WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

PROTOTYPING A SMALL MASS TIMBER HOUSE

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ABSTRACT: In the United States (U.S.) state of Oregon, a lack of affordable housing led to new legislation encouraging increased housing density by allowing for accessory dwelling units (ADUs) and "cottage clusters" (small stand-alone houses assembled around a courtyard) on sites formerly zoned for single-family houses on urban sites. This legislation coincided with the state's interest in reviving its timber economy and in mitigating increasing wildfires exacerbated by climate change through the production and application of mass timber, which can utilize fiber from small diameter trees from forest restoration projects, thereby contributing to reduction of wildfire risk. These two state challenges converged leading to significant interest in the development of a prefabricated mass timber small house prototype. In the U.S., however, it has not been demonstrated that mass timber construction can compete on cost in the low-rise housing market with the typical construction system, light-wood-frame, particularly in single-house projects. This project investigated the potential for mass timber at small scale to achieve affordability through pre-fabrication, while also creating higher quality, more thermally and natural hazard (wind, seismic, fire) resilient housing to better respond to increasing threats from climate change.

KEYWORDS: mass timber, housing, embodied carbon, resilience

1 – INTRODUCTION

In the United States (U.S.) state of Oregon there is significant interest in mass timber as a driver for both economic development and environmental stewardship. Timber is a legacy industry in Oregon, which has seen significant declines in employment and economic activity over the last 60 years. Federal forest management, which oversees 60% of Oregon's forest lands, has restricted logging due to ecological concerns, but this has led to overgrown forests subject to catastrophic wildfires. Mass timber, which can use fibre from small diameter logs sourced from forest restoration projects, can provide a commercial market to subsidize the cost of forest lands restoration, leading to healthier forests, while adding value to rural timber economies with new manufacturing facilities. At the same time, a critical lack of housing in the state [1] has led to interest in rapidly produced panelised and modular housing. With mass timber's ease of prefabrication using advanced manufacturing digital fabrication [2], its application in housing systems presented an opportunity to address economic, environmental, and housing issues. While mass timber has been demonstrated to be cost competitive with concrete and steel construction, it has been more challenging for it to compete with the standard construction system for residential applications of 1-5 stories: light-wood-frame. However, given the compelling opportunities in increasing the market for mass timber, that challenge was addressed in the project described below.

2 – BACKGROUND

In September 2020 devastating wildfires broke out in Oregon burning over 1.2 million acres [3]. Along with the loss of timber, over 5000 homes were destroyed, and communities in Oregon including urban centres had the worst air quality in the world. The fires coincided with an already existing severe housing shortage in the state, spurring state agencies and public universities to meet to address these combined crises. The University of Oregon (UO) and Oregon State University (OSU) collaborate in the TallWood Design Institute (TDI) to advance research and development of engineered wood products; TDI

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https://doi.org/10.52202/080513-0364

joined with Oregon state agencies, the Port of Portland, Oregon Department of Forestry, Department of Land Conservation and Development, and Business Oregon, to develop a project promoting a "forest to factory" approach to these converging challenges: promoting forest restoration projects to increase fibre supply for mass timber product manufacturing, which would create a commercial market for restoration logs, and to increase the market demand for mass timber products with mass timber modular housing factories. The proposal was submitted to the U.S. Department of Commerce's Economic Development Administration and received a Build Back Better Regional Challenge Award in 2022 to support research and development (R&D) projects along with infrastructure to develop the mass timber ecosystem in the state.

One of the projects supported by this award was for R&D to prototype a small, panelised mass timber house which could be fabricated in a factory and shipped as a "flatpack/kit of parts" to sites around the state. The house was designed as a small two-story, two-bedroom house to be built as part of a "cottage cluster" of small freestanding units around a courtyard or as an accessory dwelling unit (ADU) on the lot of a single-family house [4]. The need for designs for this type of housing was created by a bill passed by the Oregon legislature in 2019, HB 2001, which required cities with a population of more than 10,000 to allow duplexes in areas zoned for single-family housing by June 30, 2021 and in cities above a population of 25,000 to allow multiple dwellings on a lot, including "cottage clusters," in areas zoned for single-family housing by June 30, 2022. While other states had allowed suburban sprawl, Oregon had enacted a policy of urban growth boundaries in 1973 to protect agricultural and forest lands from encroaching urban development [5]. While this had the desired effect of preserving critical drivers of the state's economy, agriculture and forestry, it also led to restrictions on land available for new housing development. HB 2001 was designed to encourage densification of existing urban areas. The City of Milwaukie, Oregon, just outside Portland (the state's most populous city), was already facing a housing affordability crisis for middle income residents and decided to start modifying their zoning code in spring 2020 in response to the new legislation. They commissioned a study looking at "cottage cluster" and other small-scale multi-family strategies, known as "middle" housing – housing between single family and large multifamily developments that would also help to make housing more affordable for middle class residents. A UO architecture faculty design team worked with Milwaukie planners to help them visualize the implications of new zoning codes and the building types that might result. In response to the new code, the UO team developed a two-story house, 82.5 m^2 (888 ft^2), with a small footprint, 42.2 m^2 (454 ft^2), and a gable roof with a low pitch, as a response to the new "cottage cluster" requirements which addressed unit floor plan sizes, setback requirements, and heights.

While structurally certified cross-laminated timber (CLT) was manufactured in Oregon starting in 2015, the design team made the choice to work with mass ply panels (MPP) manufactured by Freres Engineered Wood in Lyons, Oregon. MPP is a new product developed by Freres in collaboration with OSU research faculty, structurally certified in 2018. While the thinnest available 3-ply CLT was 108 mm , MPP panels of 76 mm and 51 mm could be employed to build the small house, using considerably less fibre, reducing material costs. Additionally, MPP is made of plywood lamellas, which can be made from trees with a diameter as small as 127 mm, with 70% log utilization, with more efficient use of wood fibre, compared to CLT made of sawn lamellas (sawn wood generally has 50% log utilization). While volumetric modules were considered for the project, on advice from Swinerton Builders, a construction firm with significant experience in mass timber construction in the U.S., the design team chose a panelised "flatpack" approach to allow ease of shipping and assembly in dense, formerly single-family housing neighbourhood sites.

3 – PROJECT DESCRIPTION

This project focused on the design and prototyping of the compact two-bedroom two-story house to be constructed of 76 mm MPP panels for exterior walls, floor and roof and 51 mm panels for interior walls. The design objectives were to 1) use the thinnest possible MPP as efficiently as possible, with minimum waste; 2) to take advantage of the prefabrication potential of the materials with digital workflows, and: 3) to achieve a product that could compete with light-wood-frame on cost. The UO team worked with a California State Polytechnic University (CSPU) structural engineering faculty member and planned for two iterations, with the first prototype built inside TDI's A.A. "Red" Emmerson Advanced Wood Products Laboratory in the College of Forestry at OSU on its concrete strong floor to test fabrication, constructability, and structural approach. A professional structural engineering team from Ficcadenti Waggoner and Castle Structural Engineers was contracted to work with the UO and CSPU team on this novel design. The second prototype was planned to be bid and built by contractors outside the Emmerson Lab on an external

https://doi.org/10.52202/080513-0364

strong floor, to further test digital workflows and constructability, to develop data on thermal, acoustic and moisture performance, and to determine what a contractor would spend on materials and labour. The first prototype was completed in September 2024. Following a critical evaluation of the process and product, the UO team worked with the engineering team on optimizing the design, to reduce steel connections and the number of panels. An RFP has been issued for contractors to bid on the second prototype, which is expected to be completed by December 2025.

4 – DESIGN PROCESS

As noted, the design process focused on a small two-story house constructed of mass ply panels. MPP is manufactured in lengths from 9.75 m to 14.6 m. To use MPP efficiently, house dimensions were set at half the maximum length, or 7.3 m., for the length of the interior of the house. The width was also set to maximize efficiencies of the panels, which are manufactured in widths ranging from 2.4 m to 3 m to 3.6 m; we chose to use panels no wider than 3 m so that they could be fabricated on a relatively small CNC machine and transported on a truck to most locations. The ground floor included storage for coats and bicycles at the entrance along with a half bath (toilet and sink), and a kitchen, dining and living area. The second floor included two bedrooms of the same size with closets, a full bath (sink, toilet and tub/shower), a closet for a stacked washer and dryer and a storage cabinet (Fig. 1).

As the house was designed to be built close to neighbours in a cluster, windows were largely confined to the narrow front and back facades. For additional daylight, four skylights were added; to let light into the ground floor the stair was designed with open risers and with an adjacent double height open space. The storage cabinet at the top of the stairs was added late in the design process when the team determined additional storage was needed and is supported by a cantilevered floor extending from the bath area into that double height space; this closet addition still allows light into the ground floor. On the upper floor, clear polycarbonate clearstory panels let light through the house, above the bedroom closets and the laundry closet. A whitewash finish (TimberPro custom formulated with 300% white pigment with a high reflectance value) was applied to all walls and ceiling surfaces to further lighten the interior (the whitewash increased the light reflectance value from an average of 45% in the unfinshed MPP to an average of 73%, a significant increase).

Figure 1. Plans.

Much consideration was given to the integration of mechanical, electrical and plumbing services, as they could not be hidden in hollow walls and floors/ceilings as is the case in light-wood-frame construction. One furred cavity wall was created for plumbing, with second floor bath and laundry located directly above the ground floor half bath and kitchen. Electrical MC cable was concealed in baseboards made of MPP routed to accommodate them, on closet ceilings above eye height and threaded in a chase created between floor panels. The approach to heating and cooling was to first create a high-performing enclosure that relied on the monolithic nature and precision panel-to-panel connections of MPP to form an airtight volume with continuous outboard insulation, which will be performance tested in the second prototype. For much of the year in Oregon's climate, the investment in the building enclosure will allow passive thermal control for enhanced resilience; however, minimal mechanical systems were added to ensure comfort. These include electrical resistance heating under windows and a low-cost through wall air conditioning unit, that can be removed and replaced with a gasketed plug if not desired. Fresh air was introduced by an energy recovery ventilator (ERV) located in a space between the two beams under the second floor, with supply ducts routed directly to the bedroom closets above. Additional low-cost in-line duct mixing fans were added to improve mixing of air in the spaces (Fig. 2). Although vinyl windows are standard in affordable housing in the U.S., the team chose aluminium windows

https://doi.org/10.52202/080513-0364

Figure 2. Mechanical and electrical integration.

for their superior appearance, durability, low profile, function and recyclability. However, a low-cost casement and fixed sash double pane option was chosen to meet project budget goals. These were further combined with a sliding translucent polycarbonate panel, which acted as a third insulating pane, and doubled as a privacy screen that let in diffuse light (Fig. 3). This system was tested in a mock-up [6] and proved to work well in infiltration tests and thermal infrared imaging due to the precision of the CNC fabrication of the panels and tight fit of the windows.

Along with the precise fit of windows and skylights and their ease of installation, the digital fabrication of the MPP led to the approach in detailing. Interior openings were not cased or trimmed as they would be in light-wood-frame construction; the CNC process and 10 mm radius of the rotary tool were expressed. Doors did not need to be framed and hung as they would in light-wood-frame construction; interior doors were 51 mm MPP set on inexpensive pivot hinges. Door handles were routed into the door panel (Fig. 4), as were embedded wireless light switches into walls (Fig. 2). The stair railing, 51 mm MPP, served as both a beam supporting the stair and as a handrail with routed edge; the storage cabinet was also routed to allow space for a hand (Fig. 5).

5 – RESULTS

The team planned that the MPP would arrive at a site premanufactured with insulation, windows, doors, and cladding already attached. This led to considerable attention paid to the joining of the panels to prevent moisture penetration. It also led to the need for steel connections to be made on the interior of the house, where they were visible. These connections also required mortise joints in the edges of the panels (Fig. 6) and self-drilling dowels driven through steel plates to complete the panel-to-panel connection, which resulted in much hand labour. Even before construction of the first prototype started, the team projected that in the second prototype the decision would be made that the panels would be shipped without insulation and cladding which would be applied in the field; however, the team decided to finish the detailing of the house and build the first prototype with the initial assumption and assess both the hand labour and aesthetics of exposed steel connections before building the second

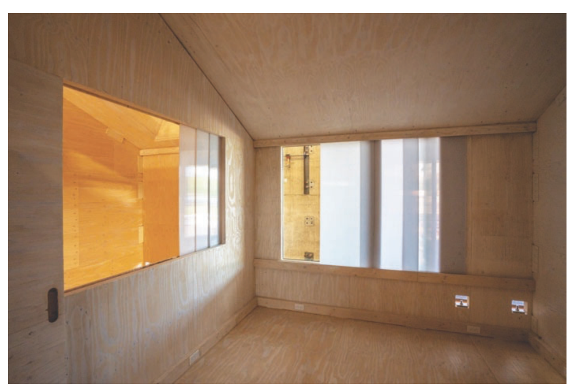

Figure 3. Translucent insulating panels. Image: Marcus Kauffman, used with permission.

https://doi.org/10.52202/080513-0364

Figure 4. Door and window details.

prototype. Another assumption was to construct the house with a "platform" approach, building the ground floor first, and then the upper floor (Fig. 9). Both the interior connections and the platform framing led to several structural design challenges.

Oregon has high seismicity, and this required special attention to connections between panels from ground floor to upper floor without extensive exposed steel (Fig. 8) on the short walls, which were load bearing. This led to the development of threaded rod panel-to-panel and panel-to-foundation internal connections that could be completed from the interior once panels were set in place (Fig. 7). On the long walls, mortised connections and self-drilling dowels were required, as noted above (Fig. 6). Custom steel plates and angles, powder coated to match the MPP whitewash, along with the custom seismic connection added cost to the project. The labour involved custom mortising and completing panel-to-panel connections using internal steel plates and self-drilling dowels (Fig. 6); this added significant labour to the project. The first prototype led the team to conclude that the second prototype would be constructed with vertical two-story panels, similar to "balloon" construction (Fig. 10). This

Figure 5. Stair handrail detail.

Figure 6. Mortise panel-to-panel connection.

Figure 7. Steel angle connections.

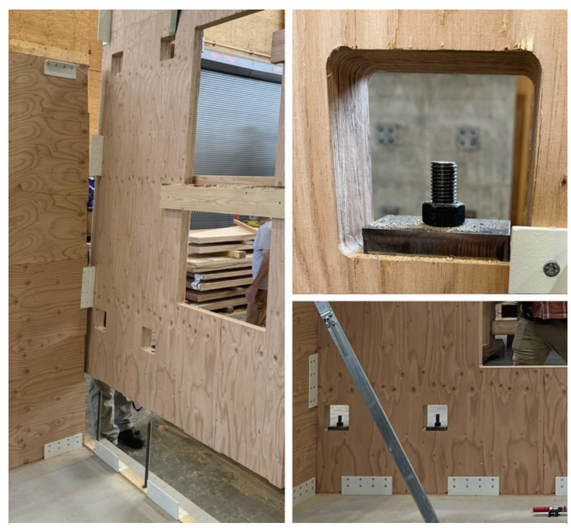

Figure 8. Threaded rod connection.

reduced the number of MPP panels, eliminating one full panel, and the need to create custom threaded rod and mortised steel plate connections. Planning for field installation of insulation and cladding allowed for the elimination of the custom steel plates and angles and for standard connections for seismic resistance. We will compare both material costs and labour of the second prototype, once completed, to the first one, but we can assume that the reduction of hand labour, custom steel, and fewer MPP panels will lead to significant cost reductions.

6 – CONCLUSION

The first prototype was successful in demonstrating that 76 mm MPP walls, floor and roof can be designed and assembled to make a structurally sound house (Fig. 11). As noted, iterative prototyping will allow the team to optimize the structural system and to test constructability, along with thermal and acoustic performance. Whether MPP construction can be cost competitive with light-wood-frame will be better understood after the second prototype is completed, however, pilot projects will be needed to confirm actual material and labour costs and constructability on sites around the state. The first prototype confirmed a commitment from a developer to build a four-unit pilot project in Eastern Oregon and additional pilot projects are in early development to establish "proof of concept."

https://doi.org/10.52202/080513-0364

Figure 9. Platform framing assembly sequence. Image: TallWood Design Institute, used with permission.

The project has been well-received by Oregon's elected and appointed representatives and members of the public [7], but more will be known about costs, constructability and market acceptance after several pilot projects are built. The Port of Portland, a "forest to factory" project partner, is developing a mass timber modular housing factory at a former marine terminal site in Portland which is being converted to a mass timber innovation campus; with factory production of the panelised components, a more complete evaluation of the affordability of these units will

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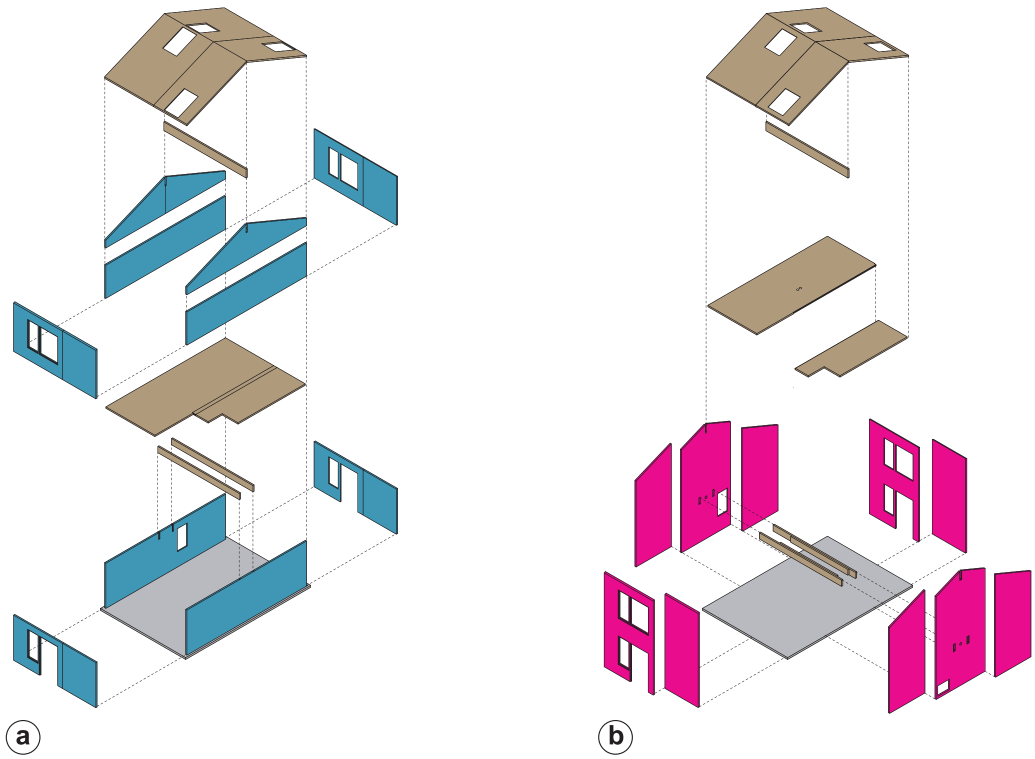

Figure 10. Prototype 1 platform framing concept (a). Prototype 2 balloon framing concept (b).

Figure 11. Prototype 1 in lab space. Image: Marcus Kauffman, used with permission.

https://doi.org/10.52202/080513-0364

be possible. Two other entrepreneurs have expressed interest in starting fabrication and assembly operations for this MPP "flatpack/kit-of-parts" in Central and Western Oregon. The longer-term plan is that the system will be adapted to other unit types, including larger units and one-story accessible unit types, produced in factories around the state.

Funding was provided by EDA BBBRC Grant # 07-79-07906, and by Business Oregon's Research Fund, Contract # C2022840. Additional support was provided by the TallWood Design Institute's Emmerson Lab staff Phil Mann, Mark Gerig, and Byrne Miyamoto, and UO students Simone O'Halloran, Kate Laue, Yash Akhouri, Karen Brittain and Daniel Essaides, and OSU students Logan Banks and Hilary Johnson.

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