Campground Cabin

I. Project Description

Our team has been awarded the Campground Cabin Senior Design Project. In short, this project involved designing a cabin from the ground-up. At length, this project involved coordination between architectural, structural, mechanical, electrical, and plumbing engineering, as well as communication with our faculty mentor, who is a professional engineer with experience in civil, structural, and forensic engineering, our project sponsor, and other useful resources, such as the project architect and involved community members.

The project design objective was to create a rustic, yet comfortable cabin for guests of all ages and backgrounds, including those with ADA requirements. The cabin space should be cost-efficient in the construction process, sustainable, and low-maintenance in the long term. These values helped guide the decision making throughout the project.

The functional requirements for this project, which follow, played a critical role in directing our focus throughout the scope of the project and shaping our final design. The cabin must comfortably sleep twelve to sixteen people, which accounts for two campers per bunk bed and one or two counselors in a separate, partitioned room. The cabin must be well lit by natural windows and artificial lighting and must also be comfortably heated and air conditioned. Since the sponsor's goal is to have the cabin populated year-round, it is expected to endure harsh winters and hot summers. Likewise, the cabin should be well-equipped to provide a safe and comfortable environment for its residents in a range of outdoor conditions. It should also include plumbing for a single toilet and sink and be designed such that cabin construction can be replicated on site, as cabins will be built in sets of four.

The design constraints were specific limitations put on the design of the cabin, which includes the desire of our sponsor that the new cabins hold resemblance to the existing cabins. This, in addition to the initial architectural sketches given to us by the project architect, helped initiate our design and accelerate us into further analysis of other cabin elements. The first of these constraints requires the cabin space to be twenty-four-feet wide by thirty-two-feet long with an eight-foot porch off the front. The ceiling will reach twenty feet above the finished floor at its peak with a forty-five-degree sloped roof. As previously mentioned, the cabin should also have a partitioned counselor's room and heated water for one of two sinks. Material constraints communicated by our sponsor prohibit the use of drywall as a finish for interior walls, require the cabin to have a green, corrugated metal roof and a concrete masonry block foundation with a crawl space and suspended floor framing, and necessitate that the majority of structural and non-structural wood components be sourced from on-site forestland. As nearly half of the owned 1,000-acre site consists of forestland, wood is able to be kiln-dried and milled to specification, within accessible limits of dimension and species available, which should substantially drive down the expected cost to build the cabin.

Additionally, the cabin must also comply with all pertinent code, including the International Building Code (IBC) and the International Residential Code (IRC). Other design standards governing the structural design and safety of the cabin include the National Design

Specification (NDS) for Wood Construction and the American Society of Civil Engineers (ASCE) Minimum Design Loads for Buildings and Other Structures, which governed much of the design of structural wood components, such as the truss system, columns, wall framing, and floor framing of the cabin, and values used for wind loading. Other codes used for structural components include the American Concrete Institute (ACI) Building Code Requirements for Structural Concrete and the ACI Building Code Requirements and Specification for Masonry Structures, together with local and building codes, which governed design of the foundation and crawl space system. The Ohio Building Code (OBC) and National Electrical Code (NEC) also specifically guided design and restrictions in the electrical and mechanical components of the cabin. Additionally, the building is designed to be ADA accessible and thereby follows associated legal protocol in the ADA Standards for Accessible Design.

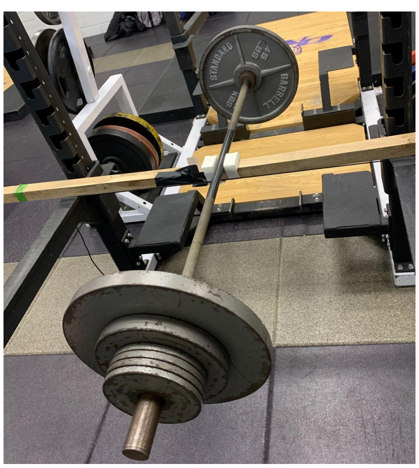
The design solution for the cabin included a few additional features that were not specified in the functional requirements or constraints. The first optimal change that was made throughout the design process was adding a second sink. The idea behind this was that we wanted campers to be able to brush their teeth or wash their hands even if someone was occupying the bathroom. The additional sink will share an interior wall with the bathroom, so the only additional need, from a plumbing perspective, was another pipe coming off the domestic cold water supply and tap off into the second sink, in addition to the fixture itself. This design solution very minimally increased the budget, but greatly increased the functionality of the cabin.

Another design solution that came along was the use of a packaged terminal air conditioner, otherwise known as PTAC unit. These are wall-mounted air conditioner units that double as heating units and are commonly seen in hotel rooms because they can efficiently heat or cool a small space. These units also provide significant advantages by reducing construction costs as there is no need for duct work and by creating functional floor space that would otherwise be taken up by the mechanical equipment room. The optimal solution for the cabin included placing two PTAC units at opposite ends of the main cabin area. In order to properly distribute the air amongst the 768 square feet of the cabin, four fans will be mounted to the ceiling. They can be run forward to push air down or run in reverse to pull air up. Each fan will come down from the ridge beam, which runs along the central peak of the ceiling, and be mounted high enough with a proper downrod to prevent kids from climbing or jumping to reach them.

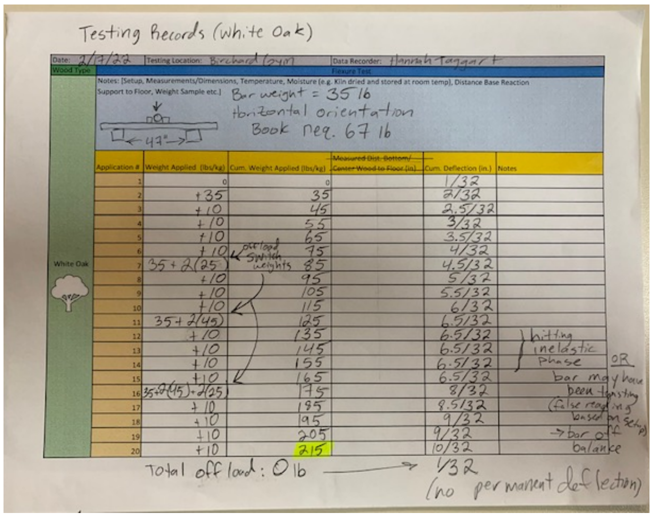
Further design solutions involved structural calculations and design. First, the site where the cabins are being developed consists of a semi-circular flat hilltop region that falls off into a small waterway around the perimeter. As the cabins will be spread along the edges of this hilltop, they will be situated on slopes, which could vary per cabin built. To accommodate this, rather than a slab on grade, we settled on suspended floor framing that would be supported by a stepped foundation wall and footing in addition to six interior piers. Though providing a crawl space area that would not be overly needed for mechanical or plumbing lines, it did avoid possibly extensive grading work due to needed cuts and fills to provide a slab on grade. In addition, the material cost should be reduced, as the material for the wood floor framing will be provided from on site, forested wood that will be kiln-dried and milled to specification.

Next, our sponsor requested to avoid using drywall for the interior wall material if at all possible. After suggesting possible alternatives, we decided to go with T1-11, which is a common material that should be cost-effective and durable, two priorities of our sponsor. In addition, this material should provide the cabin with a “woodsy” or rustic feel, another desire of our sponsor. In hind-sight of the decision, this also played a key role in the structural functionality of our cabin. Because both the exterior sheathing (plywood) and interior sheathing (T1-11) for the walls is rigid, durable, and able to transfer applied loads, these essentially made each of the four exterior walls shear walls, in that they resist in-plane lateral forces. This simplified some of the wind analysis and design by reducing typical areas of weakness in the walls and building element connections.

Another structural solution involved the wind analysis and design of the end walls. Because the roof is a forty-five-degree angle, the end walls ended up with peak heights of around twenty feet, this creates significant considerations for wind loadings and design. As the pressure increases with height and was found to be greater for the end walls than side walls, and as these larger loads are to be held by longer structural members, in this case, the walls studs and framing, we had to consider this in design. For continuous members, we would simply have to build-up the studs as needed to carry the expected loads. However, we originally had doors and windows creating discontinuity in the end walls. We ended up changing the size and placement of the gable windows, which did somewhat affect the overall architectural and aesthetic appeal of the structure, however, this allowed us to create continuity and simply the overall design of the walls. Both the back and front walls have unique structural framing elevations and details to assist the contractor and other workers in building a successful and secure building for the campers. We may have proceeded with designing a moment frame within the wall to maintain original architectural choices with the windows; however, we were running low on time remaining to complete the project and decided that splicing the studs would have created excessive material usage for the given situation. As this project, with engineering calculations included, is being passed on to licensed professionals for review and stamping, this is a design element that could be changed if desired in the future.



Another huge component of this project and its potential success has been the intent to use primarily lumber sourced from on-site forestland. The structural wood components, which will be of three different species, will be kiln-dried and milled to specification. All wooden components of the cabin will be made with on-site sourced lumber, with exception of the interior T1-11 and members which may be in contact with concrete, such as the sill plates and exterior porch posts, which may be more cost-effective to buy pre-treated. The trusses shall be made with White Oak and Red Oak, and the floor framing and wall framing shall be made with Poplar. Other components for which structural calculations were not needed or done include the hardwood flooring, which will be sourced from Hickory wood on site and the exterior board and batten siding, ceiling boards, and roof sleepers, which will be sourced from on-site wood of an unspecified type. We received dried and milled samples of the White Oak, Red Oak, and Poplar wood at the university. After researching ASTM standards for testing wood strength, we tested two of the samples (the White Oak and Poplar samples) for bending force capacity (a primary function of structurally-loaded members in our cabin and likely the most susceptible to failure) with a setup resembling that of a verified ASTM wood testing machine. As our design calculations assumed a lumber grade of No. 2 or greater, we used numbers approved for visually graded machined lumber given in the NDS for Wood Construction and followed its standard design procedures and mechanics of materials analyses to calculate the required loading that the members must take during testing to meet or exceed the assumed strength. Our results exceeded the requirements for No. 2 grade lumber, thereby verifying our design with the wood actually being used. It should be noted that the results were modified (strength being divided by a factor of two) to account for load duration. Because we only loaded the samples for upwards of ten minutes, this qualified as an impact load, while some loads on the structural members of the cabin may be considered permanent. The setup of our experiment and some of our testing results showing cumulative applied load versus resulting deflection are shown to the left. The nearly linear results also indicate minimal to no damage done to material fibers during loading, essentially elastic behavior. We loaded and unloaded our samples, taking measurements of deflection for each increment, and found that no permanent deflection existed for either species after full unloading.


Testing Records (White Oak)

Date: 2/17/22 | Testing Location: Birchard Gym | Data Recorder: Hannah Taggart

Wood Type: White Oak — Flexure Test

Notes: [Setup, Measurements/Dimensions, Temperature, Moisture (e.g. Kiln dried and stored at room temp), Distance Base Reaction Support to Floor, Weight Sample etc.] Bar weight = 35 lb; Horizontal orientation; Book req. 67 lb; 47"

Application #	Weight Applied (lbs/kg)	Cum. Weight Applied (lbs/kg)	~~Measured Dist. Bottom/Center Wood to Floor (in)~~	Cum. Deflection (in.)	Notes
1	0	0		1/32	
2	+35	35		2/32	
3	+10	45		2.5/32	
4	+10	55		3/32	
5	+10	65		3.5/32	
6	+10	75		4/32	off load, switch weights
7	35 + 2(25)	85		4.5/32	
8	+10	95		5/32	
9	+10	105		5.5/32	
10	+10	115		6/32	
11	35 + 2(45)	125		6.5/32	
12	+10	135		6.5/32	hitting inelastic phase
13	+10	145		6.5/32	
14	+10	155		6.5/32	OR
15	+10	165		6.5/32	bar may have
16	35+2(45)+2(25)	175		8/32	been twisting
17	+10	185		8.5/32	(false reading
18	+10	195		9/32	based on setup)
19	+10	205		9/32	→ bar off
20	+10	215		10/32	balance

Total off load: 0 lb → 1/32 (no permanent deflection)

In addition to the structural engineering completed, the cabin also features a bathroom that is compliant to the ADA code. All dimensions and schematics were completed by following the 2010 ADA Standards. Specifically, chapters 601, 603, 606, and 609. This includes a sixty-inch minimum turn radius for the wheelchair to make a complete, unobstructed rotation inside the bathroom. The bathroom also features three grab bars that include an eighteen-inch vertical grab bar, a thirty-six-inch horizontal grab bar behind the toilet, and a forty-two-inch grab bar that is adjacent to the toilet. The lavatory also comes to the maximum required height of thirty-four inches from the floor to the top of the sink. Lastly, the cabin includes a 1:12 ramp off the front porch for easy wheelchair access.

II. Collaboration of Students, Faculty, Sponsor, and Professional Engineer

Throughout the school year, the team of four senior engineering students worked closely with our licensed civil and structural engineering professor, who is a registered P.E. in multiple states, and with the project sponsor who lives in another state. We also gained some initial architectural sketches and minimal continuing advice from a licensed architect working with our sponsor in beginning campground development stages.

The design team consists of civil engineering students and architectural engineering students. Student A is an engineering major with concentrations in civil and architectural engineering, who was responsible for designing the wood floor framing, wall framing, foundation system, and roof design. Student B is a civil engineering student, who was responsible for designing the truss and research of metal connection brackets. Student C is an architectural engineering student, who was responsible for much of the Revit set-up and modeling as well as architectural components of the cabin. Student D is an architectural engineering student, who was responsible for the mechanical, electrical, and plumbing design, as well as Revit set-up and modeling. All students participated in detailing construction document sheets for their specialized components and areas of knowledge.

The Faculty Sponsor A was an excellent resource to the project's success. Faculty Sponsor A is a licensed professional engineer and a civil and architectural engineering professor at University O. Faculty Sponsor A met with the team weekly to discuss and check structural engineering calculations and answer questions about construction document precision. Faculty Sponsor A also let us borrow numerous textbooks, drawings, and other design manuals to aid us in successful design that is reliable for its users and in the best interest of our sponsor's objectives and values.

Project Sponsor A was another great resource throughout both semesters of the project. Project Sponsor A discussed design options and alternatives over Zoom meetings and gave us needed input on details of project construction and large-scale planning. Project Sponsor A also led the budget and fundraising aspects of the project, which aided us in the material and product choices as well as cost analysis for cabin construction.

III. Protection of the Health, Safety, and Welfare of the Public

This cabin will be constructed on a campground for religious and public group events. The cabin will be a fresh update to the campgrounds and provide a reliable, temporary living space for people of all ages and all backgrounds and provide a safe place for relational development, as desired by our sponsor. The outdoor space is a benefit to the mental and physical health of the campers and may encourage active lifestyles and appreciation for nature.

All engineering design, including structural, mechanical, electrical, and plumbing design, have been conducted in accordance with applicable code to ensure safe and reliable construction. Structural calculations have been checked by Faculty Mentor A and have accounted for gravity loading (dead, live, and snow) and wind loading. Lumber sourced from on site will be used for nearly all structural elements in the cabin, including the floor framing, wall framing, and the trusses, and for other components, such as the hardwood flooring, exterior board and batten siding, and the continuous ceiling boards and sleepers. Plywood sheathing and pressure-treated sill plates and porch posts may be purchased off site. For structural wood components being sourced on site, two of the three provided samples were tested for compliance with visually-graded, machined lumber in the NDS for Wood Construction. The results exceeded requirements for the lumber grade used in our calculations, which was extremely important for verifying our structural calculations and ensuring a stable and reliable structure for cabin users.

IV. Multidiscipline Participation

A major aspect of this senior design project was the coordination between multiple engineering concentrations. With the large scope of the design project, engineering principles from mechanical engineering, electrical engineering, structural engineering, and architectural design were required for a successful project. As different team members took on different roles, each aspect of the project had to be meticulously designed and coordinated to create a cohesive cabin structure.

A prime example of this was the coordination between electrical engineering and mechanical engineering. First, we had to choose the appropriate mechanical air conditioning unit size based on the ASHRAE 90.2 standards and practices outlined in the International Residential Code. Next, we had to coordinate with the placement of architectural components to see where the packaged terminal air conditioner (PTAC) units could be located on the interior walls. We also had to coordinate with the electrical design. This was a crucial step in the design process because the PTAC units plugged directly into receptacle outlets in the wall. Special receptacles were chosen based on National Electrical Code (NEC) 2010 and National Electrical Manufacturers Association (NEMA) standards. The amperage required was found on the PTAC unit manufacturer's website. Based on a NEMA table, we selected the receptacle outlet that matched.

Another example of multidiscipline participation was seen in the electrical design and layout of conduit and wiring. This had to be coordinated with the structural and architectural design, as wiring must be run, in compliance with code, inside conduit inside the walls of the building. The lighting layout also had to be in sync with the architectural elements of the cabin. There will be linear bar lights that will be mounted on the underside of the structural truss members. These lights do not weigh anything significant to change the beam design, but they do impact the architectural layout of bunk bed configuration. There will also be a bathroom light and wall sconce light in the separated counselor's room. The final artificial lighting pieces are the exterior wall sconce lights that will provide light to the front porch and the back steps. These are important features because they impact the safety of using the entrance and egress routes and also help to give the cabin character.

The architectural and structural disciplines needed coordination, especially for the front and rear walls of the cabin. We originally had large gable windows in the end walls which created discontinuity with the doors. We tried splicing the studs to maintain continuity, but it required excessive material usage and appeared overdesigned. We next thought to do a moment frame around the doors and windows, but as we were running low on time and had other project elements to be completed before submission, we ended up adjusting architectural elements for a functional structural solution. Rather than specifying two thirty-six-inch-wide gable windows on end walls, we specified two twenty-four-inch-wide gable windows with increased spacing. Though this somewhat compromised the overall aesthetic appeal of the cabin, it greatly reduced complications with structural framing by allowing for continuous, built-up studs to be used.

Another strong example was the interaction of plumbing elements with the structural foundation and crawl space systems. Because the cabins will be built on grades with various slopes, continuous footings and foundation walls will be stepped based on that site's unique grade change. The foundation walls are made of concrete masonry unit blocks and reinforced into the cast-in-place footing. Interior foundation piers are constructed similarly and to the same elevation as the adjacent wall footing. Because both the grade change (or the depth of the rear crawl space area) and the location of the piping supply are unique for each cabin, the plumbing had to be designed in such a way that it could be easily adjusted for construction of multiple cabins with various site conditions. This affected the sanitary pipes and domestic cold water pipes, which run from the interior partition wall of the cabin, into the crawl space, and out from underneath the cabin to attach to the main drainage system.

V. Knowledge and Skills Gained

Throughout the entire school year there was a tremendous amount of information learned, knowledge gained, and skills developed. The first main skill learned was the ability to work efficiently as a team. In order to be successful at the end of the project, we had to work as a unit, splitting up work fairly and according to our individual strengths, and coordinate four busy schedules to meet multiple times per week, in addition to meeting with our project sponsor and faculty mentor for design consultation. These skills of time management, organization, and teamwork developed throughout the project, so while many of these skills are intangible, they were undoubtedly strengthened.

Another major ability gained was Revit building information modeling. This Autodesk product allows users to draw lines in two dimensional space and transform the product into a three-dimensional model. There were many learning curves throughout the process. Beyond what we learned in the classroom, many skills had to be learned through trial-and-error, exposure to further codes and standards to guide the design process, and educational tutorial videos to aid in model design and sheet detailing. Certain skills learned included custom truss analysis and design with bracket connections, foundation design, gravity load analysis and design (accounting for the floor framing system and columns supporting the trusses), wind load analysis and design (accounting for the wall framing, column design, and shear nails fastening the exterior sheathing to the sill plates, as well as the consideration of shear walls), thermal and electrical load analysis and design, and plumbing design. We also gained knowledge and experience modeling building components and materials in Revit, such as the corrugated metal roof, floor, wall, and roof construction layers, foundation elements.

Due to the format and scope of the project, we were also able to learn cost-estimating, grow in our ability to write technical reports, and share and revise project plans and design elements based on constructive feedback. The use of spreadsheets and the ability to contact dealers about products was a timely process, but in the end was another teachable moment. Overall, leading to a successful senior design project.