leads the team to think that glass is appropriate for the shelter.

The most important properties of a core are its shear strength and modulus, as well as its compressive strength and modulus. The shear strength will determine the failure load and the shear modulus will determine the panel's stiffness [5]. Compressive properties are important in order to prevent the outer skin from wrinkling into the core. Other important core considerations for the shelter will be their cost, their 'green' factor, density, thermal conductivity, impact strength, compatibility with pultrusion manufacturing, flame resistance, and thermal expansion. Impact strength is important to consider because the shelter wall panels may have to be take shock loading from projectiles in a hurricane situation. Additionally, if the CIC wants the shelter to be able be used in cold climates, the insulative properties of the panels will be important. Cores also have many other secondary properties, but the above listed properties are the most relevant for the shelter.

Six core materials were identified as strong possibilities for the shelter. Two core materials called Ambi-core and Malama composite core are both highly green materials, but due to proprietary reasons, no technical data on them could be obtained. Ambi-core uses recycled glass beads mixed with resin creating a very high strength core [6]. Malama foam is up to 40% soy based [7]. Both ambi-core and malama foam have a standard sheet size of 4' x 8', the exact dimension of the wall panels and twice the size of the floor panels, making manufacturing easier than if the sheets had to be cut or adhered together to a 4' x 8' size.

The remaining four possible core materials are balsa, polyurethane, fiber reinforced polyurethane, and recycled PET. Balsa and Polyurethane were selected because they are the two types of core materials that Faroex has experience with. The balsa considered here is dura composites balsa [8]. Recycled PET (recycled pop bottles) from Airex (Airex®T92) [9] was selected for consideration because its material properties are readily available and it represents a core material with a very high 'green' factor. Airex®Pxc fiber reinforced polyurethane provides a core which can take high compressive loads [10].

Lastly, Nidacore foamline 6 lb polyurethane is a common foam core known for having good flexural properties [11]. Key properties for the four cores are listed in table 4. Varying densities are available for all cores, but the average or standard density was chosen.

TABLE IV. CORE MATERIAL PROPERTIES

Property	Unit	Balsa [8]	Polyurethane [11]	Glass Reinforced Polyurethane [10]	Recycled PET [9]
Density	Lb/ft^3	9.5	6	24	7.2
Compressive strength perpendicular to plane	Psi	1,885	122	1,136	260
Compressive modulus perpendicular to plane	Psi	591,600	4437	40, 153	15,950
Tensile strength perpendicular to plane	Psi	1,945	98	-	420
Tensile modulus perpendicular to plane	Psi	-	1956	-	21,030
Flexural strength	Psi	-	150	1,672	-
Flexural modulus	Psi	-		84,203	-
Shear strength	Psi	430	71	699	150
Shear modulus	Psi	23,500	614	24,575	3,335
Thermal conductivity	W/(m*K)	0.061	0.024	-	.035

Some values are missing in tables, but the most important values for compressive strength/modulus and shear strength/modulus are available. The glass reinforced polyurethane and balsa show the best compressive/shear properties, but are more dense than the PET or polyurethane. An important consideration to make with end grain balsa is that unlike the other three cores, it is not isotropic. Balsa's properties are different in the longitudinal, tangential and radial directions. Balsa is reported as having radial and tangential modulus values equal to 4.5% and 1.5% compared to the longitudinal modulus, respectively [12]. The actual compressive modulus for the end grain sheets loaded in-plane would lie somewhere in between 1.5% and 4.5%, meaning that balsa would be poor for large roof loads onto the wall panels. Balsa has a high 'green' factor, as it is wood, however it would have to be shipped from far off, reducing its 'green' value slightly.

Polyurethane has the poorest compressive and shear properties, but is a cheap and light material. It is used in the boating industry and as deck panels, but is cited as having poor impact strength and ability to bond with an outer skin [5]. The shelter's floor panels will most likely not need to be as high performance as the wall panels, meaning that polyurethane cores could be used for the 4'x 4' floor panels. PET is marketed as having good mechanical properties, dimensional stability and compatibility with all manufacturing processes, as well as superior FST (fire, smoke, toxicity) properties. PET can be made from partially or fully recycled and can be recycled over and over again. Like many 'green' materials, cost can often be higher than what normal PET would be.

The final decision on the core materials for floor and wall panels will depend on the loading requirements and service environment. In general, we can say that if the wall panels are experiencing flexural loading due to wind only, balsa should be used. In the case where the wall panels will be expected to take axial loading, the glass reinforced polyurethane is a more appropriate choice. For the floor panels, polyurethane can be used as a core, as it has been used successfully in deck panels.

Material selection will also have to be made for the floor extension panels, wall clamps, as well as the modular floor storage pieces. The extension panels have a constant cross-section and will need machining after pultrusion. The extension panel will have most of the fibers oriented perpendicular to the load from the corner pieces, which is not the best way to make a strong part. However, as part of the pultrusion process, webbed glass is added along with the longitudinal glass, which will help the strength of the extension pieces. Additionally, fibreglass pultruded parts still have a considerably high strength perpendicular to the fiber direction [13].

The most appropriate material for the wall clamp would be a solid pultruded part, as it would add rigidity to the entire wall structure. Regarding the floor storage panels, the material is assumed to be fibreglass, however it will most likely be the case that these storage panels are not taking much loading and could possibly made from extruded HDPE or ABS.

For all shelter parts, machining must be done with utmost care. Composites are extremely susceptible to damage due to drilling and cutting operations. The kind of tool used and support at the drill site will help ensure minimal fiber pullouts and damage. Additional material at the drill site may be required to ensure little damage is done. Any holes drilled though the part thickness must be properly coated inside to ensure protection from moisture.

3.0 Recommendations & Conclusion

This section will make recommendations to move the design to a production ready state, and summarize the entire design of the composite modular temporary disaster relief structure floor and wall systems.

3.1 Recommendations for Production Phase

As mentioned in the introduction section of the report, the final design will not be production ready. In order to move the design into the production ready state, stress analysis must be done on the structure. Ultimately, stress analysis dictates the geometry, joints, and material of each individual component designed. In effect, the current design could drastically change, in order to achieve a production ready state. For illustrative purposes, panel thicknesses, hole diameters, joint geometries (extruded bosses and male mating ends) and materials could all potentially be different than the original design.

In addition, further consideration should be placed on the anchoring of the structure and the routing in-and-out of the structure. Based on the last meeting with the CIC, where these issues were raised, it was recommended that the modular extension floor panels contain a hole for routing in-and-out of the structure. The extension panel would also include a cover, for locations not requiring routing out of the structure. In addition, the hole would be used for a similar dowel piece to protrude out the structure and allow for anchoring into the ground.

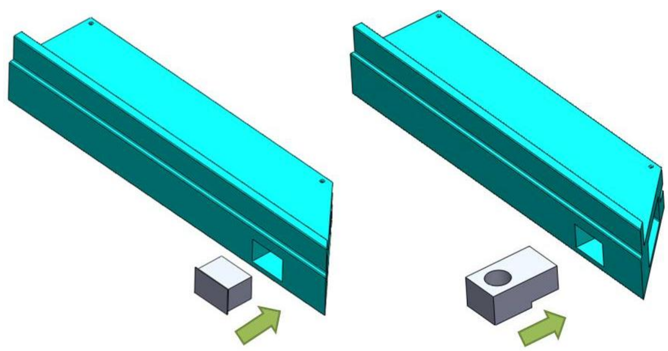

Figure 25. Suggested hole cap (left) and anchor piece (right)

While CIC recommended the modification of the extension panel and additional components, as shown in Figure 25, the current report did not include the recommendation in the design based on time constraints of the project. However, the model will be modified to include the recommendation for the oral presentation.

3.2 Conclusion

In conclusion, the final design is comprised of 9 uniquely design components. When the components are assembled together to form the floor and wall systems of the composite modular temporary disaster relief structure, they satisfy 10 ft by 10 ft and 10 ft by 14 ft structure surface area and 4 ft expansion requirements. In addition, the structure accommodates for electrical routing and plumbing, and wall amenity attachments.

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Appendix A - Disaster Shelter Research

This section will highlight some of the disaster relief structures available on the market. This research was used in aiding the design process of the composite modular temporary disaster relief structure.

Disaster relief structures are temporary shelters for individuals that lost their homes. The two common types of disaster relief structures used are, a canopy/tent design and a fold-able structure design. Canopies, like the ones manufactured by ProPac who specialize in disaster preparedness and mitigation [14], provide a temporary open shelter as shown in Figure 26.

Figure 26. Canopy as manufactured by ProPac [14]

While the structure would help protect occupants from either rain or snow, it would not provide them with insulation from the wind. Essentially, enclosing the canopy to protect occupants from the wind would classify it as a tent structure. Celina Tent Inc., a vinyl tent manufacturer and supplier [15], manufacture military grade temporary disaster relief tent structures as shown in Figure 27.

Figure 27. Military tent manufactured by Celina Tent Inc. [15]

Besides canopy/tent structures, there is also a fold-able disaster relief structure that is currently manufactured by IADDIC. IADDIC is a portable shelter manufacturer geared towards helping those in poverty in developing nations, as well as aiding those in disaster situations [16]. IADDIC's current fold-able structure is shown in Figure 28.

Figure 28. Foldable structure manufactured by IADDIC [16]

Appendix B - Geometry Design

This section of the appendix will cover the geometry of both the floor system and wall system, highlighting how the geometries of each individual part were determined and how the overall geometries satisfy the project requirements. In addition, it will also cover the alternate geometry designs of the structure.

Geometry Requirements & Assumptions

The intent of the temporary disaster relief structure is to make use of modular pieces to allow for both easy expansion of the structure and easy replacement of individual damaged parts. The structure's surface area, as provided in the Design Specification Package, covers an area of 10 ft by 10 ft, and 10 ft by 14 ft. CIC's intent with the structure's geometry is to work off the 10 ft by 10 ft area, and allow for 4 ft expansions in either directions. In other words, the structure would also need to support a 14 ft by 14 ft surface area. Thus, the requirement of the geometry is simply to make use of modular pieces able to accommodate a 10 ft by 10 ft surface area that could provide 4 ft expansions in either direction.

In addition to satisfying the expansion requirement, CIC also expressed the need for the structure to accommodate both electrical routing and plumping. Thus, the floor system geometry must be designed to accommodate electrical routing and plumbing. Assumptions that were used in the design of the floor and wall systems dealt with the height of the structure. Based on several conversations with the CIC, it was determined height of the wall panel should be 8 ft.

Floor Geometry

In this section, the floor system surface area will be discussed in order to demonstrate how the design satisfies the both the surface area requirement and 4 ft expansion requirement, and the electrical routing and plumbing requirement.

The floor system geometry was designed using two distinct features: modular center panels and modular extension panels. Shown in Figure 29, the two features work together by the modular center panels (yellow) forming a center floor assembly, and the modular extension panels (turquoise) surrounding the perimeter of the center floor assembly to satisfy the required structure surface area.

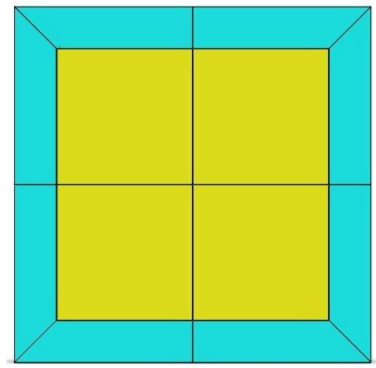


Figure 29. 10’ by 10’ center floor assembly.

The center panel geometry was based off the 4 ft expansion requirement of the structure, making the geometry 4 ft by 4 ft. Joining four modular center panels, a 8 ft by 8 ft center floor assembly would be attained; leaving a 1 ft gap surrounding the assembly for a 10 ft by 10 ft required structure surface area.

The modular extension panels are based off the 1 ft gap, thus making the width of the panel 1 ft. In addition, the length of the modular extension panel geometry would make use of a 45° angle to join the panels together at the corners. Based on the corner, the subsequent length of the modular extension panel would be 4 ft on the side joining the center floor assembly and 5 ft on the opposite side. The extension panels join together to form the perimeter floor assembly.

To satisfy the expansion requirement, for a 10 ft by 14 ft structure, two additional modular center panels and two modular extension panels would be required. However, the extension panels required would have to be modified to allow for the expansion. Instead of the extension panels having a 45° angled end, it would have two flat ends. In other words, the extension panel would have geometry of 4 ft by 1 ft.

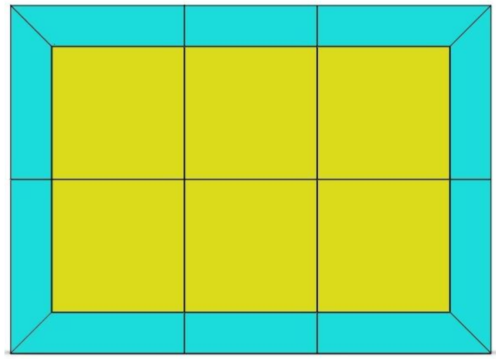


Figure 30. 10' by 14 'center floor assembly.

Thus in satisfying both the both the surface and 4 ft expansion requirements, a total of 4 types of panels (one modular center panel, and three modular extension panels) are required. The three extension panels are of the same cross-sectional geometry, but two of them require machining.

Through several team brainstorming sessions, three important floor design features were generated to satisfy the electrical routing and plumbing requirement. One of the features generated was that the floor must be raised in order to accommodate any type of routing. In raising the floor, it would provide safety to the occupants by eliminating exposure to any of the routing. Separation between occupants and routing led to the next important feature, enclosing the routing from the environment. By enclosing the routing, it would prevent and minimize any accidents such as fire caused by exposed wire, or leakage from plumbing. In addition, enclosing the routing would prevent any small creatures from using the structure as a dwelling space. The final important design feature generated was that the routing must be easy to access. Accessibility to the routing allows for easy installation and quick replacement.

Using those three important design features, the modular center floor panel was designed based on a modular storage unit. The modular center floor panel in Figure 31 was divided into two parts: a modular center storage panel (yellow) and a modular center storage lid (green). While the modular center panel was divide into two parts, it still maintains an overall surface area of 4 ft by 4 ft. The two parts work together by simply completing the routing within the storage panel and enclosing the routing using the storage lid.

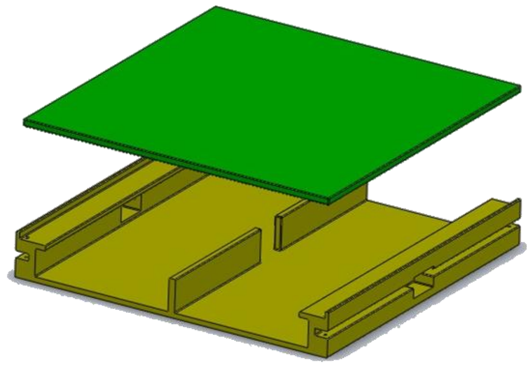


Figure 31. Modular storage panel & lid

The modular storage panel features a cross section that allows for both a raised floor and the electrical routing/plumbing. With the lid enclosing the storage panel, there is a 4 in space to allow for routing. In addition, the sides of the storage panel have a 5 in by 3 in cut out to allow for routing between joint storage panels. On the same sides of the panel, there is also a 2 in by 1 in cut running along the length of the panel to allow for the insertion of a dowel for joining the panels together. Figure 32 shows the storage panel geometry (top right: cross section geometry; bottom right: side view).

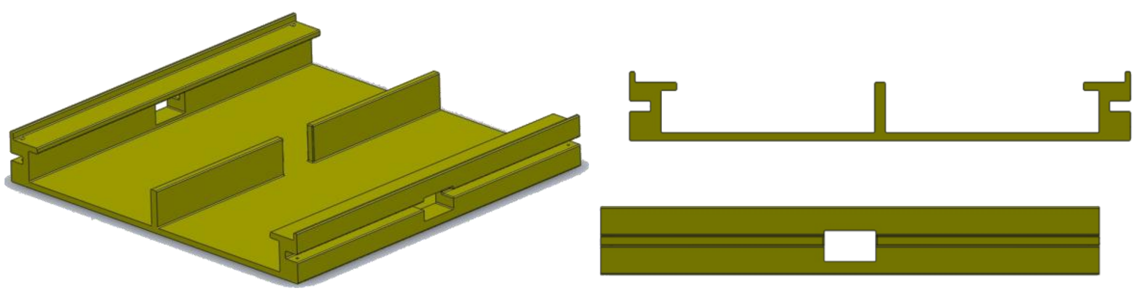


Figure 32. Modular Center Storage Geometry

As mentioned previously, the modular center storage panels join together to form a center floor assembly. When joined together, the 5 in by 3 in cut-out allows for routing between the center storage panels. Shown in Figure 33 are the center panel assembly configurations for both required surface areas.

The storage lid panel allows quick and easy access to the routing. As mentioned previously, the access makes it installation and repair of the routing easy for the user.

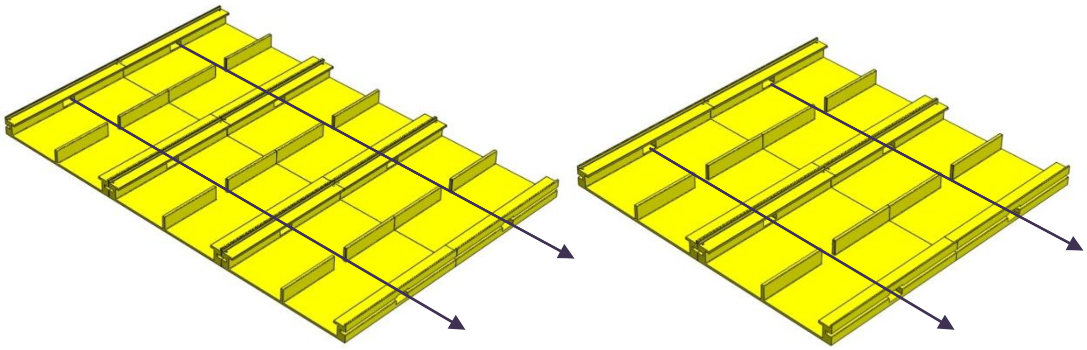


Figure 33. Floor assembly routing capabilities.

The modular extension panels primarily serve to fully enclose the routing from the environment. The extension panels, shown joined together in Figure 34, feature a 5 in by 3 in cut-out to match the same cut-outs on the modular storage panels, and a 2 in by 1 in cut running along the length of the panel to allow for the insertion of a dowel for joining the panels together. The extension panels also feature a 7.5 in by 4 in hole running through the panel, to allow for further routing along the perimeter of the structure surface area, and a 4 in by 1.5 in boss protruding from the top of the panel, to allow for joining between the floor and wall.

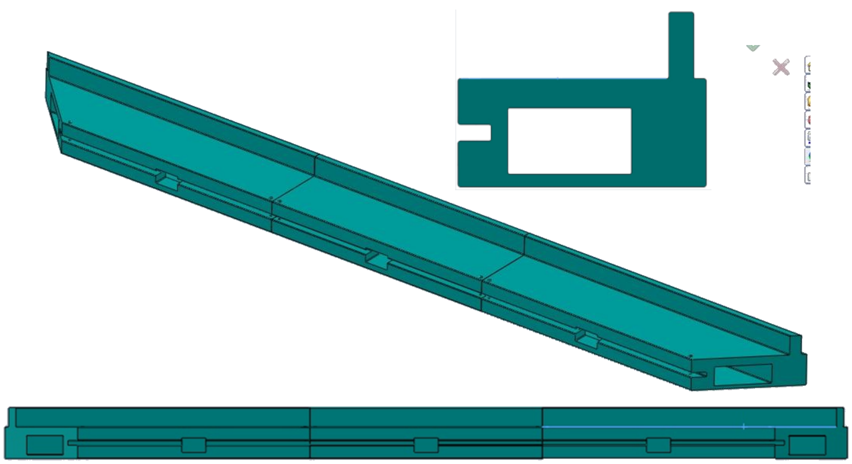


Figure 34. Modular Extension panels

When the extension panels are joined together to form the perimeter floor assembly, the 5 in by 3 in cut out allows for routing from the center floor assembly as shown in Figure 35. In addition, the 7.5 in by 4 in cut out running through the extension panels, allow for routing throughout the perimeter. The only drawback from the extension panels, or perimeter floor assembly, is the limited access to the routing itself as compared to the 'storage' design of the center floor assembly.

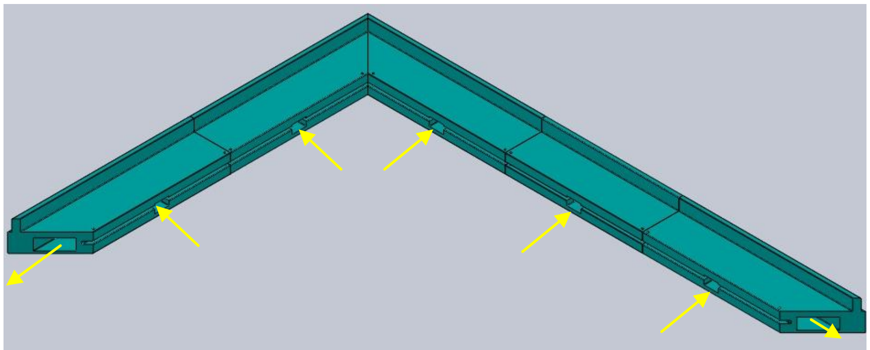


Figure 35. Modular Extension panel routing capabilities

Wall Geometry

In this section, the wall system geometry will be discussed in order to demonstrate how the design satisfies the both the surface area requirement and 4 ft expansion requirement. The wall system was design using two distinct parts: a modular wall panel (yellow) and a modular corner piece (turquoise). The corner piece was developed as a result of CIC's desire to remove the timber posts from their original gazebo design, as originally detailed in the Design Specification Package. The wall seen seen from above is shown in Figure 36.

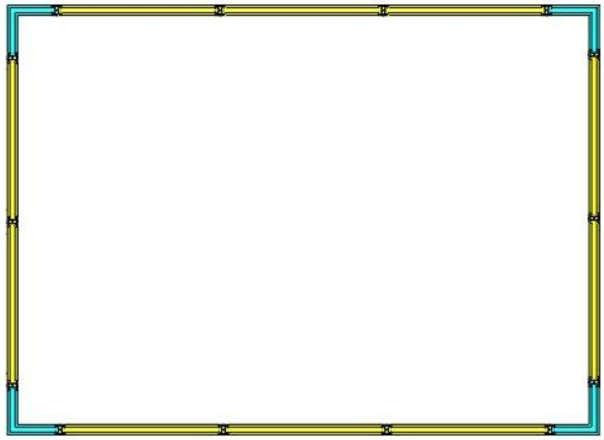


Figure 36. Wall system

The modular wall panels connect together forming a solid wall. To satisfy the lengths of 10 ft and 14 ft, two and three panels are respectively required. In order for the wall system to enclose the required surface areas, the modular corner pieces are then used to complete the perimeter around the required surface area. For either required structure surface area, four modular corner pieces are required.

In designing the modular wall panels, the same principles were applied as in the design of the modular center panels. Based off the 4 ft expansion requirements, the modular wall panels were designed with an approximate length of 4 ft. As a result the L-shaped corner pieces, as pictured in Figure 37 have an approximate length of 1 ft of each to satisfy the lengths of 10 ft and 14 ft.

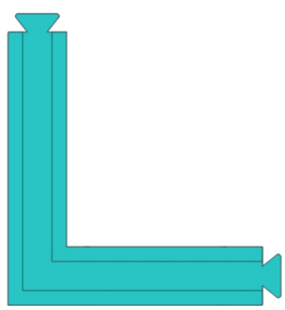


Figure 37. Wall corner piece geometry as viewed from the top down.

Both the modular wall panels and modular corner pieces are 8 ft in length, based on the height assumption, and feature a tail mating end that run along the ends the panels/pieces. The modular wall panels and modular corner pieces also feature an imbedded U-channel used to locate the wall to the extension floor panels (boss) and roof timbers as shown in Figure 38.

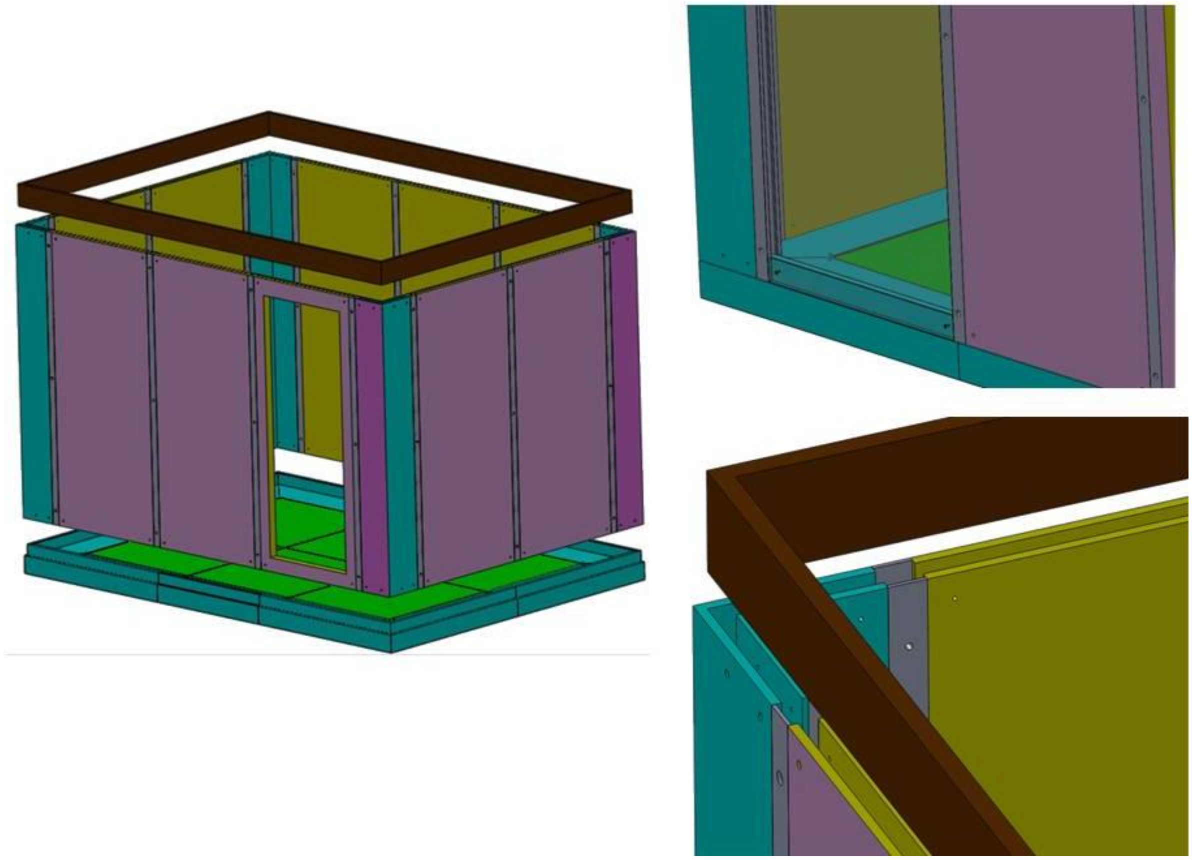


Figure 38. Embedded U-channels connections

Alternate Designs

Two alternate designs were considered for the geometry of the composite modular temporary disaster relief structure: the inclusion of corner posts and tapered walls. The inclusion of corner posts was designed with the base posts included in the design, as originally intended by CIC. Pictured in Figure 39, the design featured the addition of a timber floor frame to raise the floor above the ground and provide a space for electrical routing and plumbing, as shown on the right. The design was scrapped after CIC indicated they had wanted to remove the base posts.

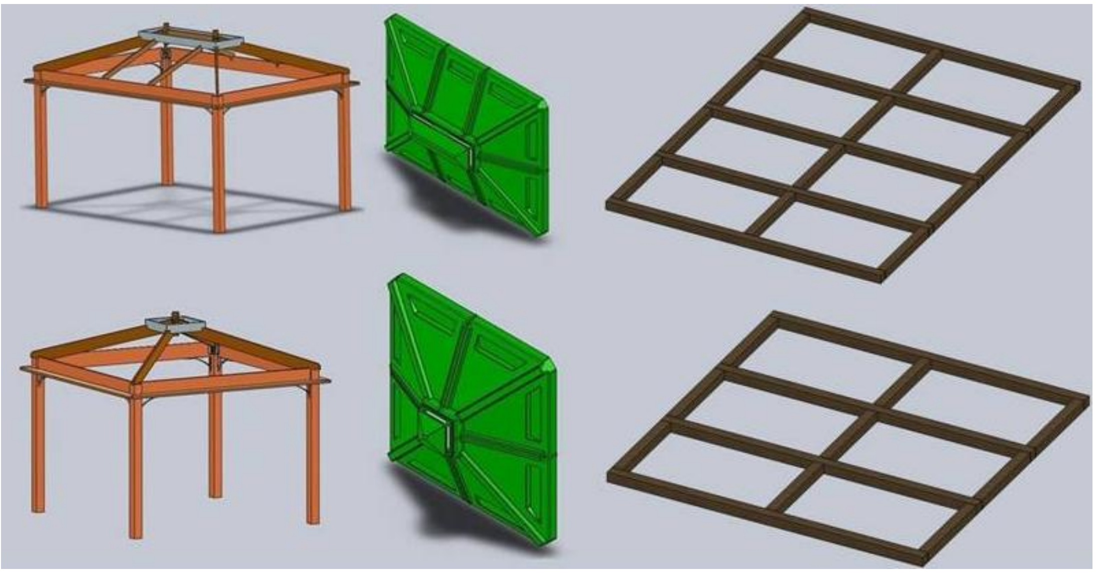


Figure 39. Geometry design w/ base posts.

The design of the tapered walls was generated as a response to the removal of the base posts. The tapered wall design, as pictured in Figure 40 would provide additional support in terms of wind loading. The design would distribute the roof loading onto the walls of the structure. In addition, the tapered wall design would increase the structure surface area. However, the design was scrapped due to complications in the stress analysis of tapered walls, the additional material required, and the difficulty in manufacturing a tapered wall.

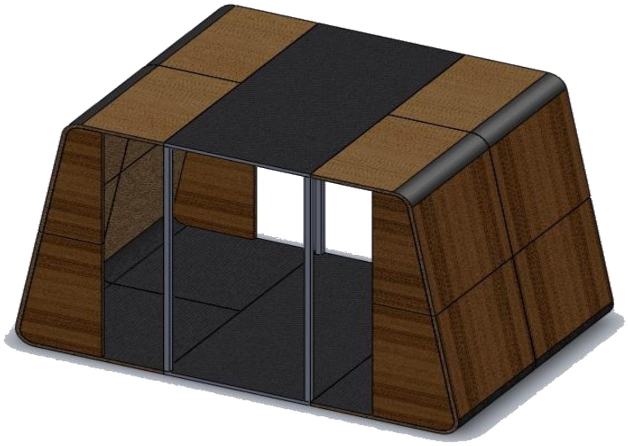


Figure 40. Tapered wall design.

In addition to the two geometry designs of the structure, two geometry designs were considered for the floor system: the I beam design and the raised floor design. The I beam design, shown in Figure 41, was generated in response to the removal of the base posts, in order to utilize the floor frame design. Essentially, the designed components form a floor frame, which is used to both raise the floor and allow for electrical routing and plumbing. The routing is covered by floor panels, which sit on top of the floor frame.

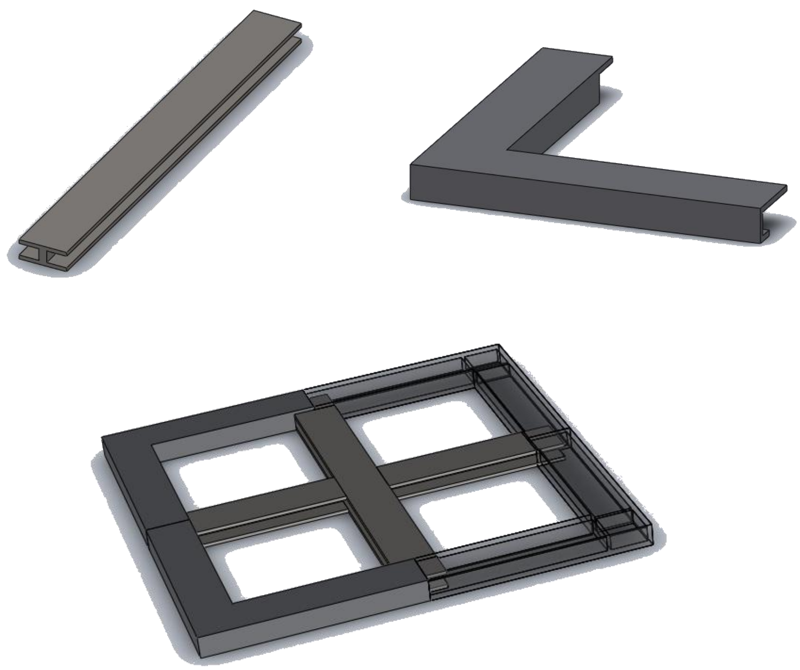


Figure 41. I beam floor design

The raised floor design eliminated the need for a floor frame, as pictured in Figure 42. Essentially, the floor components featured pultruded legs that raised the floor. This design was advantageous in that combined both the floor frame and floor together.

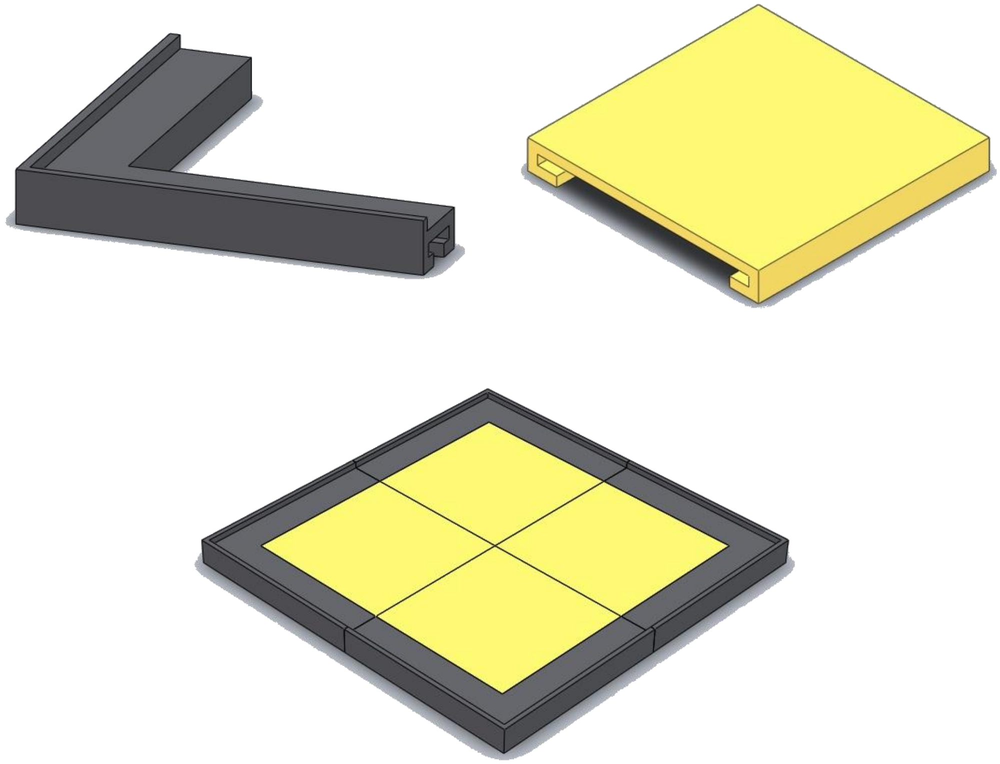


Figure 42. Raised floor design

Essentially, both the I-beam design and raised floor design were phased out due to the fact that the electrical routing and plumbing was left exposed to the environment. In addition, the routing is not easily accessible to the occupants.

Appendix C - Joint Design

This section of the appendix will cover the joint mechanisms of both the floor system and wall system, highlighting how the joint requirements and alternate joint designs of the structure.

Joint Requirements

In designing the joint mechanisms for the structure, four requirements were needed to be satisfied. The first requirement was that the number of fasteners (bolts, pins, nuts, etc) was to minimized. This was to minimize the overall number of components to be shipped, essentially driving down the cost of delivery. The second requirement was that the joints were to be self locating and locking. Self locating joints would make the structure easy for assembly, and locking would eliminate the need for fasteners. The third requirement was that the use of snap joints should be avoided. This was to extend the durability of the joints, as the joints themselves would be manufactured out of a composite material that are prone to damage from snap joints. Finally, the joints were required to maximize sealing efficiency to protect both the occupants and the electrical routing and plumbing from the environment and one another.

Alternate Designs

This section will cover the joint of both the floor system and wall system, highlighting the various alternate designs of the snap joint, bolted wall joint and U-channel joint, h beam joint, sliding joint, and the modified extension panel.

The snap joint in Figure 43 was developed based on a recommendation by the CIC. The joint was to be utilized in the joining of wall panels. The joint was advantageous in the fact that it required not fasteners. However, the joint was ultimately phased out of the design due to complexity of the joint geometry; the geometry was over located. Problems arose in the assembling of the walls, where the last piece would be difficult to join. It was also discovered that the joint would only provide strength in one direction. Additionally, this joint is only strong in one direction. In a conversation with Dr. Polyzoi, it was revealed that the wind pressure on the wall where the wind is hitting and the wall opposite to it will experience pressures nearly equal to each other, one positive the other negative. This means that the joint should be strong in both directions.

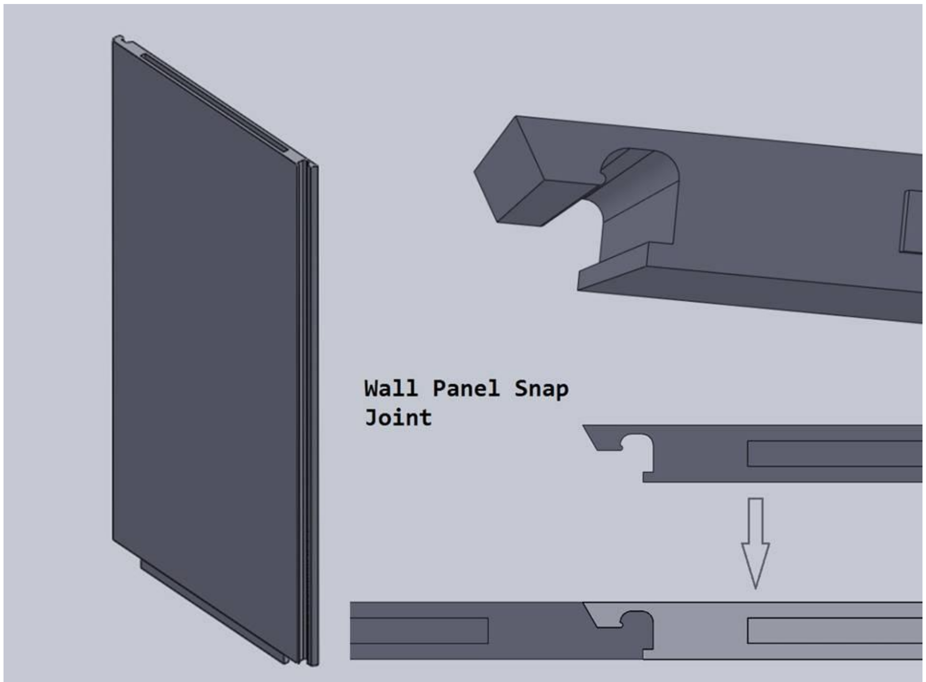


Figure 43. Snap joint

The bolted wall joint in Figure 44 featured a pultruded flange on the ends of the wall panels and corner pieces that would be bolted together within the structure. The joint design was advantageous in its simplicity and ease of locating the wall panels/corner pieces together. In addition, the pultruding flanges allowed for wall amenities. The design also featured a U-channel the wall panels would sit in. This design was ultimately phased out due to strength of the joint, as the joint only provided strength in one direction. In addition, the inclusion of the U-channel would mean additional fasteners to secure the U-channel to the structure.

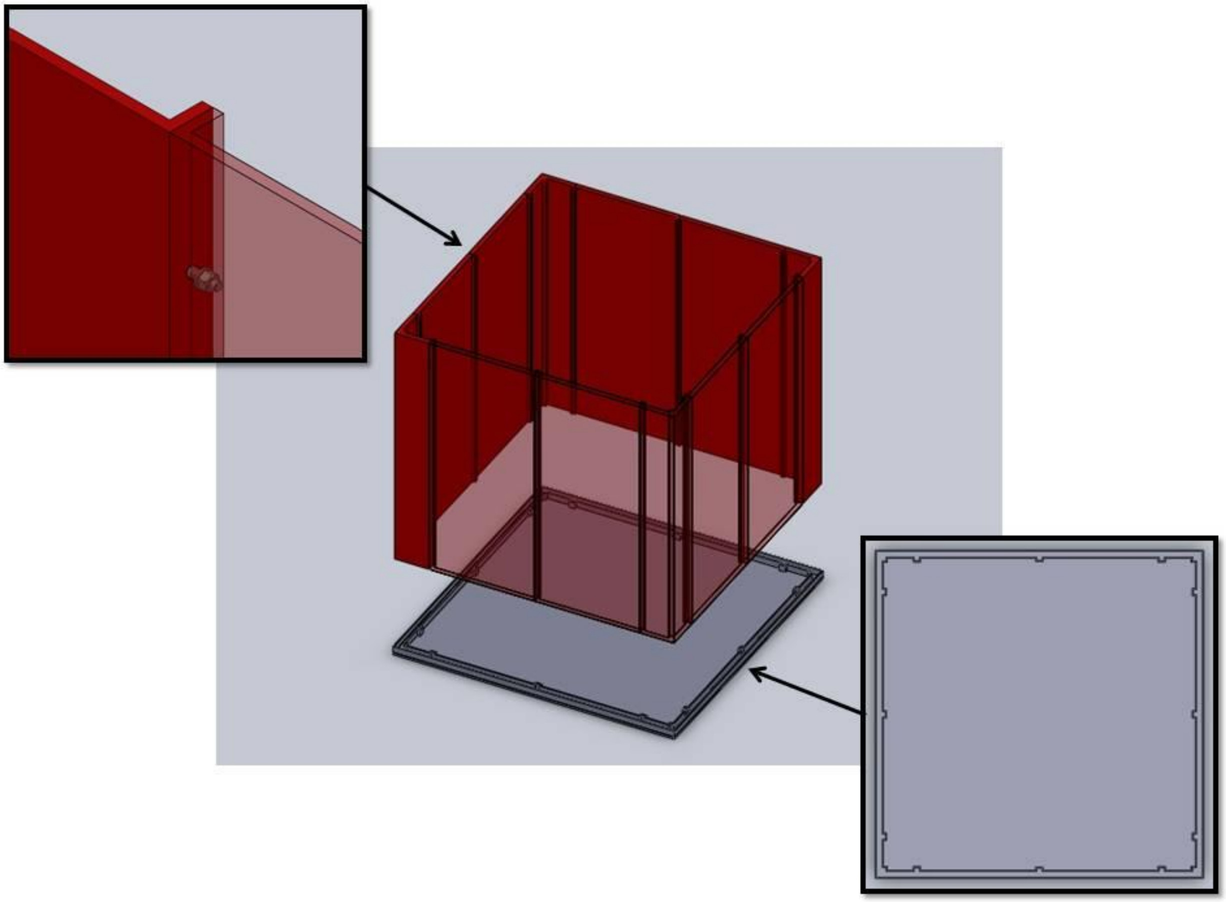


Figure 44. Bolted wall joint

The H-connector joint, shown in Figure 45, features a pultruded H-beam to join the wall panels/corner pieces together. Pictured on Figure 45, the wall panels slide into the H-beam, and are joined using a bolt and nut. While the joint is simple and user friendly, it requires many fasteners. Ultimately, the design was phased out due to the joint being made from metal.

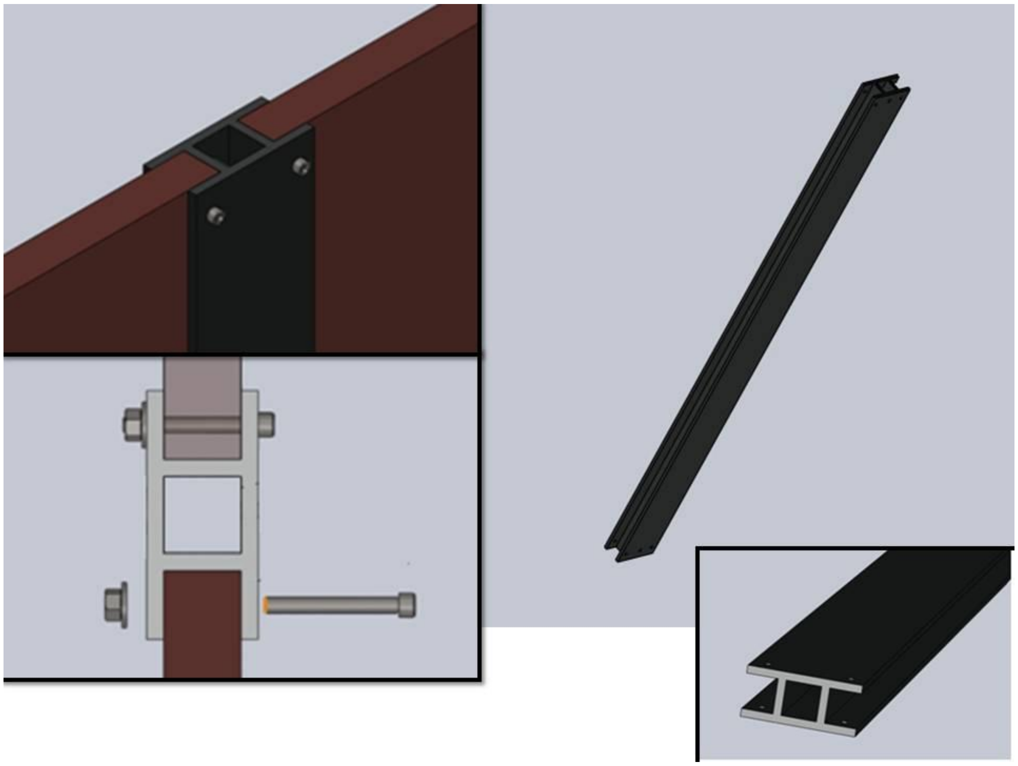


Figure 45. H connector joint

The sliding joint featured male and female mating ends, located at the ends of the wall panels, that would slide together. This design, shown in Figure 46, contained empty spaces (or joggles) along the male and female mating ends. The joint worked by lifting the panel 1 foot, inserting the male mating end into the empty space above the female mating end, and sliding down. The design was advantageous in that it required no fasters. However, it was determined that the part was over engineered in that the manufacturing of the part would be very difficult. Additionally, the joint only provided strength along half of its length. The design was ultimately phased out.

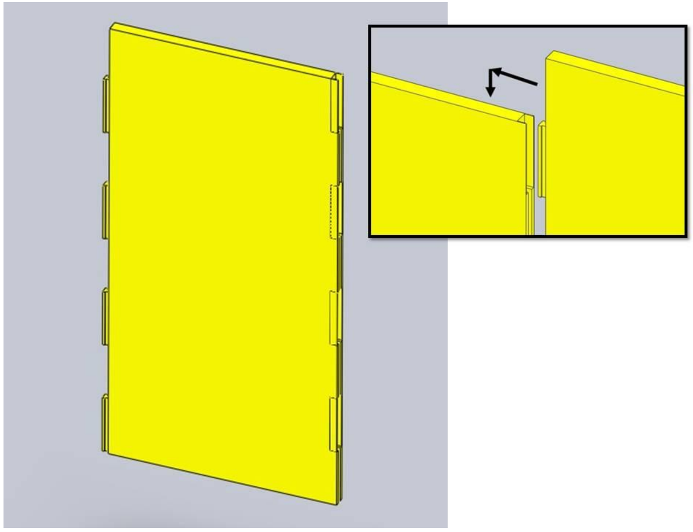


Figure 46. Sliding Joint

The modified extension panel joint in Figure 47, is similar to the current modular extension floor panel. The only difference is the exclusion of the extruded boss for joining to the wall panel. Instead the extruded base is replaced with a cut-out section to allow for the insertion of a timber to be used to join to the wall panels, pictured in the inset. This design has the benefit of making the extension panels flat on top, which allows for much easier shipping of the extension pieces. The design was ultimately phased out due to the addition of additional parts (the timber) and because it is requires twice as many fasteners as having the boss included in the extension piece. Additionally, securing fasteners along the entire length of the timber might be difficult.

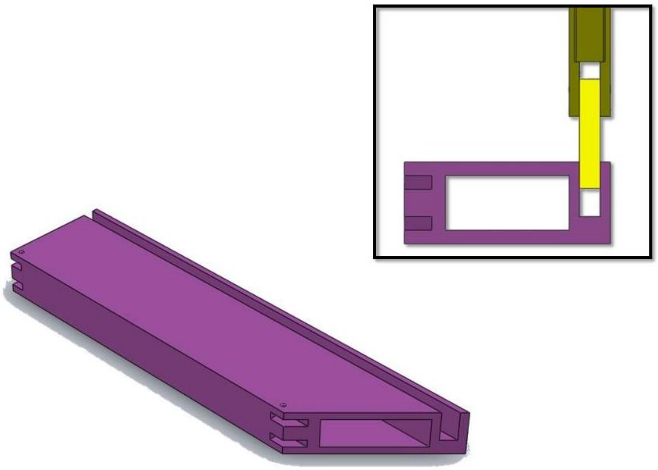


Figure 47. Modified extension panel joint

Appendix D – Stress Analysis

A thorough stress analysis for the structure would include considering all possible loading conditions such as dynamic wind loading, eccentric roof loading of walls, varying ground conditions, etc. Additionally, the joints designed in the project were not analyzed to determine their performance under different kinds of loads, which would have to be performed before deciding on the joining methods used in the final design.

The current roof structure is designed to transfer most of the compressive load from snow from the hip joists within the roof structure onto supporting base posts. For the shelter design, the posts were replaced with rigid corner pieces. These corner pieces will have to support most of the bearing load from the roof, however the wall panels will also serve to support the roof. The corner pieces will have to be a material with a higher modulus compared to the wall panels. The U of M design team, as well as a member of the CIC imagined this piece being a solid pultruded part, however a basic buckling analysis of the corner piece can be done to see if a solid pultruded part of the geometry shown in Figure 48 would be over designed. Buckling is considered over maximum compressive strength because columns will fail due to buckling before reaching the maximum compressive strength.

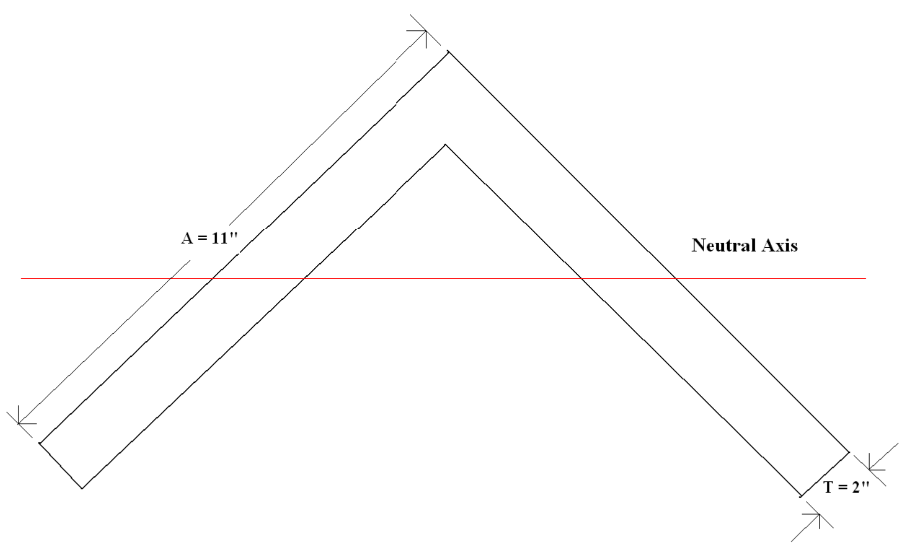


Figure 48. Corner piece cross section

Assumptions will have to be made in order to perform a buckling analysis. These include the following:

1) The bearing load is applied directly at the centroid of the corner piece (no eccentricity)
2) There is no transverse loading from the hip joist, all loading is directed along the longitudinal axis of the corner piece
3) The corner piece has an alignment perfectly perpendicular to the ground and is sitting on flat ground
4) The corner piece itself is a straight piece (no deformations)
5) Any wind loading is ignored
6) The surrounding wall panels provide no resistance to buckling
7) Corner piece is a column supported at one end and free at the other
8) The wall panels do not accept any of the roof load

In reality, the corner pieces will no experience a nice compressive load. The CIC will have to design a different way for the hip joists to connect to the corner piece, as the current design has the hip joists sitting on large wood base posts. The amount of assumptions made indicates that the buckling load predicted will be not be what would been seen in reality, however an analysis can still be performed to give a general idea of how stiff a pultruded corner piece would be. Buckling load is found using eq. 1 [17]

$$P_{crit} = \frac{\pi^2 EI}{L_e^2} \tag{1}$$

Where,

E = Young's modulus of elasticity

I = moment of inertia

L_e = column effective length

For a pultruded fibreglass part E = 17 GPa (in longitudinal direction) [13]. The effective length is 2L for a column supported at one and free at the other L = length of column). Moment of inertia about the neutral axis shown in Figure 47 is found using eq.2. Eq.2 is determined knowing that a parallelogram's moment of inertia is the same as a rectangle's about the same axis, simplifying the calculation for I.

$$I = 2[\frac{1}{12}\left(\frac{T}{cos45°}\right)(Acos45°)^3] = \frac{1}{12}TA^3 \tag{2}$$

For the cornerpiece,

T = 2" = 0.0508 m

A = 11" = 0.2794 m

L = 8' = 2.44 m

$$I = \frac{1}{12}(0.0508 \text{ m})(0.2794 \text{ m})^3 = 9.2 \text{ x } 10^{-5}$$

Using eq.2,

$$P_{crit} = \frac{\pi^2 EI}{L_e^2} = \frac{\pi^2 * 17 \ x \ 10^9 * 9.2 \ x \ 10^{-5}}{(2 * 2.44)^{\ 2}} = 648 \text{ KN}$$

The original roof load defined by the CIC for snow loading to be 93462 N. There is 4 corner pieces taking this load, so the load to each corner piece would be 23366 N. The resulting factor of safety for the corner piece would be.

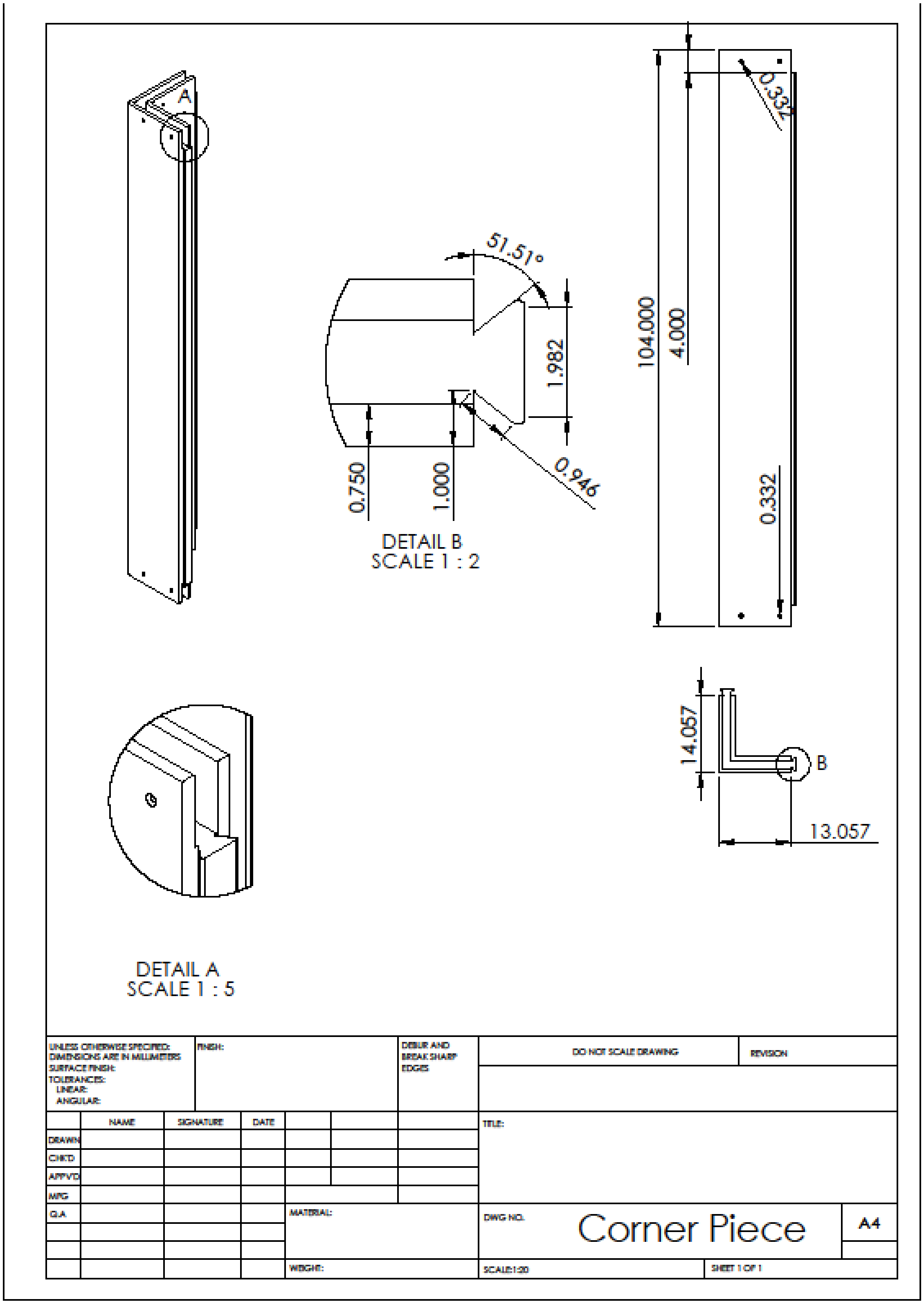
$$N = \frac{648 \ KN}{23.4 \ KN} = 27.7$$

A factor of safety will want to be included in the final design, however 27.7 is much too high, indicating that a 2" solid fibreglass corner piece is not necessary. A thickness of 2" will most likely be too high. Thickness should be minimized to reduce the cost, as a fully pultruded section of this size would be costly.

Further stress analysis will have to be performed by the CIC on the wall panels and joints in the final design of the shelter, as well as a further look at the corner pieces. The wall panel stress analysis is relatively simple if the sandwich panel is in bending, however the CIC hopes that the wall panels will take some of the roof loading as well, which makes the stress analysis for the wall panels more difficult.

Appendix E - Component Drawings

This section of the appendix will contain the various drawings of the individual components designed for the composite modular temporary disaster relief structure. The following pages will contain the individual drawings for the modular floor lid panel, modular floor storage panel, modular floor extension panels, dowel piece, modular wall panel, modular wall corner piece, and wall clamp. All dimensions are in inches.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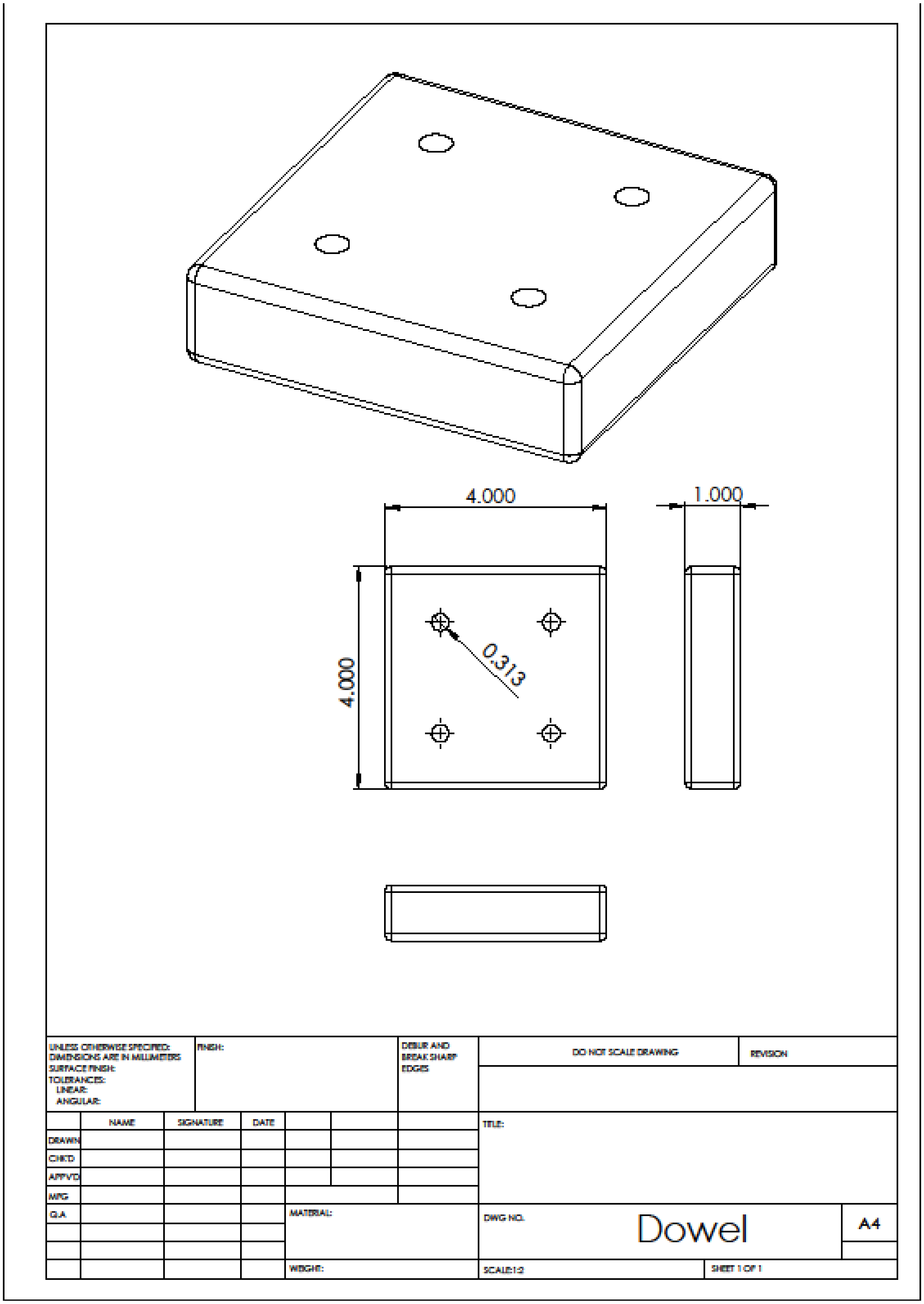
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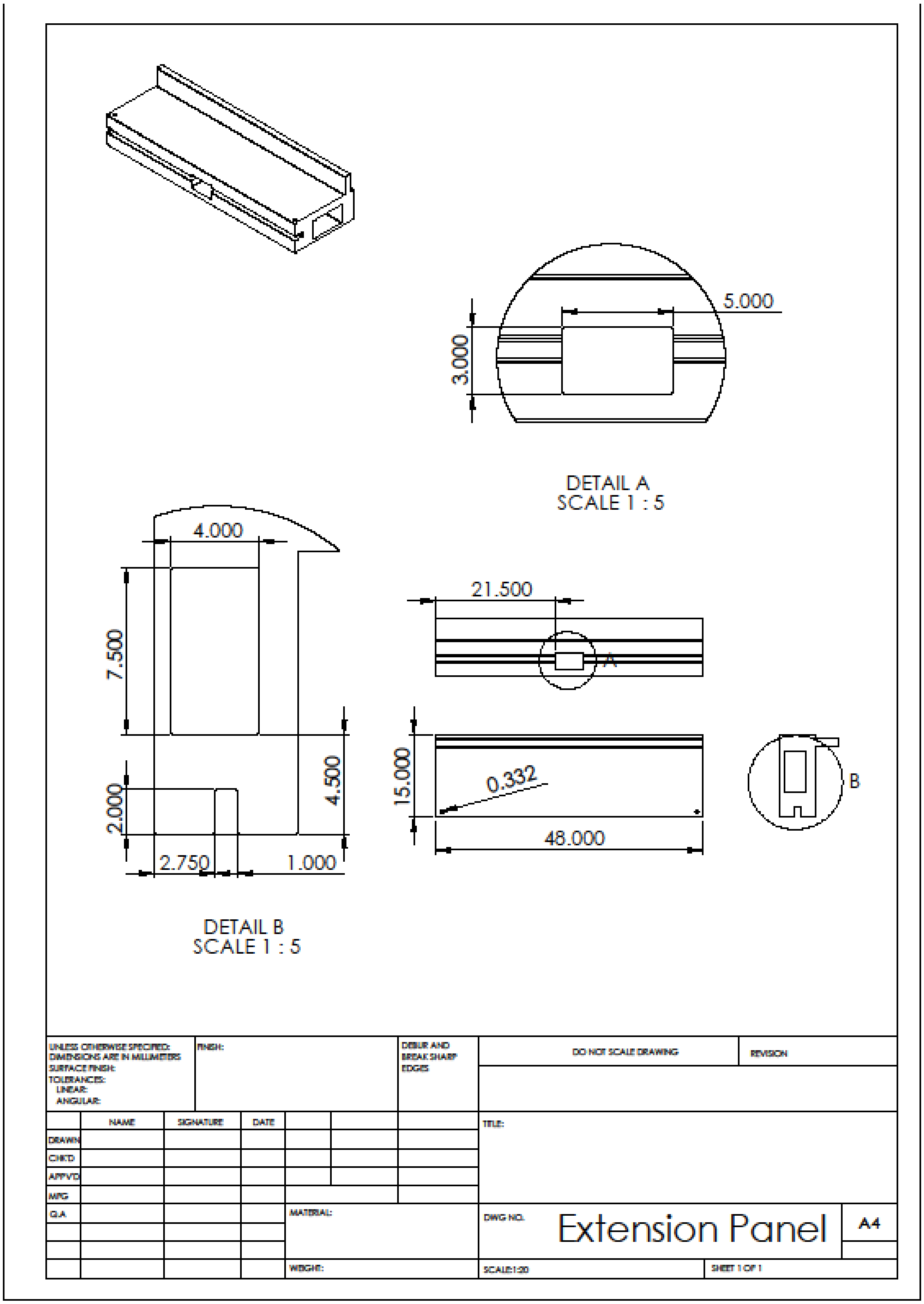
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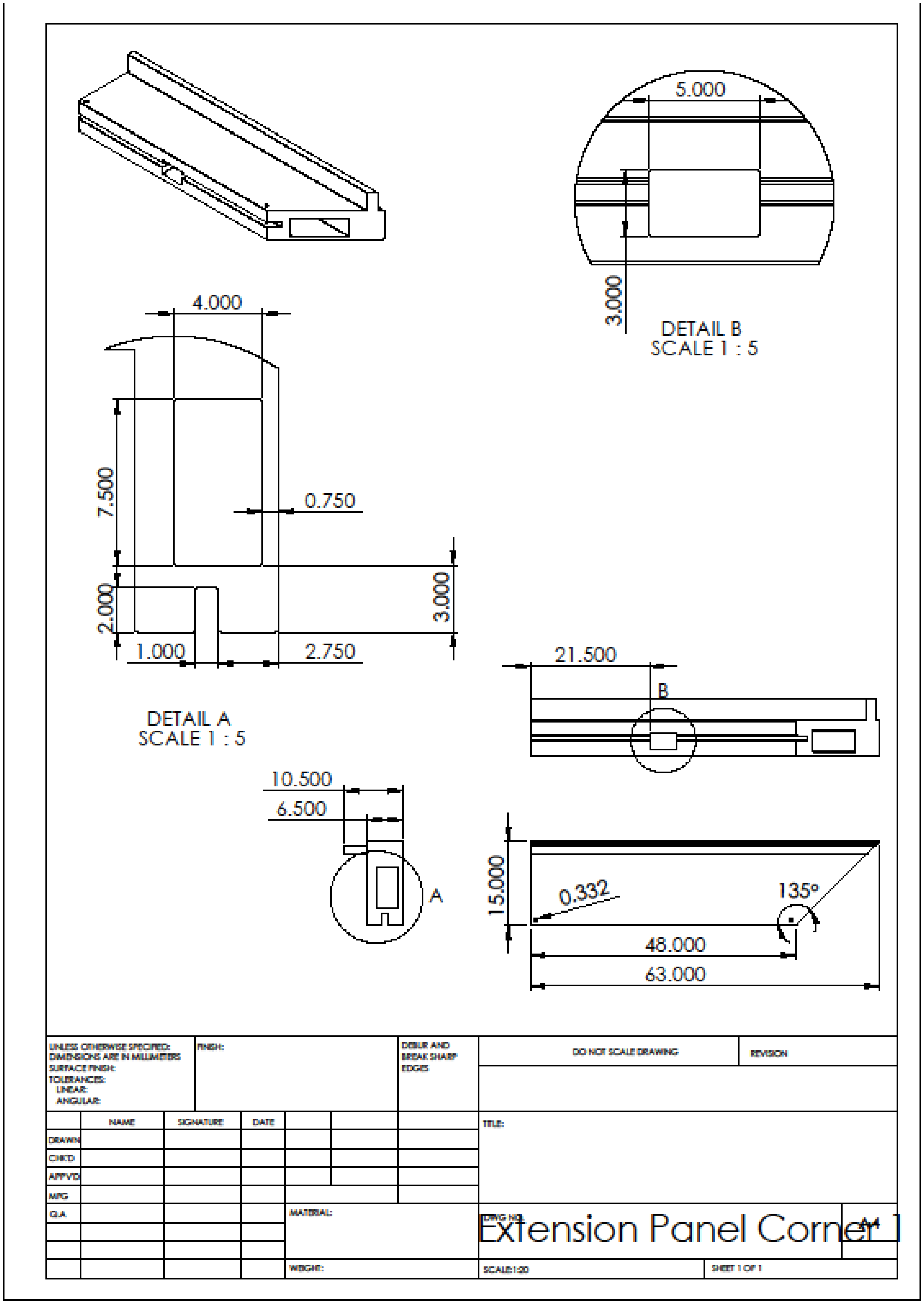
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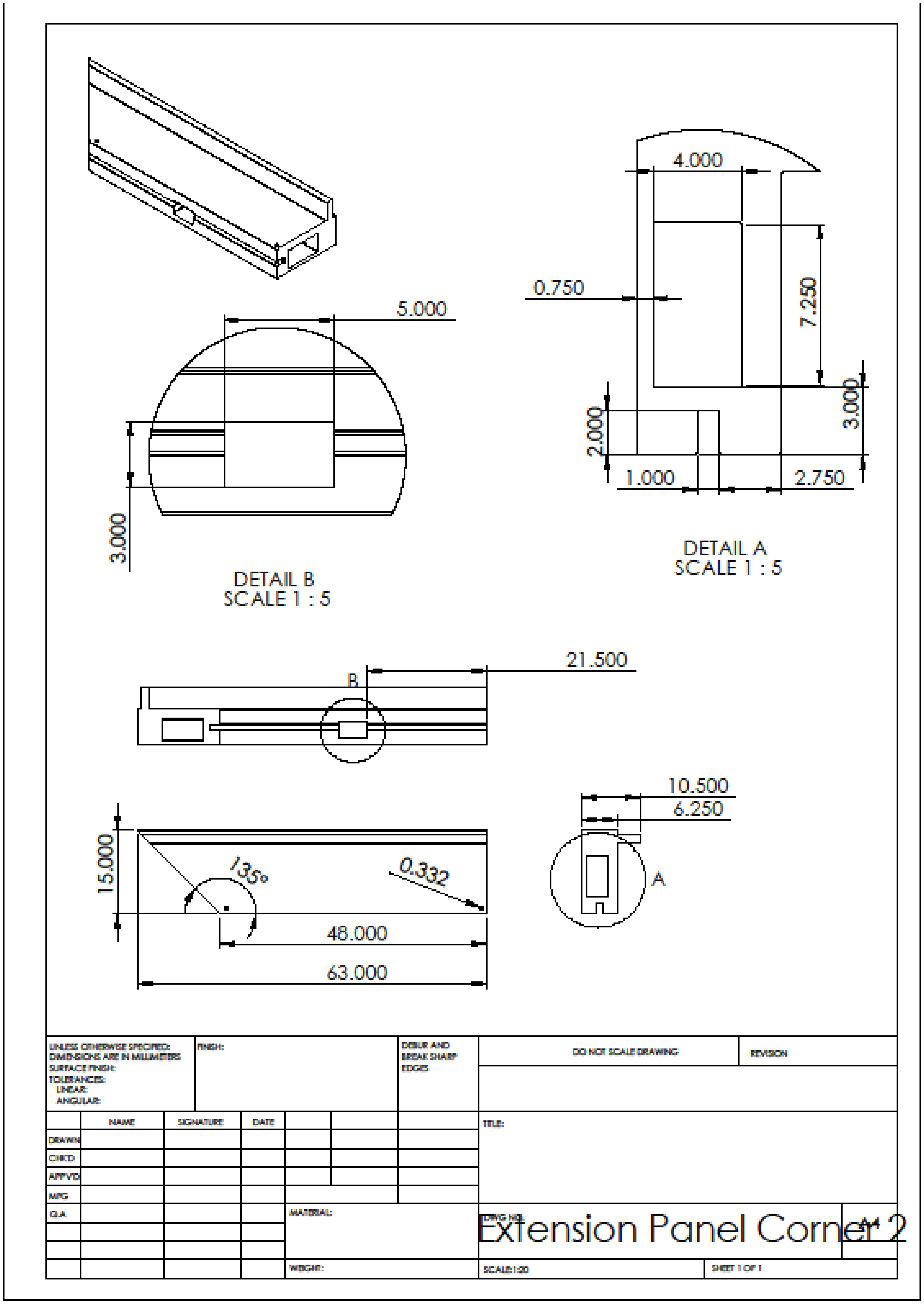
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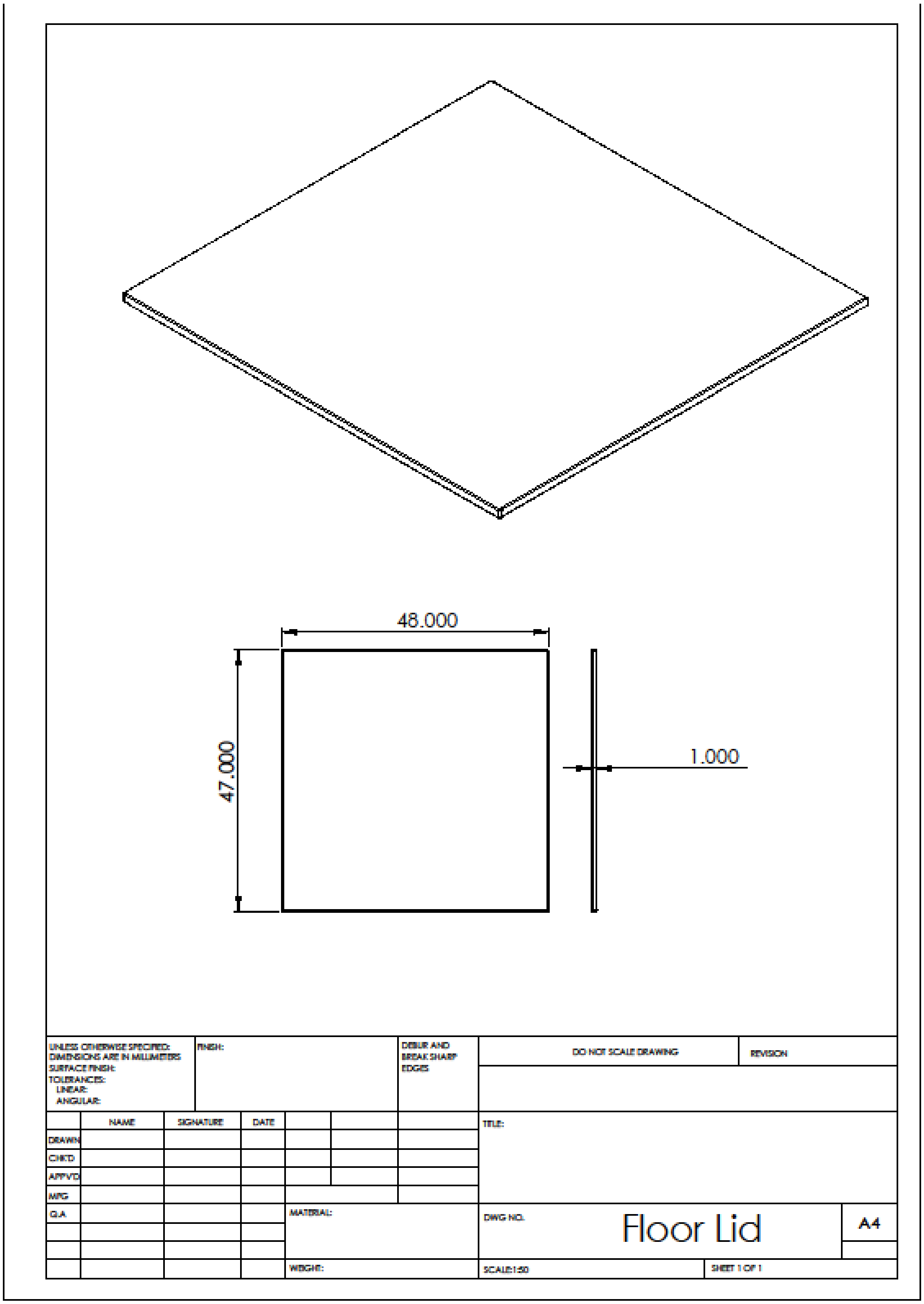
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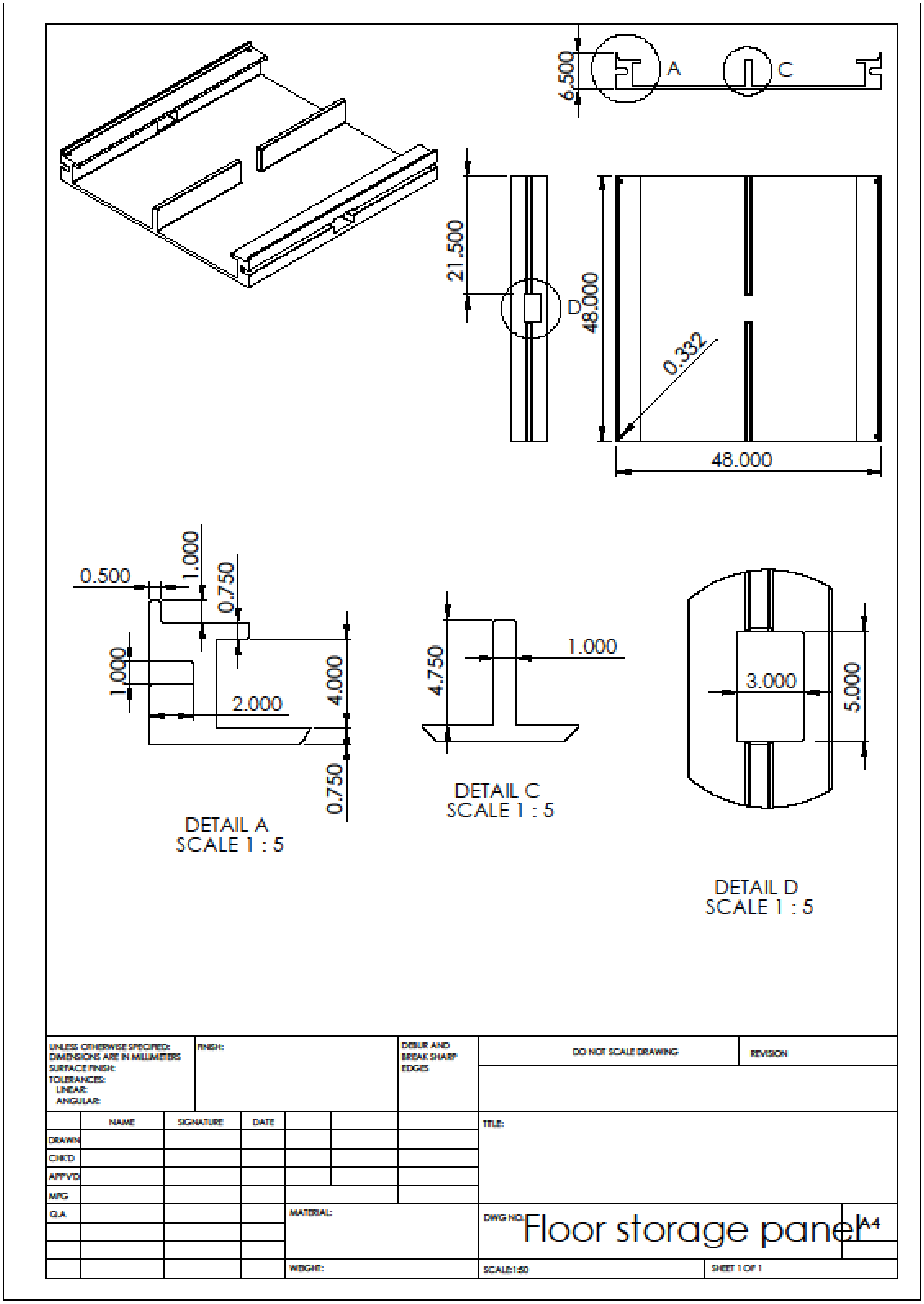
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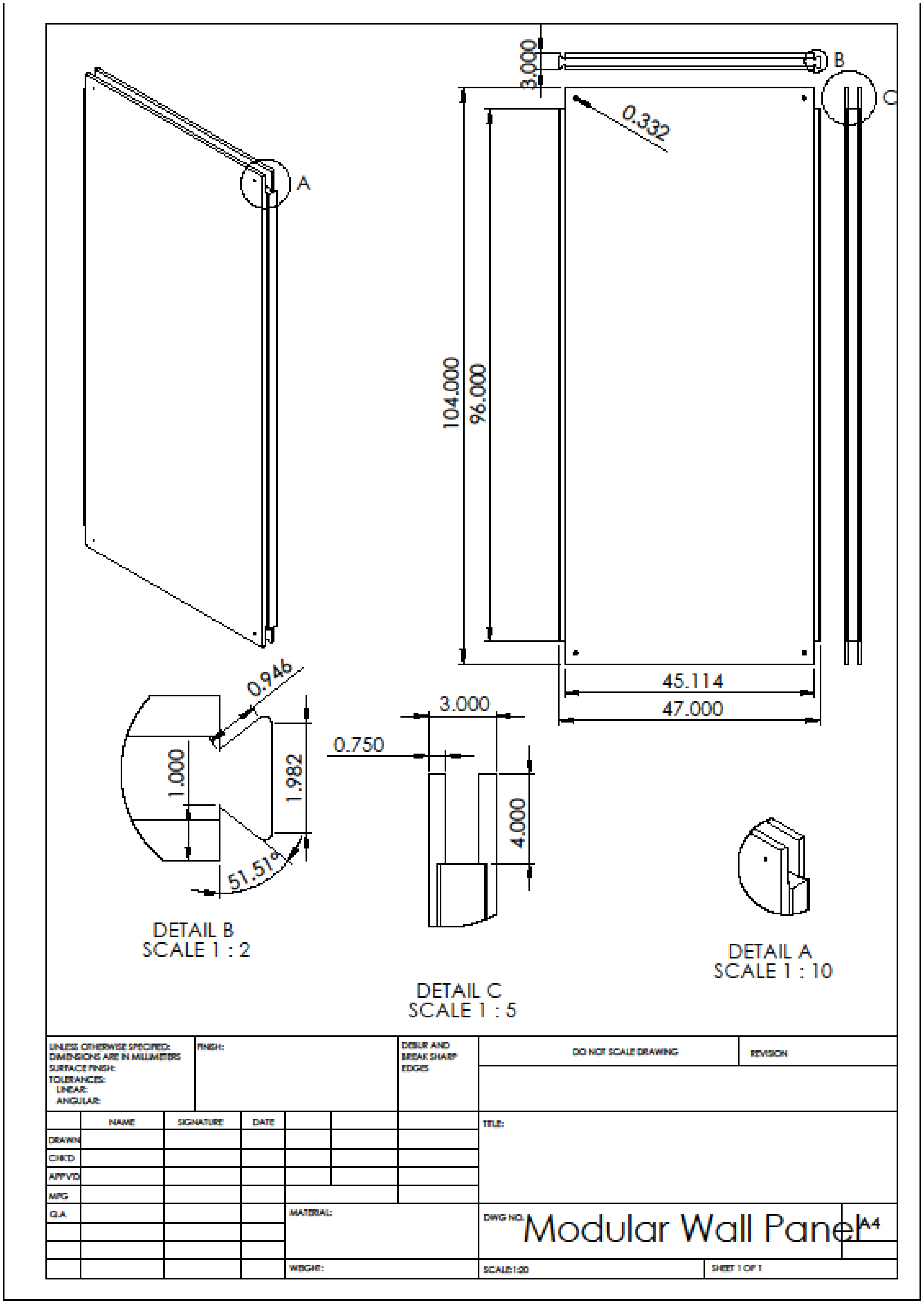

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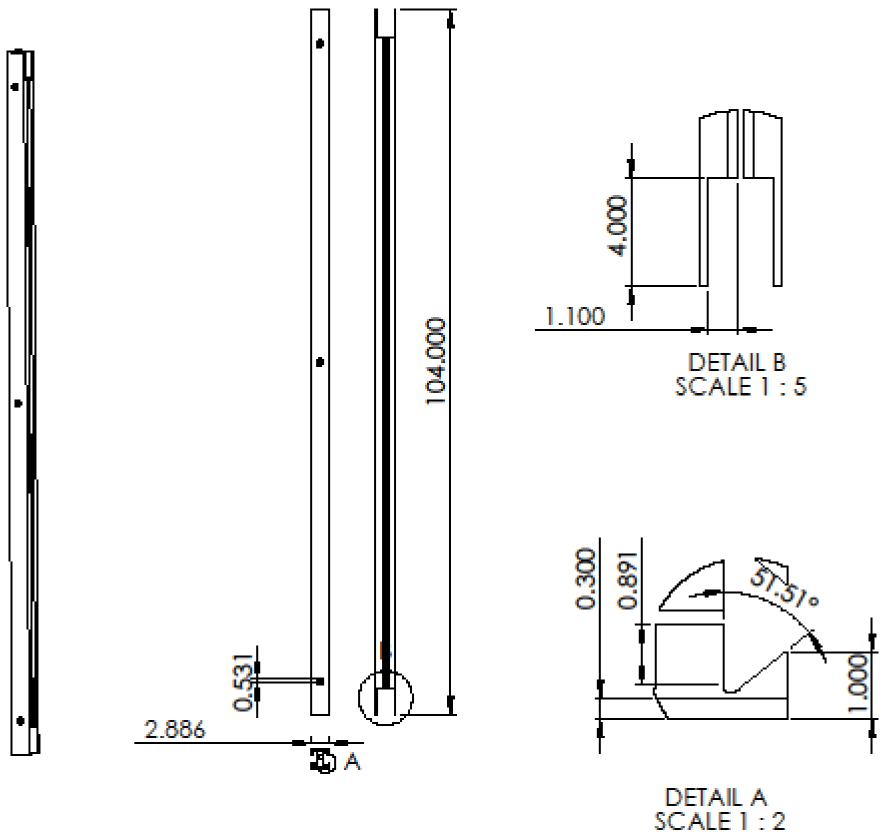

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