Home for the Homeless using Cross-Laminated Timber Waste Stream

I. Project Description

Introduction

The homeless population has been on the rise in our community due to high rents from rapid regional growth, and opioid and other drug use. Since 2010, a local architect has been interacting with the homeless community to understand their plight and needs. In 2016, he established a non-profit organization, NPO, to support this marginalized community. The aim of the NPO is to partner the homeless with homeowners in the community who are willing to install a detached accessory dwelling unit (ADU) on their property. Each ADU is a light timber framed 125 sq ft living space complete with a kitchen, bed, shower and table. The plan is for the homeowner and the surrounding community to provide shelter and support to the homeless till they get back on their feet. Since inception around 10 ADUs have been built. The NPO would like to expand these ADUs to be self-sufficient.

In 2019, our university capstone program partnered with the NPO to improve the existing design such that it meets the sustainability requirements of the Living Building Challenge. The team explored whether waste stream from local cross laminated timber (CLT) manufacturers could be used to construct the ADUs. A team of five students brought this project to fruition with the guidance of a faculty advisor who is a structural engineer (SE) in collaboration with architects from the NPO and other allied professionals.

Current Construction Approach of ADUs and the Challenges

Figure 1a shows the construction of an ADU by volunteers. To understand the challenges of designing structures which are built solely by volunteers, the student team volunteered during the construction of one of these ADUs (Figure 1b). The team learned that, the structural components should be of manageable size and weight to be carried by workers through narrow side yards to reach the back yards and that the components should be easy to assemble and disassemble to allow for relocation and reuse by the volunteer labor force.

a b

Figure 1. Accessory Dwelling Unit a) under construction, b) Student volunteers at work

Currently, the ADUs are constructed utilizing traditional light wood platform framing in a manner similar to residential construction. This type of construction requires a certain degree of skill level to construct. To accommodate volunteers of all skill levels, an architect at the NPO has developed jigs so that major elements (floor, walls, roof) can be manufactured offsite in a factory like environment. Thereafter, volunteers can assemble these pieces on-site in an Ikea® like fashion. In the early stages, most construction materials were donated by local contractors. However, with increasing demand for the homes and the rising costs of lumber, the availability of donated materials cannot be relied upon and the NPO wants to explore other options.

In addition to the modular construction, the ADU utilizes the Diamond Pier foundation (details described later) that requires minimal earthwork and make future removal easy. Diamond Pier foundations are donated by its manufacturer.

Cross Laminated Timber (CLT) Waste Stream as an Option for ADU

Cross Laminated Timber (CLT) is a relatively new construction material where 3,5,7 or 9 layers of lumber are placed such that the longitudinal grains of the timber run perpendicular to each other in adjacent layers and bonded together using a polyurethane adhesive in a press. The cross-lamination results in high strength, large flat panels (10 ft x 40 ft in plan). Building components like walls, roofs as well as beams and columns are then cut from these CLT panels using computer numerical control (CNC) machines in the factory and the components are shipped to the construction site for quick assembly. Currently this process results in a large CLT waste stream that the manufacturer needs to dispose of.

The team visited a CLT factory in the region to understand the manufacturing process and the types and amount of waste materials available. There were plenty of 6 ft x 10 ft 3-ply window cutouts discarded from CNC cut wall panels. These cutouts which the factory was willing to donate to the NPO was ideal for use in ADU construction. These waste stream panels had an added advantage that the new design could utilize cut pieces of CLT that are either large panels or modular slats as explained in the next section.

Design Options and Preferred Alternative

The team explored three design options with CLT products: a) Large single piece CLT panels, b) Small panels (16-24 in. wide) that would span full height at the walls and full width at the floors and roof, referred to as Modular CLT slats, and c) Small Building Blocks of CLT pieces. Option b, Modular CLT slats, was selected as the preferred option due to its ability to meet the need for volunteers to carry the pieces into the backyard with no specialized equipment. Due to length restriction, a summary of the pros and cons of the three options are presented in the accompanying poster and not included in this document.

In the preferred option, five different sized panels (or Modules) are cut from the 3-ply CLT waste stream panels. Table 1 shows the sizes of the five Modules, location within the ADU where it would be used, the number of pieces of each Module needed for a single ADU, weight of each member and the number of volunteers needed to handle each member. These Modules make it easy for the unskilled volunteers to assemble the ADUs.

Table 1. Sizes and Uses of Slats to Construct a single Modular CLT Accessory Dwelling Unit

Module #: Application	Module 1: Foundation Beam	Module 2: Floor/Roof Slat	Module 3: Wall Slat	Module 4: Window support	Module 5: Ring Beams
Panel Size[1]	18.5' x 16"	9.5' x 16"	8' x 16"	7.5' x 16½"	8' x 3.5" and 17' x 3.5"
Number of pieces	2	28	30	2	2 of each size
Weight (lb) (volunteers to handle)	250 (5)	130 (3)	100 (2)	100 (2)	50 (1)

[1] all panels are 3-ply with approximate total thickness of 4.5 inches.

Assembling the ADU

First eight Diamond Pier foundations are installed in two rows as shown in Figure 2. Then two foundation beams (Module 1 in Table 1) are placed on top of the Diamond Pier caps. The foundation beams are connected to the pier caps with 5/8"x 5 ½" ASTM A325 structural bolts.

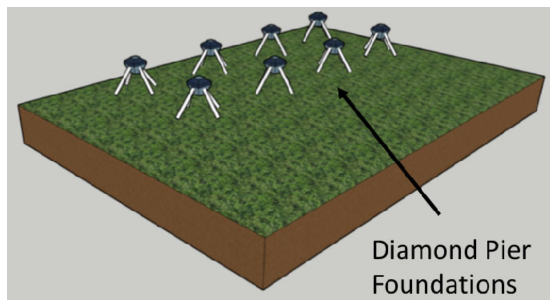

Figure 2. Foundation Installation

Figure 3 shows how Modules 2 through 5 presented in Table 1 are used to assemble the ADU. Fourteen floor slats (Module 2 in Table 1) are connected together with stainless steel 3/8" x 2" dowels, embedded on their sides. The dowels allow the floor to act like a seamless diaphragm and to carry the shear force. The floor of the ADU is connected to the foundation beams using 5/8" by 6" flat head screws that are counter sunk into the floor panel for a smooth floor finish.

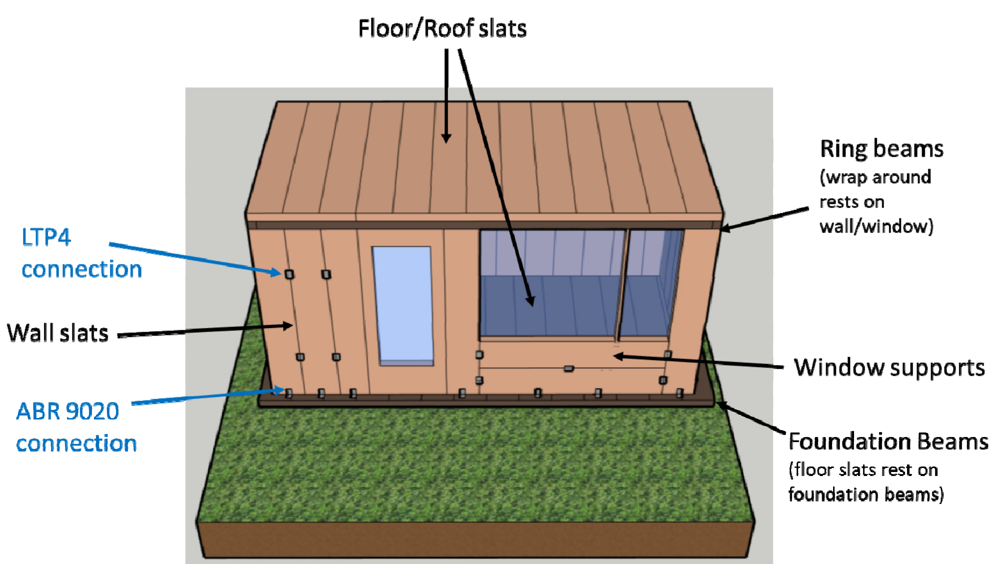

Figure 3. Assembling of the ADU

Each wall slat (Module 3 in Table 1) is connected to the floor using ABR 9020 Simpson Strong-Tie angle brackets. The wall slats are connected to each other with LTP4 Simpson Strong-Ties. The window supports (Module 4 of Table 1) are installed in a similar manner. The corners of the walls are connected with Simpson Strong-Tie SDWS Timber screws with a thread length of 11¼”. The exterior hardware connections will be covered with insulation, a vapor barrier and other external wall details.

Once the walls are erected, a ring beam (Module 5 in Table 1) is constructed on top of the walls slats so that the walls act as a single unit. The four ring beam slats are connected to each other at the four corners using two Simpson Strong-Tie SDWS Timber screws; the ring beam is attached to the wall panel using the same type of SDWS Timber screws drilled through the top of the ring beam and into each wall panel. Finally, the roof slats (Module 2 in Table 1) are placed similar to the floor slats.

Design and Analysis of ADU

In designing the ADU using CLT, the team performed the following analyses: structural analyses for gravity, seismic and wind forces, foundation design, fire resistance and vibration analysis. These are explained below.

a) Gravity, Seismic, Wind and Foundation Analyses

The team used the Local Building Code, ASCE 7-10, 2018 National Design specification (NDS) for timber construction and PRG 320: Standards for Performance-rated CLT to determine the demand to capacity ratio of the floor, roof and walls under bending and shear stresses. Table 2 summarizes the results obtained. A demand:capacity ratio of less than one ensures structural stability. Thus Table 2 shows that all building elements satisfy this criterion.

In addition to vertical gravity forces, the ADU is also subjected to lateral forces caused by earthquake and wind events. Seismic and wind analyses on the structure showed that wind forces controlled the design. Further wind analysis showed that uplift forces would not unseat the ADU from its foundation.

Table 2. Demand to Capacity Ratios of Building Elements

Building Element	Demand to Capacity Ratio	
	Gravity Forces	Shear Forces
Floor (Dead[1] +Live[2])	0.32	0.21
Roof (Dead + Snow)	0.16	0.10
Wall (Dead + Snow)	0.56	1.0

The team also analyzed the Diamond Pier Foundations for stability in the case of an earthquake and wind event. The demand to capacity ratios for lateral and uplift events were found to be 0.69 and 0.62, respectively. From this the team concluded that the ADU is safe of an extreme wind event of 110 mph and Type II seismic event (ie. experienced by most buildings of ordinary occupancy).

b) Vibration Analysis of the floor

While not classified as a life-safety issue by the building code, floor vibration in CLT structures commonly control the design. To address this concern the team conducted a preliminary vibration testing of the floor to assess the floor acceleration caused by a person walking on the CLT floor. The team installed an accelerometer on a 29 in. wide, 121 in. long simply supported, 3-layer CLT span; it then dropped a 20lb weight from a height of 3.5 inches and recorded the acceleration history. By running the time history data through a Fast Fourier transform, the peak acceleration was found to be 0.004g at a frequency of 13.5 Hz. According to design guidelines, when the fundamental frequency is greater than 9 Hz, a person walking does not cause discomfort to other users. Therefore, the floor was deemed to satisfy the serviceability criterion for vibration.

c) Fire Analysis of the ADU

A common concern of CLT structures is the safety during fire. While not required by the building code, the team performed a 1-hr fire analysis (ie. a fire that lasts for 1-hr) and found that it resulted in a char depth of 1.9 in, corresponding to a loss of about two layers of the CLT. The team recalculated the capacity of the remaining CLT layers after a 1-hr fire and compared it against the gravity loads. Results showed that the strength of the roof, floor and walls exceeded the load demands thus making the structure safe for the occupants.

Cost Analysis

The team compared the cost of the current light frame to that of the CLT construction. The cost of light frame construction was around $44,000 compared to $41,000 for the construction with CLT waste stream, a saving of 8%. Almost 75% of the total cost, $31,000 is common to both types of construction: these include the cost of foundation, metal roof, sidings, doors, windows, interior work, plumbing, HVAC, electrical, solar panels, landscaping, utilities and permits. Although timber and finished carpentry are donated by the CLT manufacturer, the materials have to be transported 300 miles to the city offsetting part of the savings. Even though switching from light frame to CLT waste stream did not result in a significant cost saving, the team concluded that the environmental and sustainability benefits were invaluable. The project poster provides a detailed breakdown of the estimated cost.

II. Collaboration of Faculty, Students and Licensed Professional Engineers

All engineering students are required to successfully complete a nine month-long, team-based, capstone project for an external client. The team for this project consisted of five civil engineering seniors. A licensed structural engineer who has 35 years of consulting experience served as the faculty advisor to the team. In addition, the engineer of record, a PE, for the current ADU design served as professional mentor and explained the current design and his concerns with switching to a CLT solution. Additionally, the team met with engineering staff at a local CLT manufacturer who explained the current state of the art of CLT structural design and how they are addressing the challenges to this new material. The senior design course is taught by a licensed faculty member who mentored and guided the team throughout the year.

The students met with the faculty advisor weekly and with industry mentors twice each quarter. The professional mentors provided technical assistance when needed and provided feedback on the proposals, reports, and presentations. The faculty advisor and the course instructor provided guidance as necessary and feedback on several drafts of the proposal in fall quarter and the final report in spring quarter.

The teams participated in an annual ASCE local section presentation competition; due to the Covid19 pandemic, the event was held via Zoom; a panel of five licensed civil engineers served as judges. The oral presentations were followed by questions from the judges.

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

Homelessness is an increasing social crisis in our region due to reasons stated earlier. The ultimate goal of this project is to provide an opportunity for the less advantaged to turn a new leaf with the support of the surrounding community. This project helped the student team to be aware of social issues and learn how an engineer's skills could be put to good use to improve the lives of the community as a whole. The health, safety and welfare of the homeless community was the focus throughout the project. The team also learned about serviceability criteria such as fire safety and floor vibration in timber structures.

IV. Multidiscipline, Allied Professional and Unskilled Volunteer Participation

The team worked with a multitude of allied professionals on this project. As mentioned earlier, the project was initiated by an architect who started the nonprofit organization. The architect met with the team every couple of weeks and served as the "owner representative" like in a typical engineering project. In the early stages of the project, the team volunteered their time to help with the construction of one of the light frame ADUs. This gave them an opportunity to understand the ability of the non-skilled volunteer workforce so that they could take that into account in their own design. The team also visited a CLT factory in early winter where they met with the factory personnel to understand the CLT manufacturing process and to learn about the amount and nature of the waste stream. The team also interacted with the foundation manufacturers to understand the installation and specifications of the Diamond Piers.

V. Knowledge and Skills Gained

Through this project experience students developed a wide range of knowledge and skills: technical expertise, communication and project management skills, ability to work in a team setting and to interact with a non-engineering client, and awareness of ethical and social responsibility of the engineering profession.

a) Technical Expertise Gained

The students learned how to carry out a client's dream from the conceptual stage through architectural drawings to engineering design. Through the design process they acquired skills and working knowledge in the following:

- Design Codes, Manuals and Guidelines: Local Building Code, ASCE 7-10 Minimum design loads for buildings and structures, American Wood Council 2018 National Design Specification, American Institute of Steel Construction Design Guide 11, 2018 Standards for Performance-rated Cross Laminated Timber, Residential Diamond Pier Guidelines
- Design/Computer aided drafting software: Sketchup 3D modeling software for presentation of design and AutoCAD for development of the final drawings.
- Miscellaneous issues related to hardware and connection design, sustainable design features, concept of Living Building Challenge and cost analysis.

b) Communication Skills

This project required the students to interact with engineers, architects, and construction material suppliers. These interactions made the students aware that each profession has its own jargon and that one needs to modify their language when they interact with other professionals.

The students were required to make oral presentations to their peers twice a quarter. Each student had to make at least one presentation each quarter. The academic year concluded with a grand virtual event where the team presented its work to the university community, sponsors of all capstone projects, prospective sponsors, friends, families and alumni.

Improving technical writing skills of our graduates is an important focus in our program. Hence, the team was required to submit a written proposal to the client at the end of fall quarter, describing the scope of work, plan of implementation, schedule and budget. At the end of spring quarter, they submitted a final report describing the work done, engineering calculations, drawings and other deliverables as initially agreed upon with the client.

The first two thirds of the academic year was in the traditional format with in-person meetings and in-class presentations. When the pandemic hit during the academic year, the project moved to a virtual platform. The team seamlessly transitioned to the virtual environment through Zoom for working sessions, meetings and presentations. The skills the students developed will be of value in the post pandemic and global work environment where virtual or hybrid work may become more common.

c) Project Management skills

Each team member played the role of a project manager for part of the academic year and had the following responsibilities: setting up team meetings, developing meeting agendas, conducting the meetings, assigning tasks to the team members and following up on action items. In addition, the project manager was in charge of contacting the client, the liaisons, and the faculty advisor in between team meetings, as necessary.

d) Awareness of Ethical and Social Responsibility of Engineers

This project made the students aware of engineers' ethical and social responsibility. It provided a great opportunity for the students to apply their knowledge and skills to improve the health, safety, and welfare of the less fortunate. This project also showed the students ways in which engineers can contribute to solutions for large social problems, a connection that they may not have previously envisioned.

VI. Summary

A team of civil engineering seniors designed a 125 sq ft detached accessory dwelling unit that could be used to address the homeless crisis in our city. The ultimate aim of the project is to install them in backyards of homeowners who are willing to support the homeless get back on their feet. The team explored the use of cross laminated timber waste products to develop a design that would utilize offsite manufacturing techniques, could be assembled with volunteer labor with no specialized equipment and meet the sustainability requirements of the Living Building Challenge. The project was supervised by two faculty members, one a licensed structural engineer and the other a professional engineer. The team received mentoring from a nonprofit group headed by an architect and a local structural engineering company. In addition to developing technical and professional skills, the team was made aware of some of the social issues faced by our community and the ethical and social responsibility of engineers in finding solutions that would better the community as a whole.