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Advancing Timber for the Future Built Environment

RE-USE OF MASS TIMBER: A CASE STUDY

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ABSTRACT: The American Institute of Architects'(AIA) Materials Pledge calls for the preferential use of building products that reduce carbon emissions by sequestering carbon and support a circular economy by designing for resiliency, adaptability, disassembly, and reuse with zero-waste. Life cycle analysis (LCA) demonstrates that timber-based materials, including mass timber, store carbon and have a smaller carbon footprint than reinforced concrete or steel; however, few case studies exist on the reuse of mass timber. This paper documents the reuse potential of mass timber using a three-story mass timber structural test specimen that employed a variety of approaches to lateral force-resisting systems using vertical splines. The project utilized mass ply panels (MPP) in floor and wall elements, LVL beams and columns, and steel connections. Working with engineering and architecture faculty, an architecture graduate student catalogued the mass timber elements projected to be undamaged after testing and removing connections, along with the reusable steel connections. This catalogue was shared with design professionals to find a suitable project for the material reuse. An architecture firm took up this challenge, and a majority of the mass ply panels were refabricated for installation as non-structural elements in an adaptive reuse of an existing building.

KEYWORDS: mass timber, re-use, circularity, embodied carbon

1 – INTRODUCTION

The American Institute of Architects (AIA) Materials Pledge [1] calls for designers and design firms to voluntarily pledge to specify building products that conform to five sustainability pillars: climate, ecology, health, social equity, and circularity. Environmental impact assessments demonstrate that timber-based materials store sequestered atmospheric carbon and can have a smaller carbon footprint than reinforced concrete or steel [2]. However, few case studies exist on the reuse of mass timber products, which would extend the duration of their stored carbon and decrease their global warming potential, since few buildings using mass timber structural systems have yet reached their end-of-service. Thus, the deconstruction of short-lived testing projects presents an opportunity to explore possible reuse scenarios and functional challenges. One previous study examined the reuse of cross-laminated timber (CLT) that was disassembled from a structure tested at the Japanese E-Defense shake-table facility and redeployed in the construction of a new café in Kobe, Japan [3]. While significant challenges encountered in reusing the material were discussed, a life-cycle analysis (LCA) indicated that this reuse decreased the global warming potential (GWP) of the panels. More recently, an LCA was performed for a ten- and six-story shake table structure tested in San Diego, California, although the material has not yet resulted in an application [4]. Although these case studies represent only a small sample set of mass timber buildings, they establish actual field data for LCA calculations using mass timber projects. They represent a step towards more accurate end-of-life models for mass timber since the current inputs in LCA calculations for timber reuse are based on lightwood-frame construction reuse models,

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which do not represent the unique challenges and opportunities for mass timber end-of-life reuse [5,6,7,8].

2 – BACKGROUND

Design professionals are exploring ways to create a circular economy with building materials by basing initial design decisions on future material reuse opportunities. Mass timber's future reuse depends on multiple market and technological conditions, many of which are yet unknown; however, the opportunity to design buildings for ease of disassembly and material recovery must occur many decades in advance. Therefore, questions that are currently prevalent in the design community include: should composite assemblies be employed; how much material is recoverable based on connection design; what percentage of material is lost due to refabrication operations; how are materials regraded; and what are the functional logistics of transferring material from recovery to new projects? The answers to these questions will not only impact design decisions; they will also better inform LCA outputs for mass timber.

An opportunity to explore mass timber reuse potential in Oregon was presented by a mass timber testing project at Oregon State University (OSU) that occurred during 2021-2023; "Innovative Lateral Systems for Mass Timber Products," tested innovative lateral force resisting systems (LFRS) comprised of newer mass timber products and different energy dissipation mechanisms in a three-story structure [9,10,11]. These LFRS represent a suite of resilient design techniques that can localize damage in special hardware designed to dissipate energy during an earthquake or similar disturbance. The project was designed to demonstrate that applications of these systems would produce a building that is potentially more resilient to natural disasters than conventional construction.

The three-story project was built and tested in the TallWood Design Institute's (TDI) A.A. "Red" Emmerson Advanced Wood Products Laboratory (Emmerson) at OSU's College of Forestry. The TallWood Design Institute is a collaboration between OSU's Colleges of Forestry and Engineering and the University of Oregon's (UO) College of Design focused on advancing engineered wood products in support of economic development and environmental stewardship in Oregon. The LFRS project was one of the first to use the Emmerson Lab's strong floor and wall and was named the Emmerson Lab Launch Initiative (ELLI). See Fig. 1.

In the ELLI, systems were constructed and tested in a three-story, 40'X40′ (12.2m x 12.2 m), mass timber structure comprised of Freres Engineered Wood mass ply panel (MPP) floor diaphragms and shear walls, Boise Cascade laminated veneer lumber (LVL) columns and beams, and Simpson StrongTie connectors. The structure was tested and augmented in multiple phases, each phase utilizing a different LFRS in terms of design and materials.

Phase 1: involved testing of a seismic-force resisting system including a hybrid MPP "spine" with two steel buckling-restrained braces (BRBs) attached to the first-story wall ends as hold-downs. For this phase, the MPP spine was conceived as a pivoting wall, with a plate support located at the base midpoint to allow the wall to jointly pivot and move upward. Shear transfer to the foundation was ensured using two stiff steel shear key assemblies, designed to prevent in-plane sliding and out-of-plane displacements. These base conditions mimicked a compression-only pin support, with the BRBs resisting the base moment and the MPP wall resisting the story shear [10,11].

Phase 2: involved testing a LFRS of 30-foot (9.1m) balloon-type "spine" shear wall made from a MPP. The MPP shear wall was combined with four external post-tensioned high-strength rods to provide the self-centering capacity through rocking. The shear wall was connected at each side of the wall to steel columns and U-shaped flexural plates (UFPs), which help dissipate energy during a seismic event. The displacement- and performance-based seismic design procedures were utilized for the design of the LFRS [9,12].

Phase 3: involved testing a system similar to Phase 2 but with a coupled shear wall system involving two Veneer Laminated Timber (VLT) panels and UFPs placed between them throughout the length of the wall. The coupled shear wall was post-tensioned using high-strength steel rods to impart self-centering attributes. [13,14].

The engineering design team for the ELLI projected that the MPP floor diaphragms and the LVL columns and beams would remain substantially undamaged after the series of tests, raising the question of their disposition after decommissioning and deconstruction of the lab specimen. With the example of CLT reuse recovered from a seismic test in Japan and reused in the construction of a café [3], it seemed logical to explore the reuse of material from the ELLI in which considerably more mass timber material would be available. Additionally, while the CLT from the

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Figure 1. Emmerson Lab Launch Initiative project

test project in Japan had been stored in a warehouse before reuse, resulting in some deterioration, there was an opportunity to plan for reuse that would avoid that potential problem.

3 – PROJECT DESCRIPTION

In 2021-2022, a UO Architecture student, Amanda Stanton, analysed the reuse potential of the ELLI for her Master of Science terminal project (note: a terminal project is similar to a thesis, but includes creative design elements along with research) [15], with a committee that included OSU engineering faculty leading the OSU ELLI and UO Architecture faculty. The terminal project, initiated in October 2021 and completed in June 2022, began with the construction of a detailed Revit model of the ELLI that included all timber elements and incorporated all steel elements (which had not been included in the engineer's less detailed Revit model). This new model allowed a detailed cataloguing of the MPP floor diaphragms, the LVL columns and beams, and the steel connections. It further allowed a projection of which sections of MPP would be suitable for reuse after the larger steel connections and fasteners were removed, which would leave holes compromising those sections. Using the new model, Stanton created a catalogue of MPP panels and steel connectors that would be available for a new application. To show the variety of ways the large 178 mm MPP floor panels might be used, the panels were converted to several standard sizes of LVL beam elements, with diagrams showing how many beams of which sizes could be created. This catalogue was created in winter term 2022, before Freres Engineered Wood produced their catalogue of their mass ply beams and columns, so Boise Cascade LVL beams were used to determine beam sizes. This catalogue became a "bill of materials" that could be used as outreach to possible clients for reuse applications (Fig. 2).

During spring term 2022, as part of the terminal project, designs were suggested that made use of some of the materials in the catalogue. One project proposed by OSU faculty, a long-span roof to cover a storage yard at a lab near Emmerson, was determined to be infeasible due to material limitations and potential cost. As Emmerson needed a storage shed, this was evaluated as a more realistic approach project and Stanton created a design that included reuse of a small portion of the MPP, LVL and steel connections (Fig. 3). During the same time, a non-profit organization in Corvallis, Oregon where OSU is located, expressed interest in using the ELLI materials for a three-story affordable housing project (made more affordable by reusing the material). However, a significant barrier emerged to any of the projected uses: the lack of a structural re-certification process and standards for used mass timber elements, making it unlikely that a building department would issue a permit to reuse the timber components structurally in a new three-story structure or even in a single-story one, such as the storage shed.

In the fall of 2022, a search began for possible non-structural reuse of the ELLI material. TDI hosts an annual research symposium in which faculty present recent projects to industry professionals in the architecture, engineering, construction (AEC) and manufacturing mass timber community along with academics. The ELLI project was presented along with the catalogue or "bill of materials" accompanied by an announcement that TDI was looking for applications of these materials in a non-structural capacity. LEVER Architecture, a member in TDI's industry research consortium, started to consider the potential for reuse of these materials in one of their projects. LEVER had recently received the commission for a renovation of an existing building for the new home for the UO Architecture Department on their newly acquired campus in Portland, Oregon (while the UO is based in Eugene, Oregon, several departments have a second location in Portland, and these were moving to a new campus recently purchased from a university that had closed). This new project, Highland Hall, was in early design stages, and the firm saw an opportunity for reusing the materials in that project, in non-structural applications, such as low pony walls, entry portals and defining volumes for seminar/conference rooms within the larger space. Discussions were begun with TDI in winter 2023 and by spring 2023, LEVER had produced 3D files for Highland Hall mass timber reuse components based on the dimensions and quantities of materials available in the ELLI catalogue (Fig. 4). In the summer of 2023, the ELLI

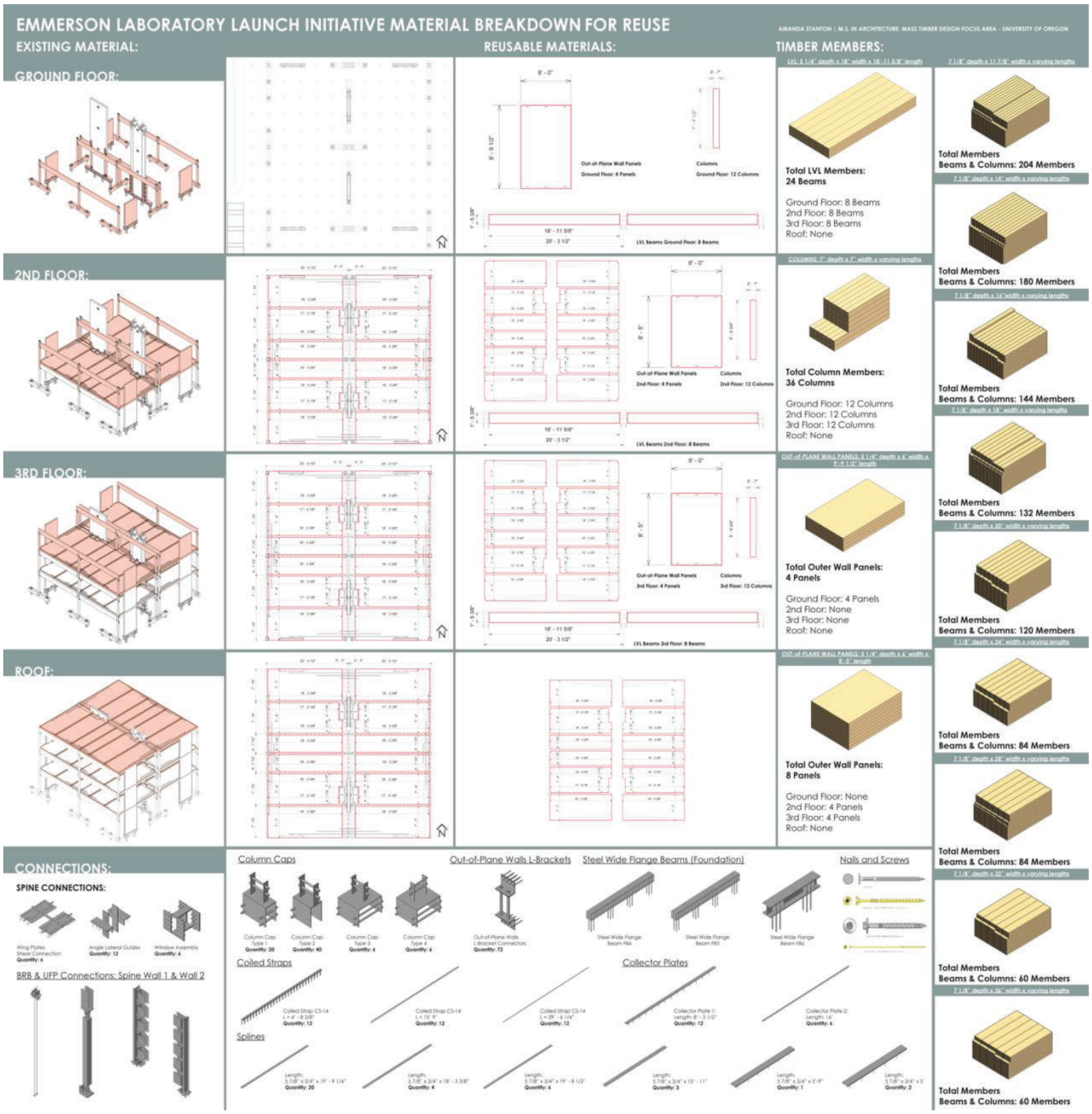

Figure 2. ELLI Catalogue: Bill of Materials. Image credit: Amanda Stanton

was deconstructed. TDI staff translated the LEVER 3D elements to machine language for the Biesse CNC (Fig. 5) and performed the refabrication over a 10-week period in summer and early fall 2023 Due to a long delay in building permitting, the reused panels had to be transported to a warehouse for interim storage rather than directly to the Highland Hall project site; fortunately, this storage did not result in any damage to the panels. The reused panels were installed in the project in spring/summer 2024, so that the project was ready for occupancy in late September 2024 (Fig. 6).

4 – DESIGN PROCESS

This project required significant collaboration, contributions by several key individuals, and the coincidence that the UO was designing a new architecture facility and the design firm leading the renovation was a member of TallWood's industry consortium. Faculty and industry members associated with TDI were key to realizing the project by connecting multiple stakeholders and advocating for material reuse. In the winter of 2023, Thomas Robinson, founder and principal of LEVER Architecture, was lecturing in a UO Architecture class taught by Professor Judith Sheine, the MS terminal project committee chair, who is also the Director of Design for TDI. After the class, Robinson expressed interest in

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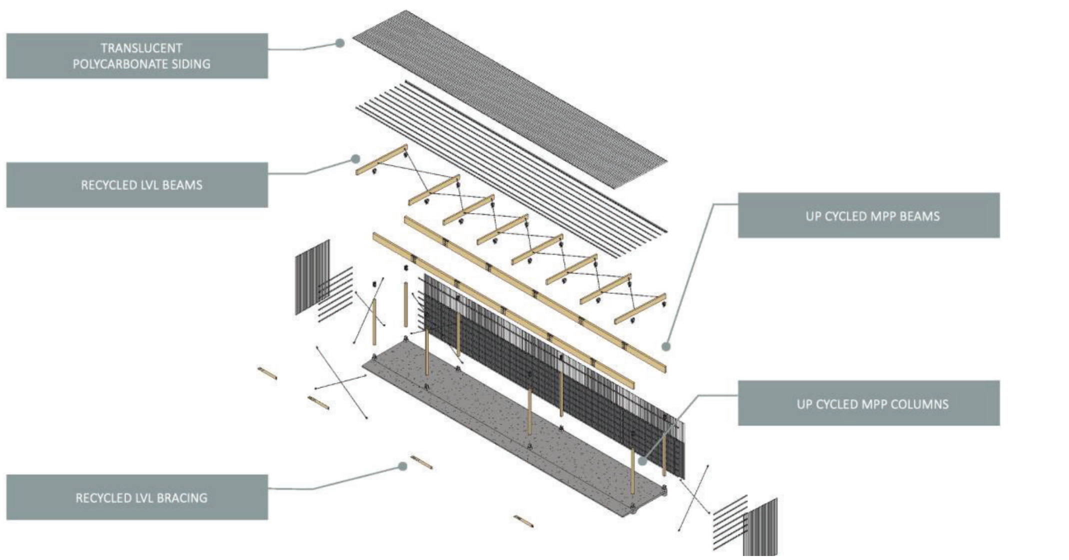

Figure 3. Shed design with reused ELLI materials. Image credit: Amanda Stanton

reusing the ELLI material in the Highland Hall project; however, the UO budget did not provide for the cost of the CNC refabrication the panels would require. Sheine discussed this with Iain Macdonald, TDI Director, and due to the connection of the project to the UO Department of Architecture, the Directors agreed to have TDI staff perform the refabrication of the panels for the project on the Biesse CNC in the Emmerson Lab without charge as it represented a further collaboration of the UO and OSU Colleges. This agreement eliminated the considerable expense of refabrication and made the project feasible.

Several other special steps had to be taken to make the project work. In most projects, the architecture team does not produce detailed 3D files for fabrication; this work is generally outside their scope. However, the Revit model and catalogue of the ELLI made it possible for the architecture team to produce those files. The UO Capital Projects team (client), and Howard S. Wright Construction (contractor) all had to cooperate in this unusual addition to the project; fortunately, all were enthusiastic. The contractor had to take on the extra expense of transporting the MPP material first to a warehouse and then to the project site and coordinating with the UO and LEVER teams on the installation method in a renovated building with restrictions due to existing entry door sizes. The MPP material, which might have been considered too industrial for many projects, with many visible marks from the ELLI assembly and disassembly processes, was ideal for the architecture department as a client; both the faculty and students had significant interest in the potential of mass timber's design for disassembly and reuse, as sustainable design has been the department's defining mission for nearly six decades. The panels were installed in a nearly "as is" condition with only a whitewash finish (Sansin White), to aid in light reflection in the space (Fig. 6).

5 – RESULTS

The project successfully demonstrated a path for reuse of mass timber. It utilized 34 of the 36 MPP floor slabs, a significant diversion from possible landfill. However, a full LCA of the end-of life scenario would need to be performed, which would include reprocessing, transportation to an interim storage facility, transportation to the project site, and installation, to determine if this reuse actually constituted a reduction in GHG emissions over landfill or energy recovery pathways.

A master's student in OSU's School of Mechanical, Industrial, and Manufacturing Engineering, David A. Brown, working with his faculty advisor Professor Karl R. Haapala, performed an LCA analysis for the ELLI project reuse at Highland Hall for his master's thesis [16]. He compared the GWP for the reuse of the MPP with light-gauge steel framing and gypsum board, which comprise a typical assembly of the materials used for non-structural partitions in commercial and institutional settings. Brown used an open loop cut-off method for end-of-life method for the LCA for the MPP panels, as they had already been manufactured, or a "gate to grave" approach, while the gypsum board partitions were analysed with a "cradle to grave" approach. For the MPP, Brown included electricity used in refabrication and fuel used in transportation and

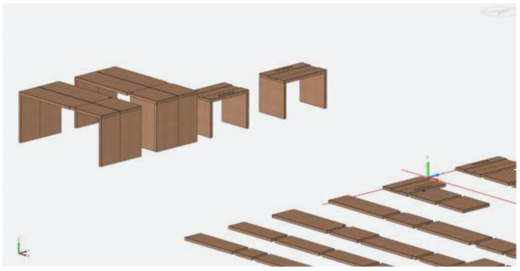

Figure 4. 3D model files from LEVER

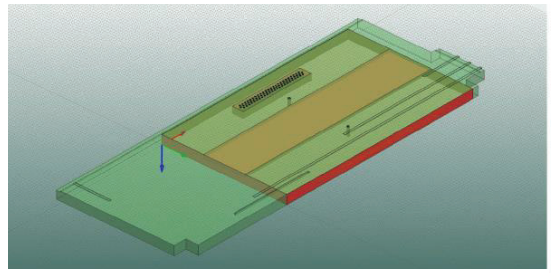

Figure 5. Diagram of panel refabricated from ELLI showing sections impacted by steel connections. Image:Mark Gerig

construction in Highland Hall. He found that "the remanufactured MPP partitions feature lower environmental impacts than the gypsum board partitions in this case, including a 65% reduction in global warming potential, a 58% reduction in acidification, and a 27% reduction in smog." However, since the "gate to grave" analysis did not include a consideration of the biogenic carbon in the MPP, Brown found that if that was considered, the MPP reuse would represent "a 704% reduction in global warming potential compared to the gypsum board partitions." Thus, this LCA study validated that the reuse of mass timber has significant potential to reduce GWP – even with the inputs of a refabrication process.

6 – CONCLUSIONS

With the collaboration of all parties – OSU and UO faculty, TDI, LEVER, UO Capital projects, Howard S. Wright – the decommissioned and deconstructed MPP from a three-story test specimen found reuse in an architecture studio in a renovated building. However, this reuse opportunity was only made possible by the close collaboration of OSU engineering and UO architecture faculty and students, the availability of the TDI industry network, the fortunate timing of one industry collaborator that was inspired by the MPP reuse potential and had an available project in the right (early) stage of design that could incorporate the MPP in a non-structural application, and was willing to go beyond the scope of normal design services, and TDI having the capacity to refabricate the test specimen panels on the CNC in the same facility as the ELLI project and the willingness to contribute the staff time and use of the CNC. Considerable goodwill and personal relationships were leveraged to make the material reuse possible, as it would not have otherwise been economically viable to accomplish the project.

As Brown noted in his study, reuse projects need to consider the potential costs and carbon footprints of refabrication, storage, and transport [16]. In this case, the cost of refabrication was assumed as part of the research unlikely to be the case, and cost could be a significant factor in determining feasibility. As this testing project did not have any composite assemblies, architectural finishes or equipment, it was far more straightforward to carry out reuse than for an occupied building with significantly more complex issues to consider. A testing project is by its nature designed for deconstruction because it is temporary, but buildings intended to be permanent would likely encounter challenges beyond deconstructing the structural system.

Given the size and potential structural capacity of the MPP, finding structural applications would have been more desirable. While this project was successfully concluded, it revealed the need to establish a structural re-certification process for mass timber panels, beams, and columns – preferably via non-destructive testing. In addition, Stanton noted in her terminal project that the MPP floor panels were not manufactured for use as beams and would have to be very carefully evaluated for subdivision to avoid edge conditions in which small pieces of laminates would be subject to delamination [15], an issue addressed in the manufacture of mass ply specifically designed for use as beams and columns by Freres Engineered Wood.

Complex collaboration, costs of refabrication, transportation, intermediate storage, disassembly of composite elements and removal of finishes, and structural re-certification are all issues that need to be considered carefully in circular design and are all topics for future research as mass timber buildings age. While it is possible to reuse mass timber panels in new construction projects, future research is still required to better inform cost and LCA models to support wider adoption in the design and construction communities.

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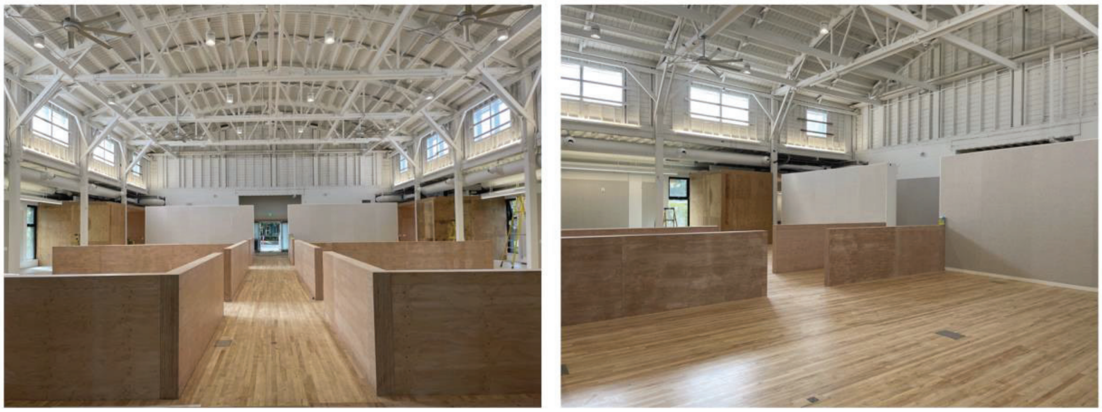

Fig. 6. Highland Hall with reused MPP from ELLI. Photographs: LEVER Architecture

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