World Conference on Timber Engineering
Oslo 2023

MASS TIMBER PANELIZED WORKFORCE HOUSING IN OREGON, U.S.

Judith Sheine[1], Mark Fretz[2], Simone O'Halloran[3], Mikhail Gershfeld[4], Jason Stenson[5]

ABSTRACT: Mass timber panel production came to the United States after developments in Europe and Canada; the first domestic structural cross-laminated timber (CLT) panels were manufactured by DR Johnson Wood Innovations in Riddle, Oregon in 2015. With its history of timber product manufacture, the state has embraced this new material for its potential for economic development and environmental stewardship and Oregon has become the epicentre of mass timber development in the U.S. As in many places in the U.S., Oregon has a critical shortage of affordable housing and it has been challenging to find paths for mass timber to enter this market where light-wood-frame construction is dominant. In 2018, Freres Engineered Wood, working with the TallWood Design Institute, a collaboration between the University of Oregon and Oregon State University, developed a new product: mass plywood panels (MPP). This product provides a possibility for constructing single-family houses economically with mass timber using thin panels derived from small diameter logs. This paper describes the research leading to a pilot project utilizing MPP for workforce housing in Milwaukie, Oregon.

KEY WORDS: Mass Timber, Affordable Housing, Oregon

1 INTRODUCTION

Mass timber panel production came to the United States, after developments in Europe and Canada; the first domestic structural cross-laminated timber (CLT) panels were manufactured by DR Johnson Wood Innovations in Riddle, Oregon in 2015. With its history of timber product manufacture, the state has embraced this new material for its potential for economic development and environmental stewardship and Oregon has become the epicentre of mass timber manufacture, design, research, testing and construction in the U.S.

While timber production has been central to Oregon's economy since its founding, timber production has fallen significantly over the past 50 years, due to environmental regulations restricting timber harvest, and job losses have been severe due to the reduced production and to automation in the industry [1]. Combined with changes in tax laws that have led to further losses of income, rural counties in Oregon have suffered significant economic declines which have exacerbated tensions between environmentalists and those in the timber industries and communities [2]. However, with climate change leading to worsening drought conditions in the American West and years of forest management policies restricting harvest, coupled with the promotion of fire suppression, devasting wildfires have served as an impetus for change [3]. Because mass timber utilizes small diameter logs that can be harvested from forest restoration projects that reduce wildfire risks, environmental groups and the timber industries have been able to find common ground in advocating for changes in forest management policies that allow for additional selective harvesting. Mass timber manufacture provides economic benefits by creating well-paid high tech jobs manufacturing mass timber panels and environmental benefits by utilizing forest restoration products and by substituting a bio-based carbon sequestering material for steel and concrete [4].

Because the state recognizes these benefits, the Oregon Legislature provides funding for the TallWood Design Institute, (TDI) a collaboration of the University of Oregon's (UO) College of Design and Oregon State University's (OSU) Colleges of Forestry and Engineering. TDI's mission is to promote economic development and environmental stewardship by advancing engineered timber products through research, testing, outreach and education. TDI has been critical in providing research and testing for DR Johnson Wood Innovations to produce their CLT panels and worked closely with Freres Engineered Wood in Lyons, Oregon, to develop a new mass timber product, mass plywood panels (MPP).

At the University of Oregon, we have engaged in design research projects demonstrating the feasibility of using mass timber products in a variety of building applications.

[1] Judith Sheine, University of Oregon (UO), United States, jesheine@uoregon.edu
[2] Mark Fretz, University of Oregon (UO), United States, mfretz@uoregon.edu
[3] Simone O'Halloran, University of Oregon (UO), United States, simoneo@uoregon.edu
[4] Mikhail Gershfeld, California State Polytechnic University, Pomona (CPP), United States, mgershfeld@cpp.edu
[5] Jason Stenson, University of Oregon (UO), United States, jstenson@uoregon.edu

https://doi.org/10.52202/069179-0484

However, demonstrating that mass timber can provide affordable and energy efficient housing at single-family scale has been an elusive goal. With the development of MPP, we saw an opportunity to use thin, very strong panels that could be fabricated with digital workflows to make affordable single-family houses, adding social equity to mass timber as an additional benefit for Oregon.

2 BACKGROUND

As in much of the U.S., Oregon has a critical shortage of housing that is affordable. Lack of housing inventory and spiraling home prices have reached a crisis point in both rural and urban communities; over the next 20 years, Oregon will need about 584,000 new homes [5]. It has been challenging to find paths for mass timber to enter this market where the dominant construction method for up to five stories of a structure is light-wood-frame; since CLT uses comparably more wood fibre it can be more costly. However, MPP is 20% stronger than CLT and allows the use of thin panels (51-76 mm) derived from small diameter logs (as small as 127 mm) [6], providing a new possible path for a sustainable mass timber product to be used in residential construction [7].

To address the housing shortage, the Oregon Legislature passed House Bill 2001 in June 2019; it requires cities with a population over 10,000 to eliminate single-family zoning and allow two or more units on sites that were previously zoned for only single-family houses. In the metropolitan area around Portland, the largest population centre in the state, the law has allowed cities and counties to permit quadplexes and groups of small units ("cottage clusters") in areas previously zoned for single-family housing. This law was meant to promote the creation of more housing units and to reduce their cost by increasing land use intensity on sites formerly zoned for only a single house.

The City of Milwaukie, just outside Portland, took a proactive approach to respond to these new requirements and commissioned a planning study of the impacts of this required land use change with recommendations for the new standards [8]. These included updating their existing "cottage cluster" code to stimulate development of these groups of small freestanding houses arranged around a communal open space, and also allowing for groups of attached houses, known as "middle housing," all on single-family lots with bicycle storage, open space and tree canopy standards, and associated reduced parking requirements.

3 UNIVERSITY OF OREGON DESIGN RESEARCH STUDIO

At the University of Oregon, Professor Judith Sheine taught a design studio in winter 2020 focused on creating modular mass timber housing for a single-family double lot in Milwaukie that was part of the cottage cluster feasibility study. The studio followed the land use and massing guidelines recommended in that study and focused on using volumetric modules of MPP, producing some compelling designs that were presented to the Milwaukie planning staff, who found the visualizations of these zoning proposals useful for their development of their new land use regulations. These regulations evolved over the next two years, and were finally adopted by the City of Milwaukie in June, 2022, allowing for cottage clusters and middle housing on a single lot.

Figure 1: *MPP Modular Housing, Milwaukie, Oregon; University of Oregon Student project by Flynn Casey*

4 PROJECT

Following the studio project, UO faculty Sheine and Mark Fretz and structural consultant Mikhail Gershfeld, started a collaboration to design a small, energy efficient house constructed with MPP panels that would result in publicly available documents for application in cottage clusters, or stand-alone units, affordable to households with 80-100% of the area median income, which includes middle class households for whom housing in Oregon has become unaffordable. Swinerton Builders, a construction firm with significant expertise in mass timber, joined the team and provided critical practical advice on cost and construction efficiency. At their urging, the design team decided to embrace panelised prefabrication of the modular units, to avoid the transportation challenges of the volumetric modular model and to produce a design that could be built by small construction firms on a variety of sites with panels that could be prefabricated in a small warehouse facility or in a large factory.

The design team partnered with an affordable housing developer, HomeWork Development, that was interested in using these units for a pilot project in Milwaukie, on the lot that was the site for the 2020 design studio and some nearby lots. A large healthcare provider, Providence Health, which was eager to provide affordable, healthy housing for their workforce in Milwaukie, decided to invest in the project and contribute two small conjoining lots; however, due to the economic conditions following the Covid-19 pandemic, Providence was unable to follow through on this commitment and the pilot project was scaled down to two lots. The design team explored a variety of site configurations over the two-year period that the new Milwaukie zoning ordinance was being

https://doi.org/10.52202/069179-0484

developed and, once the ordinance was adopted, found that the most efficient site utilization resulted in cottage clusters of free-standing units, with 11 units on one site (Figures 2, 3) and 15 units on the second one, for a total of 26 units. While originally the designers had planned for both two-and three-bedroom prototypes, the developer advocated for one repeatable two-bedroom unit for maximum site utilization and potential cost efficiencies.

Figure 2: *MPP Panelized Housing, Milwaukie, Oregon; rendering by Simone O'Halloran*

4.1 THE OREGON MASS TIMBER COALITION

Following devasting wildfires in September 2020 in Oregon, which burned 4,452 square kilometres and destroyed over 4,000 houses, many of them manufactured houses occupied by low-income households, several Oregon state agencies started holding (virtual) discussions about how to address reduction of wildfire danger and the creation of affordable and more resilient housing. Business Oregon (BO), the state's economic development agency, the Department of Land Conservation and Development (DLCD), the Oregon Department of Forestry (ODF) and the Port of Portland (Port) joined with TDI, which included UO and OSU, to strategize about creating mass timber housing at a large scale, housing that would be far more resilient than the manufactured houses built with light-wood-frame to minimal standards that had burned in the wildfires and that would provide economic and environmental co-benefits by expanding the mass timber market.

These discussions evolved into the Oregon Mass Timber Coalition (OMTC) that applied in October 2021 to the U.S. Economic Development Administration's (EDA) Build Back Better Regional Challenge (BBBRC) to address economic development, environmental sustainability and social equity with investments in research and development and infrastructure that would drive a new industry. The OMTC proposed a group of projects that spanned the mass timber housing supply chain, from forest restoration and mass timber manufacturing (ODF and OSU) to updated land use legislation (DLCD) to MPP panelised prefabricated housing development (UO) to infrastructure for a mass timber housing factory at an industrial site in Portland (Port), along with new research facilities for testing mass timber assemblies for acoustic and fire resistance ratings at UO and OSU, respectively, and workforce development in forest restoration, mass timber manufacture, and housing construction (Port, ODF, OSU, DLCD). The OMTC was one of 60 regional coalitons (out of 529 applicants) to receive Phase 1 funding ($500,000) and one of 21 coalitions to receive finalist funding: $41.4 million; Business Oregon supplied an additional almost $6 million in required matching funds for UO and OSU. Out of this funding, $2 million was awarded to UO for developing and building prototypes of the MPP panelised housing, to determine the most efficient construction methods and the labour and material costs. This work will be undertaken over the next several years, 2023-2025.

In order to continue to develop the design of the MPP housing unit for prototype construction, funding was supplied by TDI and by the developer, HomeWork, with funding from two U.S. Forest Service Wood Innovation Grants for design development and an Energy Trust of Oregon Fellowship for energy efficiency analysis, and funding from the EDA BBBRC Phase 1 award.

4.2 UNIT DESIGN

Mass timber panels are a prefabricated building material as either small lumber or veneer elements are glued together and pressed into large panels, beams and columns in a factory, as opposed to framing a wall on site as is done with light-wood-frame construction. These panels can be manufactured to order and can be digitally pre-cut and routed to achieve panels with door and window cut outs to be quickly assembled on site. Additionally, vapor barriers, insulation and cladding can be pre-applied off-site, to simplify construction in the field. While even more efficiencies can be achieved with assembling a volumetric module in a factory [9], it is more efficient to ship flat panels which may not require special permits (and costs) for oversized truck loads. In the case of our pilot project, while the panels can be prefabricated in a factory, the mass timber housing factory is still at least several years from existence in Oregon, and the panels can also be fabricated in a smaller warehouse setting with existing facilities.

In order to allow the MPP construction to compete in cost with light-wood-frame, it was necessary to work with the panel sizes that Freres Engineered Wood manufactures and to minimize waste. The length of the basic unit footprint was established as half of the maximum panel length Freres produces, or 7.3 m (total maximum panel length of 14.6 m), and the width was based on a combination of the panel widths in the Freres catalogue, or about 4.9 m. As noted above, the units are identical two-bedroom units; in order to fit a maximum number of units on each site, the units are two-stories (about 6.5 m at the top of the gable roof).

For this project, only stand alone and duplex units were considered, due to higher fire ratings required by triplex and quadplex units, which would have added additional wood fibre or the inclusion of gypsum board to achieve

https://doi.org/10.52202/069179-0484

the required fire resistance. The design team wanted to avoid the use of gypsum board, with its high carbon footprint. And, in order to maximize the number of units allowed within the new Milwaukie zoning code, the units are stand alone in cottage clusters, which did not require any on-site parking (Figures 2, 3).

The units have living spaces on the ground floor and two bedrooms on the upper floor. The upper floor bathroom is stacked over the half bath and kitchen, with one plumbing wall applied as a chase over the MPP panel, in order to separate it from the exterior solid wall panel. Apart from the plumbing walls, all interior surfaces are MPP, eliminating the need for finishes (Figure 4).

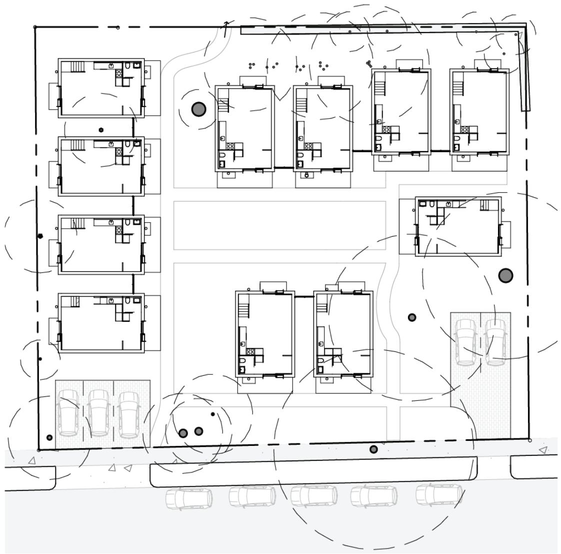

Figure 3: MPP Panelised Housing, Cottage Cluster, Site 1, Milwaukie, Oregon

Within the cottage clusters, units are set 1.8 meters apart (a code requirement), leaving the front and back elevations as the best locations for windows. These were aligned on the upper and lower floors to allow sufficient solid panels to support the roof. To allow more light into the units, skylights were added, and a space was opened to below adjacent to the stairs, allowing light to penetrate to the lower floor. A translucent polycarbonate material is used in strategic locations to allow more light to penetrate the unit. (Figures 4, 5, 6).

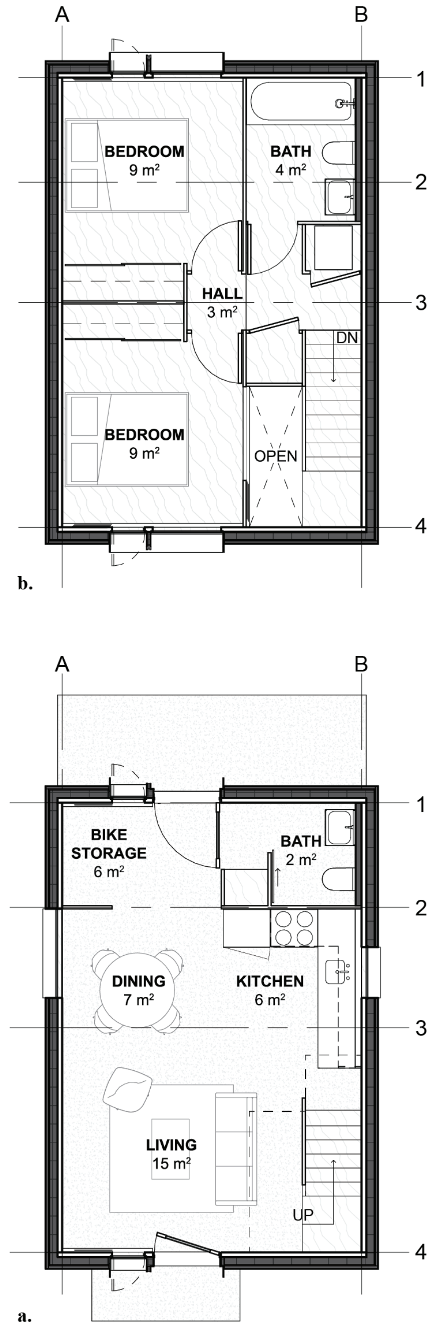

Figure 4*: MPP Panelised Housing, Floor Plans. a. Ground Floor Plan, b. Upper Floor Plan*

https://doi.org/10.52202/069179-0484

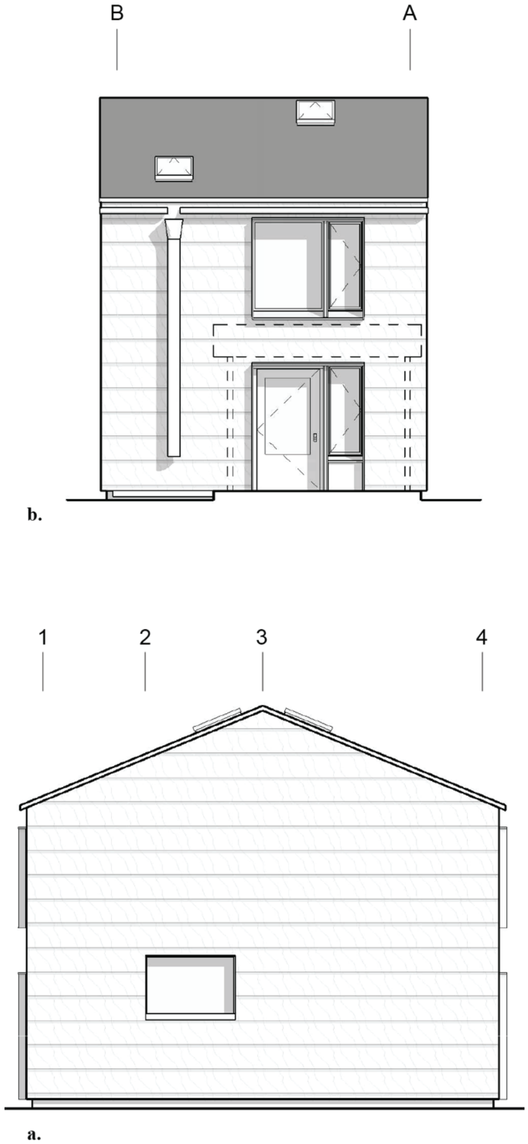

Figure 5: MPP Panelised Housing, Elevations: a. Side elevation; b. Front Elevation

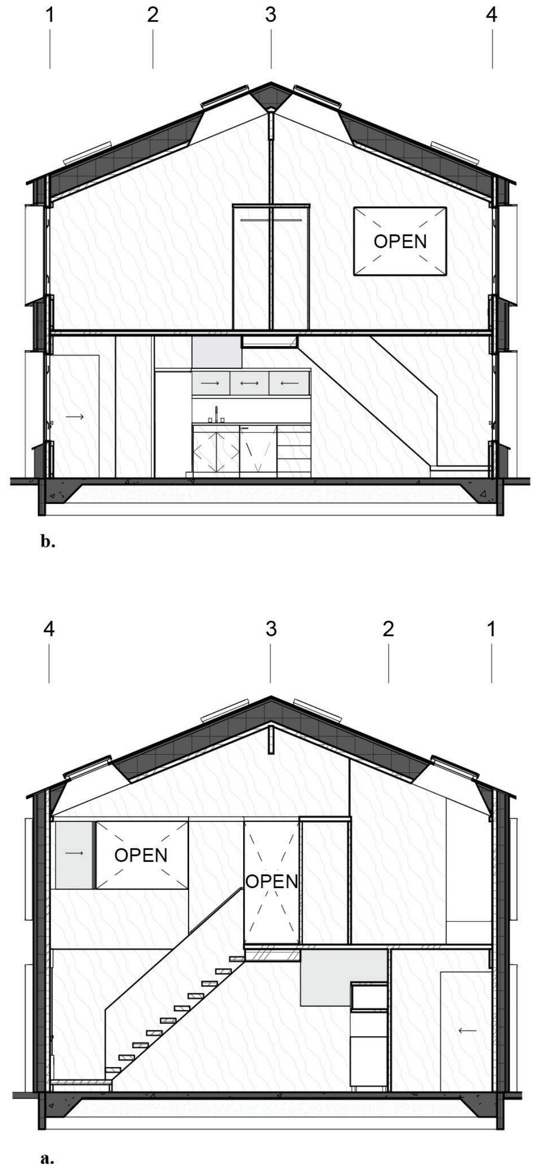

Figure 6: MPP Panelised Housing, Sections. a. Section through Stair b. Section Through Living Space

4.3 STRUCTURAL DESIGN

The use of MPP panels, 51 and 76 mm, would reduce the use of wood fibre but does not currently meet the code requirements of SDPWS 2021 [10]. Comprehensive testing of MPP to assess the global and local stability performance of thinner shear walls resisting both gravity and lateral loads is not currently available.

Based on Frerres MPP design guidelines, it was determined that a minimum of 76 mm panels would be required for the roof, floor and exterior wall construction assemblies. The use of 51 mm panels placed horizontally for the exterior walls that are not supporting roof or floor loads, and thus non-bearing, was explored. This design would require the addition of posts, would complicate the construction process and could be significantly below approved lateral system requirements. Thus, 76 mm panels were considered a more effective solution for all exterior walls. All non-bearing interior walls remained at 51 mm (Figures 7, 8).

Also, hybrid construction (MPP + light-wood-frame) vs. an entirely panelized system was considered. While hybrid construction would reduce wood fibre use, it would impact prefabrication potential and efficient constructability and thus overall cost.

The panelised system selected requires beams at two locations; a ridge beam, 76 mm MPP, at the intersection of the roof panels and a wide MPP floor beam, to break the floor span sufficiently to allow the use of a 76 mm floor panel. The wide beam (flat use) was chosen to minimize its intrusion into the ground floor space, keeping it as open as possible (Figures 7, 8). MPP ledgers are used to support the floor and roof MPP panels and also help to create spaces for electrical routing, lighting and window shading.

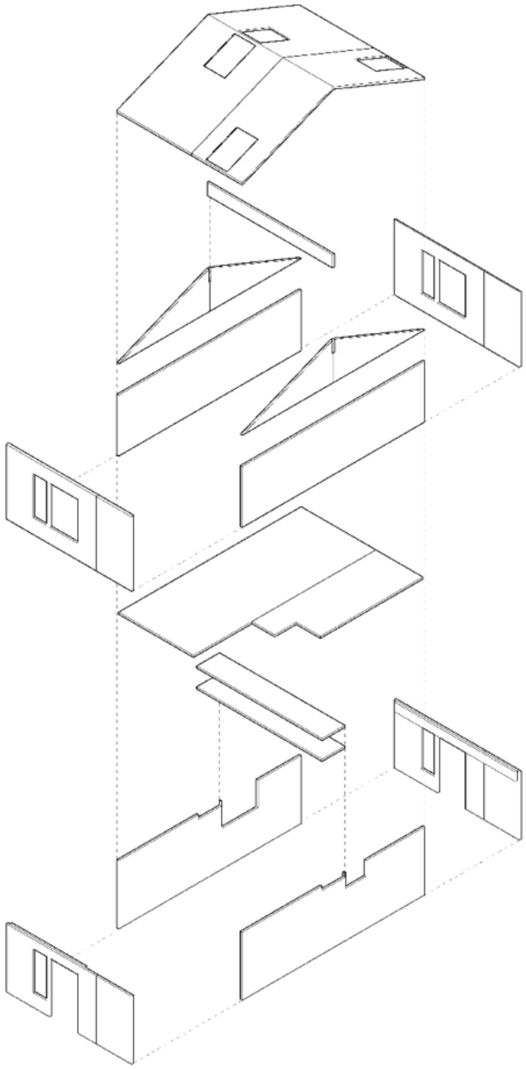

Figure 7: *MPP Panelised Housing, Assembly*

4.4 MATERIAL EFFICIENCY

An additional consideration was minimizing waste in the usage of the panels. Trials with panel layouts eventually allowed a realization of around 95% utilization for 51 mm material (Figure 9) and around 90% utilization for 76 mm material (Figure 10). The overall wood fibre volume for the house, which includes structure, partitions, doors and casework, is approximately 19.9 m^3. To eliminate the

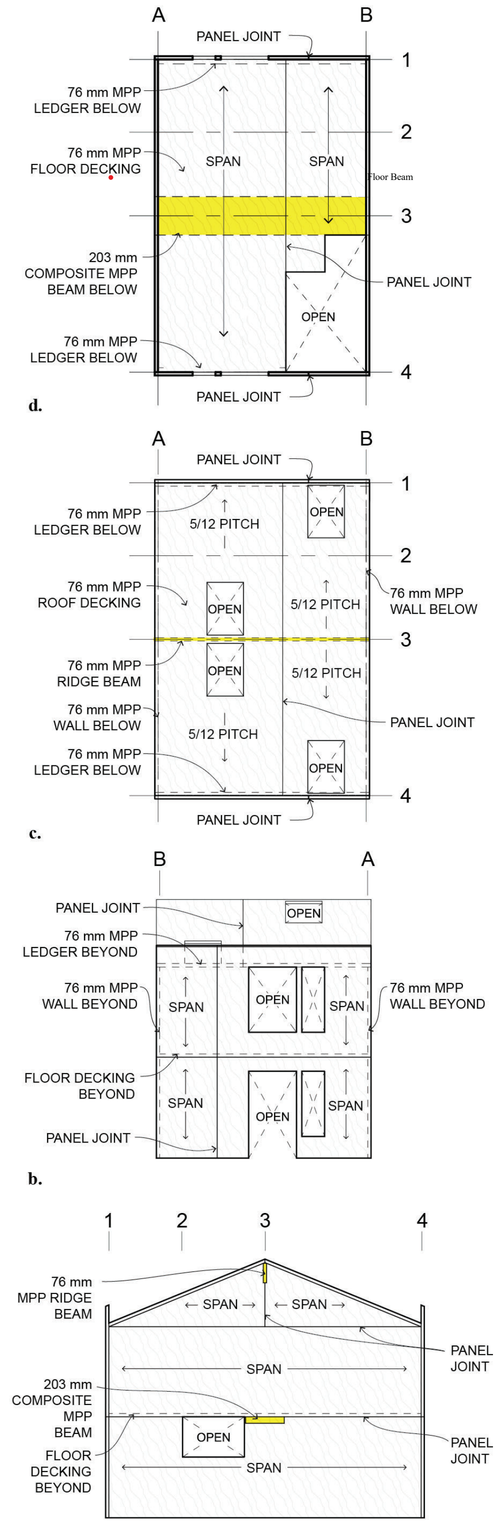

Figure 8: *MPP Panelised Housing, Framing. a. Side Wall Framing Elevation; b. Front Wall Framing Elevation; c. Upper Floor Framing Plan; d. Roof Framing Plan*

https://doi.org/10.52202/069179-0484

expense of transporting oversized loads, panels that are no more than about 2.4 meters wide were used.

One issue to be resolved in the first, iterative prototype is whether window and door openings for the front and back walls of the unit will be cut out of the panels, or assembled through a series of straight cuts that are infilled with rectangular panels above and beneath those openings. The latter method would result in an approximate 5% increase in material use efficiency due to not having the leftover fibre from the cut-outs, but would also increase the number of parts to handle from 25 to 41. Therefore, a higher fibre utilization could be offset by higher labour. Also the cost of routing the openings using a CNC versus cutting them with a handheld electric panel saw using a prefabricated jig will be compared.

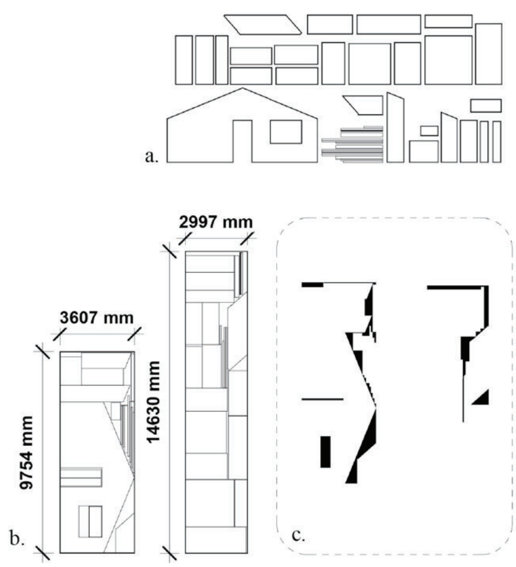

Figure 9: *MPP Panelised Housing, 51 mm Material Efficiency. a. Panels for Project; b. Panels Arrainged on Standard-Size Billets for Material Efficiency; c. Unused MPP Material.*

4.5 ENERGY EFFICIENCY

The goal of the study funded by Energy Trust of Oregon was to meet net zero energy goals while reducing the cost of these standards in construction in the residential sector, a primary barrier to deploying net zero ready construction at scale without substantial subsidy. The use of MPP to create a higher performing thermal envelope was explored by the design team. With MPP, the envelope is more monolithic than light-wood-frame construction, with fewer joints for air infiltration, and outboard insulation that wraps the entire structure with fewer thermal bridges. Furthermore, the MPP itself has insulative properties. The panelized wall assemblies facilitate a novel window integration (Figure 11) that seeks to increase the energy performance and esthetics of low cost off-the-shelf windows, employing a twin-wall polycarbonate shade and

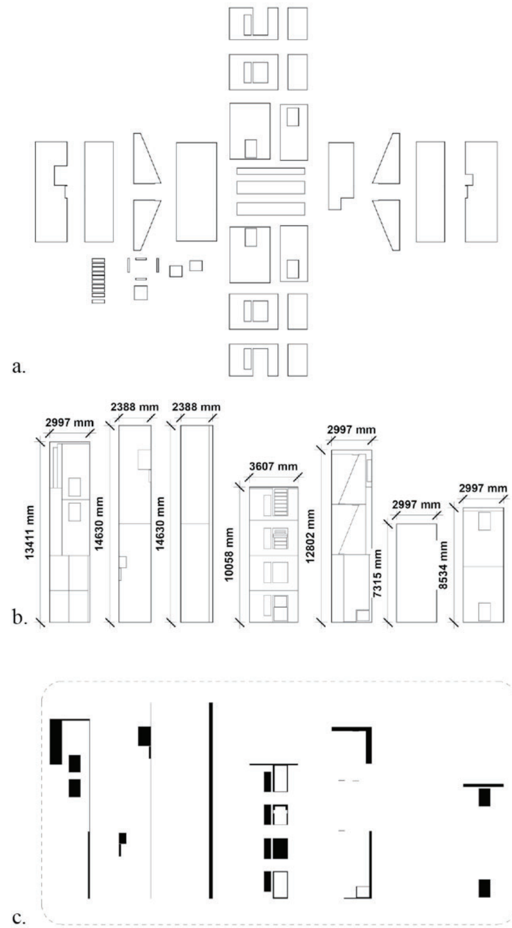

Figure 10: *MPP Panelised Housing, 76 mm Material Efficiency. a. Panels for Project; b. Panels Arrainged on Standard-Size Billets for Material Efficiency; c. Unused MPP Material.*

deep inset for solar shading while maintaining simplicity to reduce construction costs. Moreover, as the new MPP units can be arranged in dense courtyard clusters they create opportunities where the units could share thermal energy through district heating/cooling strategies and charging of a high-mass ground floor slab and shared peer-to-peer solar photovoltaic energy, thus simultaneously preserving existing tree canopy while balancing loads across the site and larger energy grid. The buildings themselves will serve as thermal storage, with the concrete slab and the high-performing thermal envelope facilitating proactive strategies for optimizing when and how energy is consumed on site.

This study included:
1. An energy model of a prototypical MPP panelized single-family house with concrete slab-on-grade, and an all-electric monobloc heat pump system configured either individually for each unit or as a district strategy.

2. A physical mockup of a higher-performance low cost window that includes infiltration testing (Figure 12) and thermal imaging (Figure 13).

4.5.1 Energy Model

The energy analysis was based on a combination of Honeybee 1.4.0 (via Grasshopper and Rhinoceros 7) and OpenStudio 3.3.0, both of which rely on EnergyPlus 9.6.0 for the annual energy calculations. The MPP model geometry was based on the most recent design documents, while the model performance is reflective of the U.S. Department of Energy (DOE) Zero Energy Ready Homes (ZERH) standard. The model is currently set with a packaged air-to-air heat pump system as baseline. The team is exploring system options, including an air-to-water district heat pump and hot water strategy to serve multiple units. Targeting the ZERH standard for the basis of design, the simulated preliminary results show an EUI of 52.7 kWh/ m^2 with the majority of energy consumption attributed to heating and interior equipment. Additional selection and testing of low cost windows will be performed in future prototyping, in order to meet the prescriptive requirements of the ZERH standard

The design of each housing unit is configured for hydronic heating, cooling and coupled domestic hot water. Units can be coupled with a district heating loop that supplies domestic hot water all year using a dedicated heat exchanger and additional space heat to the floor slab during heating and shoulder seasons. During the cooling season, natural ventilation will provide the primary cooling with supplemental cooling provided by centralized heat pumps that are staged to deliver chilled water via a cooling loop and floor slab hydronics valved to switch from heating to cooling. For both space heating and cooling seasons, the slab and centralized thermal storage tanks can be either heated or chilled at night to take advantage of off-peak electrical rates from the grid. This design is intended to not only reduce unit energy use but provide overall operational affordability, load sharing and resilience since the centralized heat pumps can be operated by site microgrid photovoltaics during a grid outage.

In the case of a single unit configuration, the district heating and cooling loops can be substituted by an air-to-water heat pump and a small heat exchanger for domestic hot water.

Primary cooling will be provided by cross-ventilation and stack ventilation using operable skylights. Supplemental cooling will be provided by a chilled slab using an air-to-water heat pump coupled to a hydronic cooling loop.

4.5.2 Physical Mockup

While the MPP can create a tight thermal envelope, the performance of the windows is critical to overall energy efficiency. The team explored an alternate to costly triple-pane windows by employing a double-pane window coupled with a sliding shutter of twinwall polycarbonate, which would provide additional thermal insulation while allowing some light into the interior (versus a solid panel). The upper track for the shutter additionally conceals LED strip uplighting. The space between the lower track and the floor allows for a service chase running the width of the window wall to be used for electrical and other services without any penetrations or chases occurring through the MPP exterior wall panel.

An assembly detail prototyped with the mock-up had the window frame sit within the thickness of the MPP panel, including 51mm of MPP (R-value of 2.50) covering the window frame when viewed from the interior. The intent was to have the MPP serve as structure, finish material and frame insulation; thus, requiring no additional trim work or finish treatment (Figures 11, 12, 13).

The relatively thick outboard insulation with rainscreen and cladding at the exterior allows the window plane to be recessed providing some inherent exterior shading. A sheet metal window surround including a vertical mullion between the two windows adds some depth and improves shading performance while acting as window trim. The sheet metal work proved a complex process between model, fabrication, and installation. A number of interface issues will be able to be refined and improved based on mocking up this façade integrated element. Alternate materials (e.g., fiberglass, plate steel, wood) may also be pursued for constructability, cost, thermal and durability considerations.

The tolerance for a CNC-cut window opening was much tighter than that of a conventional light-wood-framed rough opening, where a process of shimming and squaring a window during installation requires extra space in the site-built structure. The precision fabrication possible on the CNC allowed for the rough opening in the MPP to be less than 2 mm larger than the window itself on each side, whereas window manufacturers require rough openings for conventional construction to be anywhere from 13 mm to 25 mm larger on each side. The tighter tolerance meant that the window was square as soon as it was placed in the opening and air sealing was more precise.

One benefit to panelized wall construction using MPP is a significant reduction in the possible locations for air infiltration to occur. With fasteners not penetrating the surface, potential infiltration locations are limited to panel-to-panel joints and panel penetrations like window openings. Furthermore, electrical outlets located on exterior walls are all surface mounted on the interior, thereby reducing the need to pay particular attention to outlet air sealing.

For performance testing, an enclosure was constructed and air sealed to the interior side of the mock-up for use of a blower door fan and instrumentation to positively pressurize the interior of the wall assembly. Smoke was introduced to the pressurized interior side of the mock-up at 30 Pascals and ramped to 62 Pascals while the exterior

https://doi.org/10.52202/069179-0484

was visually inspected for smoke leakage. Window penetrations were sealed with a liquid applied membrane (Soprema Sopraseal Liquid Flashing, SKU: A508). Minimal smoke leakage was observed around the window; the team plans to explore further sealing steps in the larger prototypes.

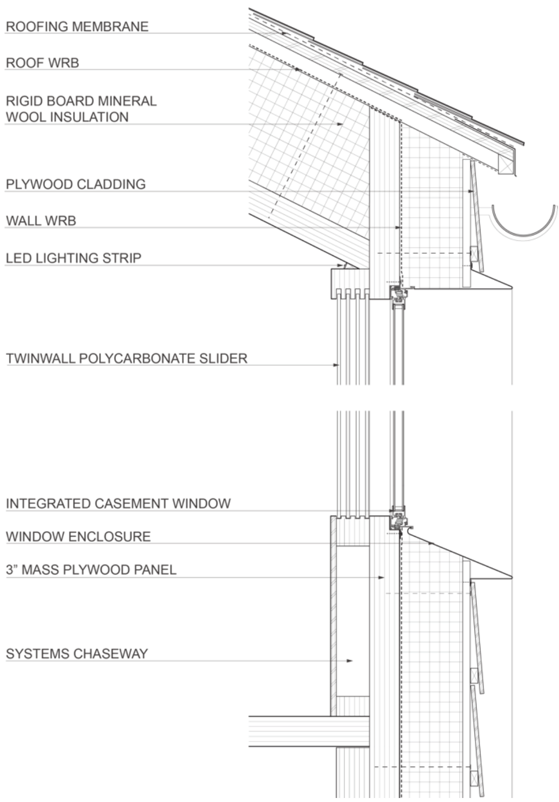

Figure 11: *Detail of window mockup showing wall and roof assemblies*

4.6 PROTOTYPES

The EDA BBRC award with BO match will allow the team to test and refine the design and construction methods of the MPP unit. The first prototype will be constructed in TDI's A. A. "Red" Emmerson Advanced Wood Prodcuts Lab, using the strong floor and wall to conduct structural tests of the MPP building envelope, which will be required by building departments in local jurisdictions in order for permits to be issued. This prototype will also entail fabrication of the MPP panels with insulation and cladding, iterative assembly and evaluation of details, including window assembly, panel connections, and electrical, mechanical, and plumbing systems integration. Following the documentation and disassembly of the first prototype, a contractor will be employed to fabricate and construct a second prototype in the Emmerson Lab's exterior yard. This will test construction means and methods, including evaluation of shipping efficiency and field assembly, and include documentation of costing of materials and labor. The team will test the performance of the design, including

Figure 12: *Window mockup*

Figure 13: *Window Mockup Thermal Performancem, False Color Infrared Image*

confirmation of energy modeling by measuring envelope infiltration, and acoustic testing, followed by documentation and disassembly. Documentation will include data collection and fabrication- and construction-

https://doi.org/10.52202/069179-0484

ready documents, including digital files. Prototyping is scheduled to begin in June 2023.

5 CONCLUSIONS

The success of this project depends on the efficient utilization of the MPP panels, including digital fabrication workflows, reduction in finish materials, the capacity to offset small cost increases above light-wood-frame with more efficient energy performance, and their affordability to the workforce market (those earning 80-100% of the area median income). The preliminary costing model indicates that this is achievable, but the prototyping of the project will be able to provide proof of concept for the open-source documents that will be available for construction on multiple sites in Oregon.

ACKNOWLEDGEMENT

The authors wish to acknowledge the contributions of Swinerton Builders and the support of the TallWood Design Institute for this work. Funding was also provided by HomeWork Development and Shortstack LLC via subaward from two U.S. Forest Service Wood Innovation Grants, “Milwaukie Courtyard Housing Project,” Grant # 22DG11062765744, and “Shortstack Housing Mass Timber Platform to Develop Prototype Replicable Affordable Housing,” Grant #21DG11062765738, and a fellowship from the Energy Trust of Oregon, Contract #3431. Additional funding was provided by a subaward from the Port from the EDA BBBRC Phase 1, “Build Back Better with Mass Timber,” Grant #ED22HDQ3070069. The prototyping is funded by the EDA BBBRC “Mass Timber Prefabricated Panels for Affordable Housing Prototypes,” Grant # 07-79-07906, and by Business Oregon’s University Innovation Research Fund, Contract # C2022840.

REFERENCES

[1] Daniels J. M., Wendel K.: Production, Prices, Employment, and Trade in Northwest Forest Industries: 1958-2019. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2020.

[2] Bosworth D., and Brown H.: After the timber wars: community-based stewardship. *Journal of Forestry*, v.105 no. 5 271-273, 2007.

[3] Stephens S. C., Battaglia M. A., Churchill D. J., Collins B. M., Coppoletta M., Hoffman C. M., Lydersen J. M., North M. P., Parsons R. A., Ritter S. M., and Stevens J. T., Forest Restoration and Fuels Reduction: Convergent or Divergent?, *BioScience,* Volume 71, Issue 1, 85–101, January 2021.

[4] Mishra, A., Humpenöder, F., Churkina, G. Reyer C. P. O., Beier F., Bodirsky B. L., Schellnhuber H. J., Lotze-Campe H., and Popp A.: Land use change and carbon emissions of a transformation to timber cities. *Nat Commun* **13**, 4889, 2022.

[5] Oregon Housing and Community Services: Building on New Ground: Meeting Oregon's Housing Need, February 2021.

[6] Freres Engineered Wood: MPP Mass Plywood Panels by Freres Lumber Co., Design and Construction Guide. Lyons, Oregon, 2021.

[7] Puettman, M., Sinha, A.: Life Cycle Assessment of Mass Ply Panels Produced in Oregon, November 2020.

[8] City of Milwaukie: Milwaukie Cottage Cluster Analysis, June 2019.

[9] McKinsey Global Institute: Reinventing Construction: A Route To Higher Productivity, 2017.

[10] ANSI/AWC 2021 *Special Design Provisions for Wind and Seismic (SDPWS)* Appendix B3.1

https://doi.org/10.52202/069179-0484