

PDX Airport: 9-acre Mass Timber Roof

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1. Project Overview

The Terminal Core Redevelopment (TCORE) project at Portland International Airport (PDX) expands and modernizes the existing terminal core to meet current and future capacity needs. The project includes a mass timber and wood roof and is expected to cost about USD \$2.15 billion



Figure 1: TCORE existing and new main terminal

The new design of the Portland International Airport draws on inspiration from the Pacific Northwest landscapes. The new main terminal was designed to feel like a walk through the forest.



Figure 2: Ticket lobby rendering

The centerpiece of the PDX Terminal Core Redevelopment is a 400,000 square foot timber roof that pays homage to Oregon's rich natural beauty while also highlighting its growing wood innovation sector. The lush biophilic design provides travellers with a deep connection to the forests of the Pacific Northwest.

The roof is comprised of approximately 3.3 million board feet of Douglas Fir, and features 277 80-ft glulam beams with the deepest being 9-ft and the largest single span arch being 16-ft. They are supported by large 20-ft wide x 40-ft long steel girders spaced every 100-ft on center with bucket connections for the glulam, spaced every 10-ft. The deck on top is made of 1347 2-inch mass plywood panels (MPP), serving as the roof diaphragm.

The result is a roof with rising arches and undulating edges that form domes and vaults. There are 49 large glulam framed skylights with MPP curbs. There are nearly 40,000 individually crafted sticks of 3x6 lattice on the underside of the glulam beams spaced every 1-ft on center.

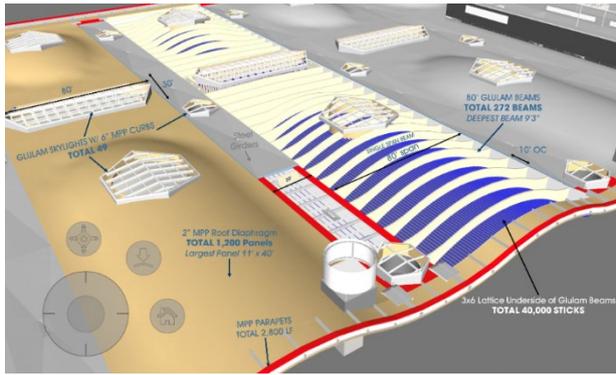


Figure 3: Rendering of roof layers

To avoid disruption to the traveling public, the new roof was built a half-mile away from the existing airport terminal at a prefabrication yard setup on the airfield. The roof will then be disassembled in 100x240 modules and assembled above the existing roof in segments.



Figure 4: A new roof is assembled on the airfield, secure side, nearly a mile away from the existing airport terminal

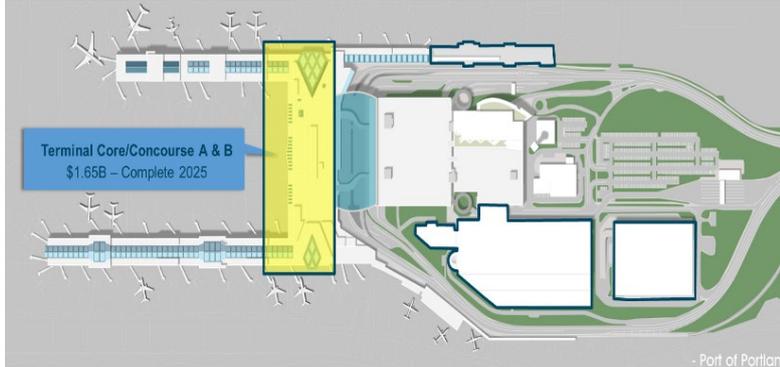
Sourcing timber has significant purpose to this project. The timber used on this project was sourced from a diverse array of local landowners and Pacific Northwest tribes across the region within 300 miles of the Airport.



Figure 5: Timber Procurement – Regional and Local Forests and Makers

2. Design

A stunning wood roof greets visitors upon arrival and celebrates the state’s history of forest product innovation with wood locally sourced from landowners and mills within a 300-mile radius. The undulating mass plywood and glulam canopy is penetrated by skylights under 34 Y-shaped columns which hold the 18-million-lb, 400,000-sq-ft roof in place. [ZGF]



The project includes everything from remaking back-of-house operations to a completely new layout for ticketing and the lobby, but it’s the new roof that will lead everyone to look up, literally. The new roof is centred over the main terminal core that will double in size compared to the existing footprint.

Figure 6: Portland Airport – Terminal Core Redevelopment Project

The complete T-Core redevelopment eliminates eight buildings that had been stitched together since 1954 to create the existing floorplate. Instead of the current 200 columns in a seismically vulnerable design, the design uses only 34 columns—half of them new and half that use existing footings—to hold the 18-million-lb, 380,000-sq-ft roof while opening 100-ft by 125-ft bays between the columns to create more operational flexibility. [ENR]

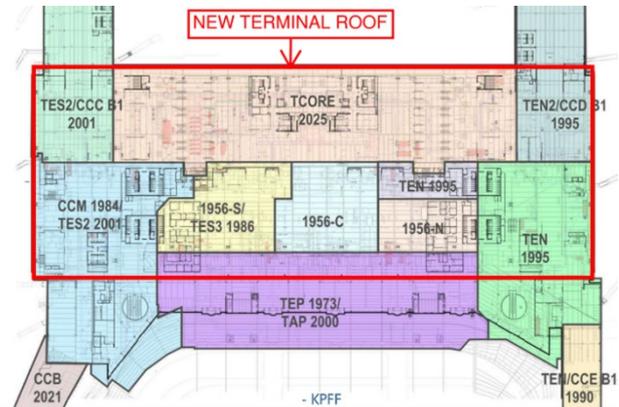


Figure 7: A terminal of past terminals

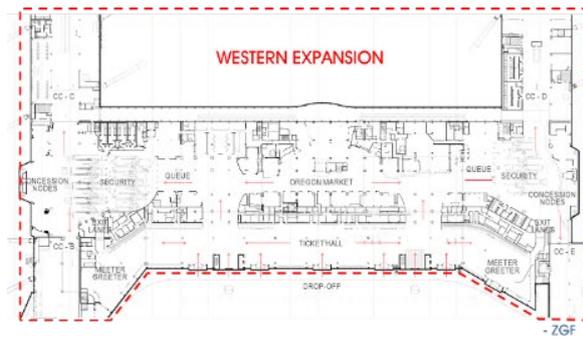


Figure 8: Existing Terminal Footprint (Left), New Terminal Footprint (Right)

The roof is not only visually unique, but also seismically different because it will be completely isolated from the existing structures below.

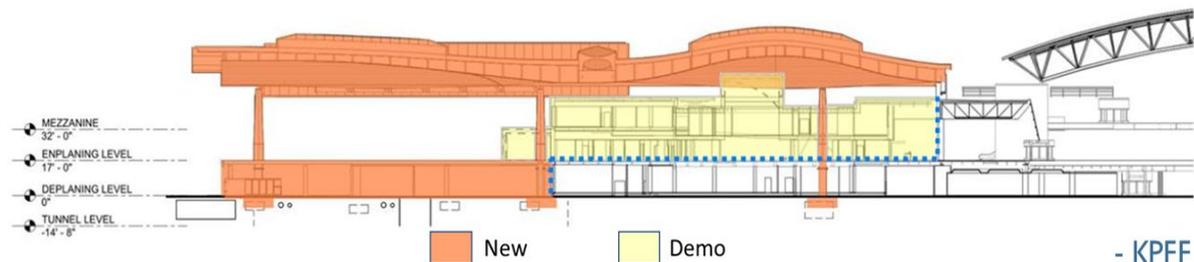


Figure 9: The new seismically isolated roof structure over the existing

The design was developed with the strategy to modularize sections of the roof to launch into place over the existing airport.



Figure 10: Modular concept: girders as «rails» infill cassettes

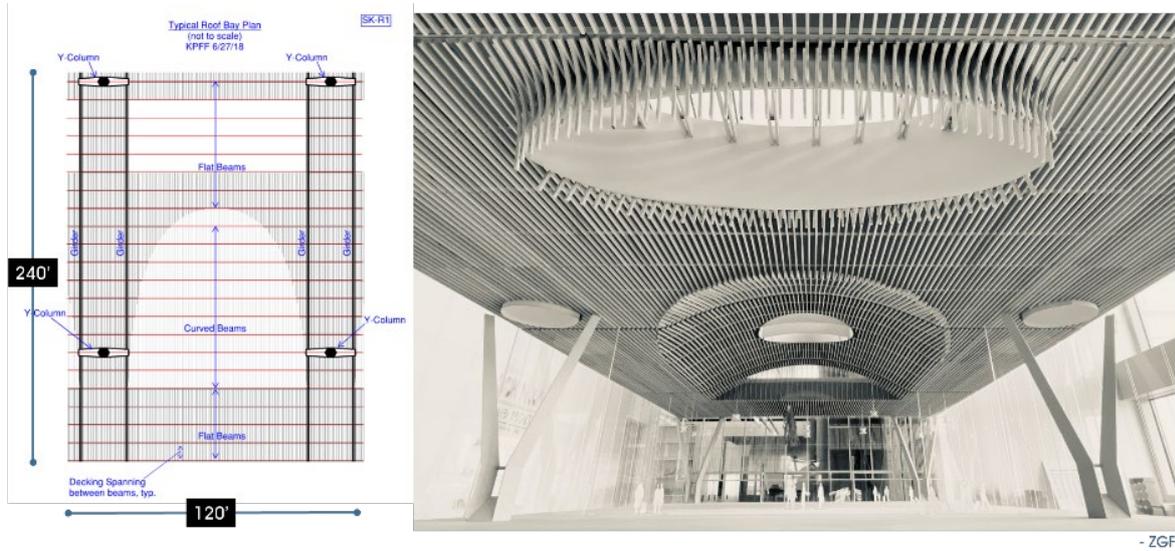


Figure 11: Kit of parts: girders + cassettes

To modularize the roof, the design developed into a kit of parts comprised of steel girders every 100' on center with 80' glulam beams spanning girder to girder. The final cassettes are sized as large as 120-ft wide and 240-ft long and weigh more than a million lbs.

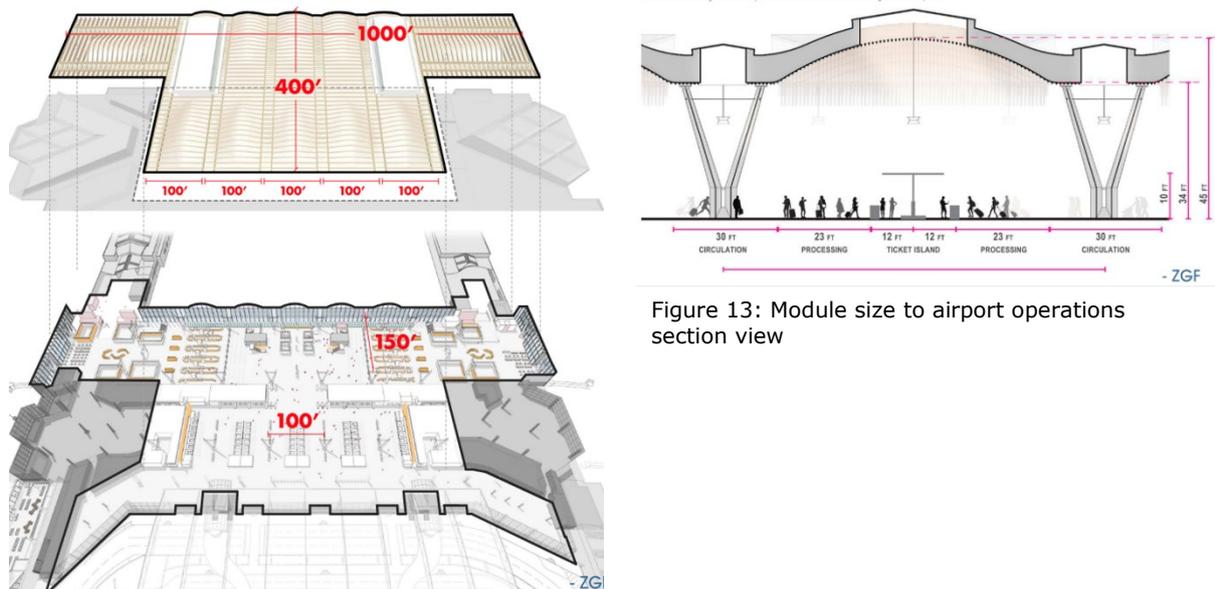


Figure 12: Module size to airport operations bird's eye view

Figure 13: Module size to airport operations section view

3. Engineering

3.1. Prefab to Modular

The roof was designed so that it could be built off site, within the secure side of the airport, nearly a mile north of the terminal. Then broken into large modules and transported to the terminal where they would be slid into place resting on Y-columns with seismic isolators. The engineering around the modularization drove the glulam connection design to allow for portions of the roof to be completely unbolted from the main girders, and to rest on the temporary transport girders.



Figure 14: Drawer cassette unbolted from the main roof girders prior to transport.

The roof modules were then transported on SPMT's (Self propelled modular transport), from the prefabrication yard to their final position over the terminal, where they were slid into place. They moved at a walking pace

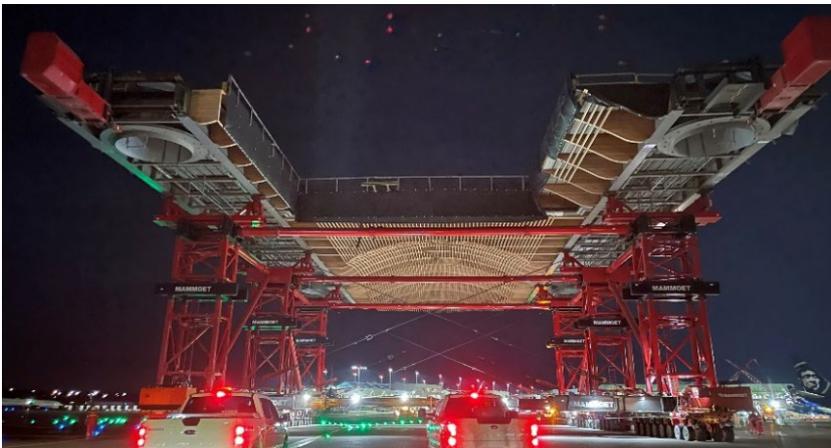


Figure 15: The 1st Mega Cassette transported from the prefabrication yard to the terminal - Aug 25, 2022

3.2. Seismic Resilience

The engineering of the primary column connection to the roof allows the roof to move up to 22 in. in any direction and the curtain wall system to move with it. To make it happen, the isolators were engineered to the top of the Y-columns. The curtain wall, which won't break during movement, has hinged connections so it can move with the roof, independent of the foundation. It took years to come up with a system that can handle the seismic requirements.

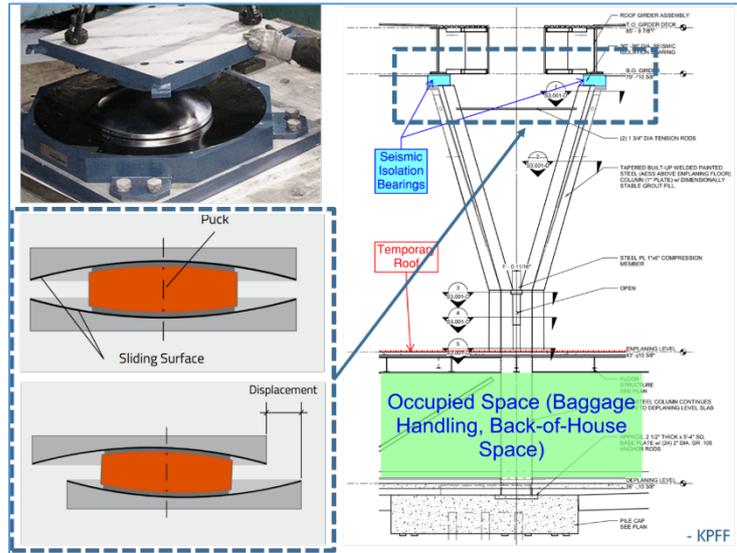


Figure 16: Y Column Seismic Isolators



Figure 17: Y Column Seismic Isolators

3.3. Glulam End Tension/Moment Connections

There are two main types of glulam to girder connections, (1) welded connection and (2) bolted connection. Both are engineered as tension/moment connections. The connection types are driven by the modular plan to break apart the roof for transport from the pre-fabrication yard to the main terminal.

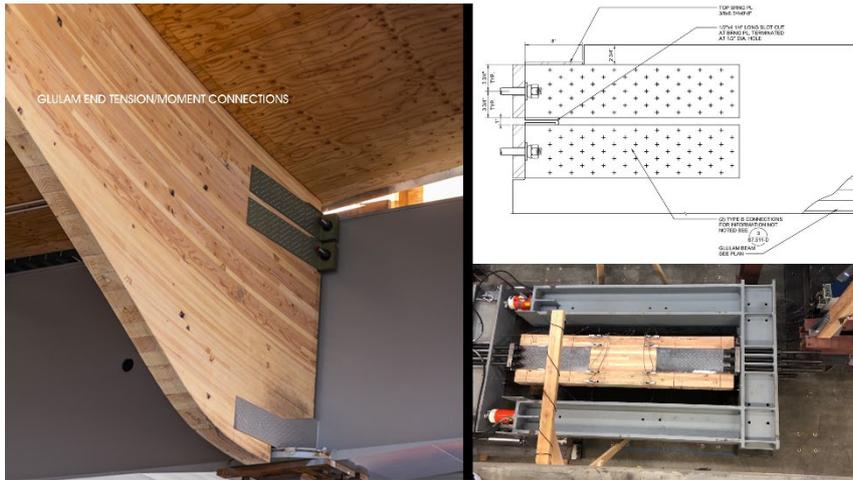
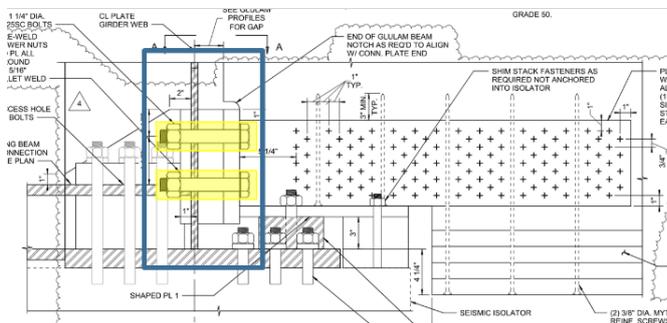
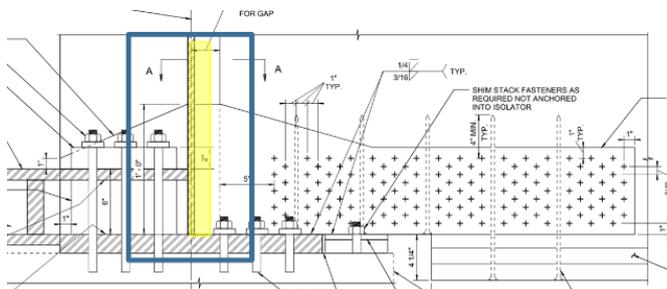


Figure 18: Glulam End Tensions/Moment Connection (Left and top right), Testing connection (Lower right).



The bolted connection is engineered for the roof's «Drawer» cassettes that would be unbolted and slid out like a drawer from the main girders during transport of the roof module, and then bolted back up to the girder once it was slid into place at the terminal side.

Figure 19: Bolted Connection at «Drawer» [KPFf]



The welded connection is engineered for the «Mega» cassettes that would transport the glulam intact with the girder(s).

Figure 20: Welded Connection at «Mega Cassette» [KPFf]

The connection evolved as the design team coordinated with the modularity puzzle.

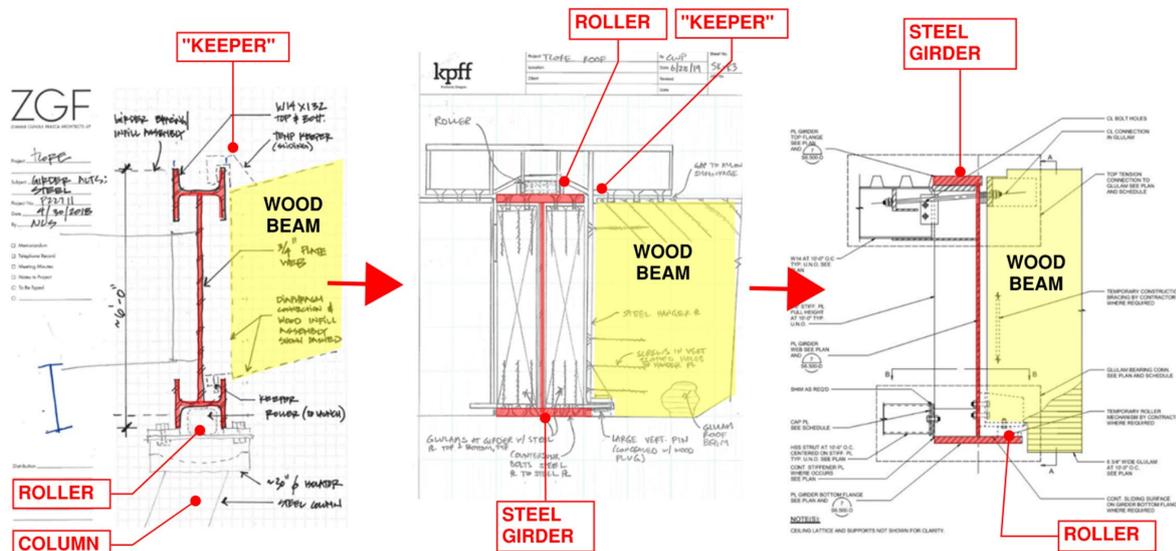


Figure 21: Evolution of the connection between girders and mass timber cassette to support modularity.

The module assembly of the overall roof is broken down into Mega cassettes and Drawer cassettes. The Mega cassette is a portion of the roof transported with girders and glulam intact. On the other hand, the Drawer cassettes separate the glulam from the main girders and are transported on temporary girders.

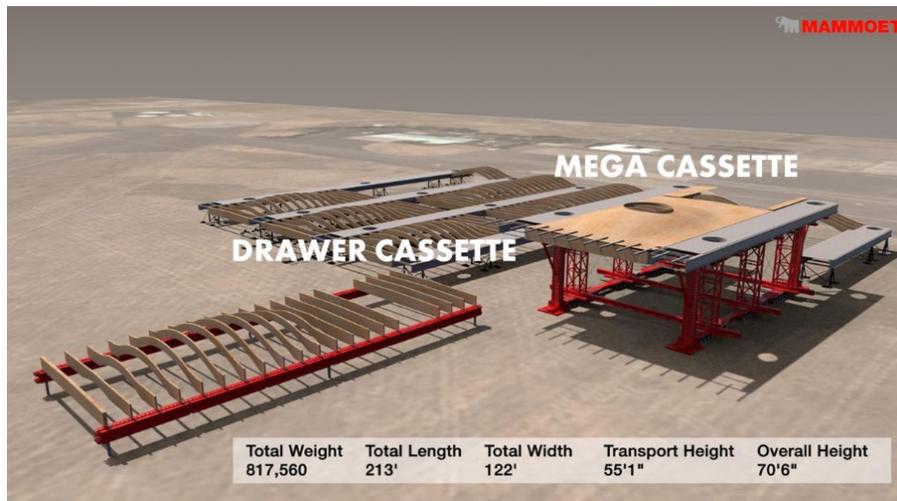


Figure 22: Roof Kit of Parts - Drawer Cassette and Mega Cassette [Mammoet]

The modular concept relies on the girders to serve as transport support rails. Overtime, the connections evolved into a bolted moment/tension connection. The final design uses the girder not only as the transport support rail supported by the SPMT's, but also uses the bottom flange as a roller track for the module to slide in and out of the overall roof.

3.4. Glulam Single Span Arch – No Splices

The glulam arches were initially designed as four separate glulam's spliced together with steel connections. This was based on initial feedback from manufacturers due to space and equipment limitations. It was through close partnerships and crucial collaboration to develop unconventional ways to overcome the limitation to produce hundreds of large-scale arched beams at a constant production pace for a year.

The result was not only a magnificent single span beam, but it brought ease to the assembly process and produced a shape that was consistently within the tight tolerance needed. The quality ensured the arched glulam beams, interfacing with the prefabricated individually shaped MPP panels on top of, and the lattice below, would precisely fit into place.

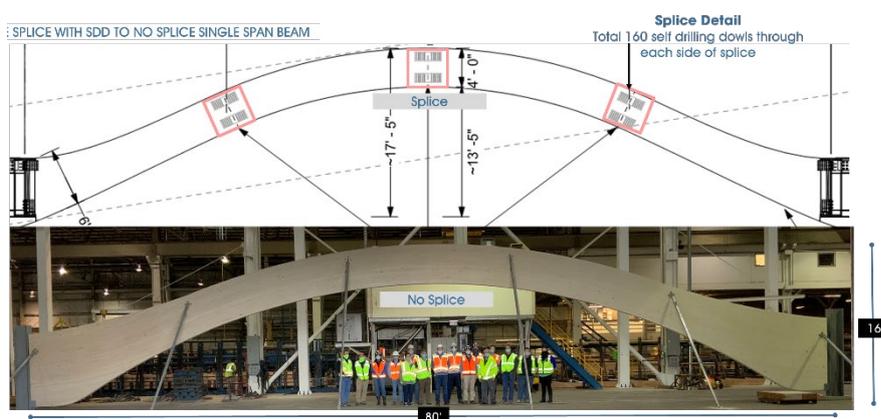


Figure 23: VE 3 splices to 0 splices as a single long span arched glulam

3.5. MPP Diaphragm

The use of MPP made it possible to efficiently shape the roof into the glulam structure. To ensure the mass plywood diaphragm could match the undulating geometry of the roof, there were full-scale mock-ups constructed to validated detailing assumptions to manufacture and fabricate accurate shapes.



Figure 24: Full size mock up a ¼ of a roof dome representing the most complex shapes for the MPP



Figure 25: View from on top the MPP Roof Vault with MPP Roof Domes ahead

4. Detailing

In addition, to keep the airport in operation, the roof had to be split into 15 modules, pre-installed at a lay-down yard and reassembled at the terminal within a limited time window (airport shutdown hours). Therefore, extensive Design for Manufacture and Assembly (DFMA) considerations have been applied to the project and multiple dynamic installation processes have been simulated from the digital twin in advance. [CadMakers]

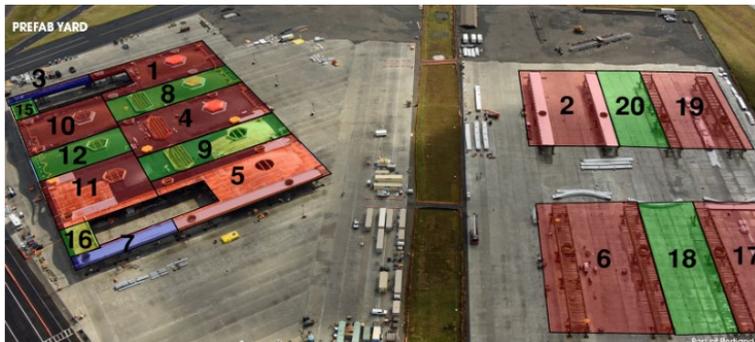


Figure 26: Prefabrication Yard – The order the modules will be removed and reinstalled over the terminal.

4.1. Curved Panels

The roof structure is a highly accurate master surface of the MPP panels following the 3-dimensional curvatures driven by the shape of the Glulam beams.

The MPP fabricator has to cut the panels flat, which means the curved roof panels had to be «flattened» into a developed shape during 3D modelling, to be fabricated and then fitted (bent) to the roof curvature during on-site construction. Studies and information on the curving of MPP panels are extremely limited.

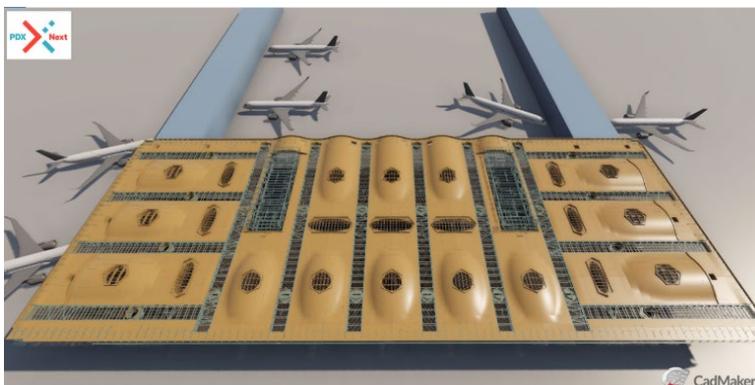


Figure 27: PDX Next Roof Structure – Birds Eye View

Several different modelling methods were used to develop the roof panels into a flat shape. Considering the potential deviation between model and reality. The process included co-ordination with the fabrication and installation teams to optimize and eliminate extreme curves and keep the material waste to a minimum.

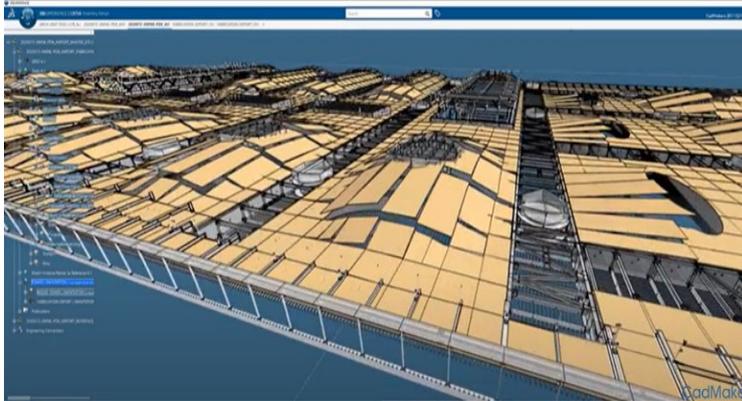


Figure 28: The curved roof panels «flattened» into a developed shape during 3D modelling.

4.2. Glulam

The glulam beams are connected to the steel frame structure which are directly supported by the main columns. The cambered beams are the main structural element that support the MPP roof panels, skylights and decorative lattice. The glulam beams have a span of 80 feet and a depth of 7.5 feet at the ends. Each beam is a continuous piece, meaning there is no splice, for aesthetic and structural reasons, which also reduces the cost of the steel hardware. In total, there are 837 glulam beams, 277 are 80-beams with 20+ different unique shapes (1684 elements).



Figure 29: Comparison Actual and 3D Model

Due to the physical properties and long span of the glulam beams, as well as the weight of the roof structure, the arch of the beam will deform slightly after being installed. As a result, each type of beam has a camber prescribed for manufacturing.

Both initial shape (for fabrication) and final installed shape (for coordination) were modelled. There was a lot of consideration needed for the pre-cambered shape, especially at the end-cut for steel bucket connections to the steel girders. The beams were then accurately manufactured and fabricated offsite, and then fitted into steel bucket end connections perfectly to have its live load start to deform to the post-camber shape. Then the MPP roof panels were installed, further adding to the post cambered shape.

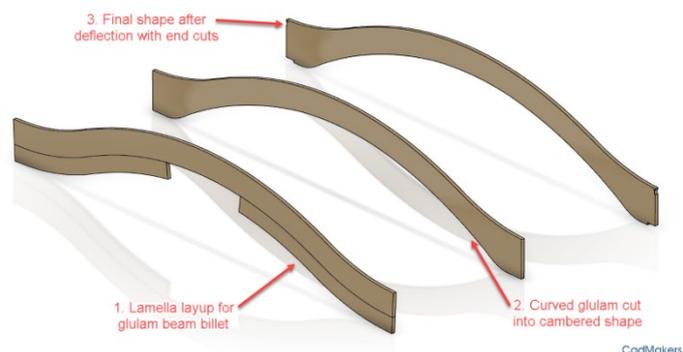


Figure 30: Development of the Glulam beam model



Figure 31: Underside of a roof dome

The wood beams and panels are closely related to the position of the steel. Regular coordination with the steel trade provided validation of all gap tolerances and potential clashes that are detectable only with a precise 3D model in such a variety of complicated situations. Coordinating with the steel 3D model helped identify constructability problems and coordinate the solutions before installation. [CadMakers]

4.3. Lattice

The nature of the lattice design following the dome shapes of the roof and its large quantities made it difficult for 2D design drawings to give the full picture. The challenge was finding all the unique conditions as they relate to each specific detail and then adapting to all the situations. To avoid any surprises and further comprehend the design intent, the strategy was to start from a virtual mock-up study with installation simulations.

The process helped identify numerous situations that were not captured in the drawing details. The findings ranged from the need to install screws at an angle with limited access for the tools (or use bevel washers) to the requirement of different angles of cross-bracing plates at each location to match the MPP roof curvature.

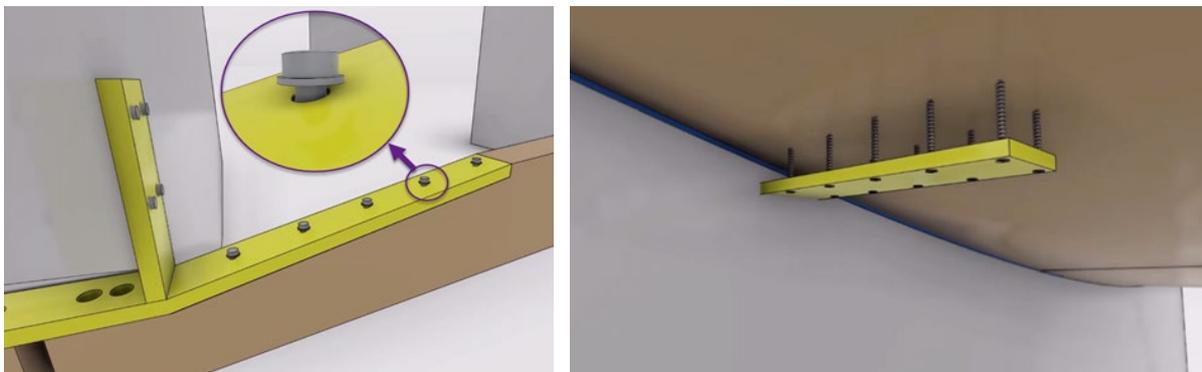


Figure 32: Installation Simulation for a virtual mock up to help identify install challenges during design stage.

The simulations were of a significant value to narrow down on-site conflicts by finding solutions prior to construction. It was greatly beneficial to the project to undergo the initial study showing what possible situations might occur was done early in the project.

Once the mock up process was complete, the integration of all the possible configurations and logics to the automation tools (30000+ lattices and countless unique situations) could be finalized. To save time and make deliverables ready ahead of deadlines, the team ran multiple computers in parallel to create critical geometry inputs (slope, start and end points), generate physical lattice, add fasteners/hardware and pre-drills, and create the cross-bracing steel all simultaneously.

4.4. Skylights

There are six types of skylights made of thousands of individual elements. The last piece of the puzzle on this project; the skylights geometry depends on the complex shapes of other structural elements (steel, glulam beams, MPP) of the roof. Installation Simulations were created for virtual mock-ups to help identify install challenges during de-sign stage.

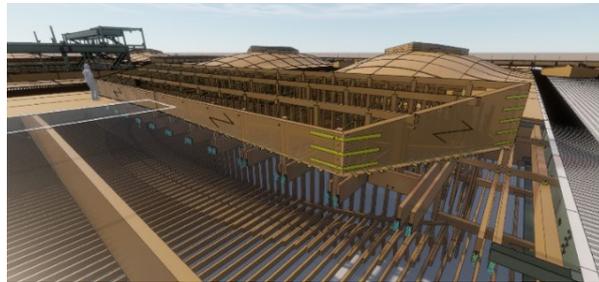
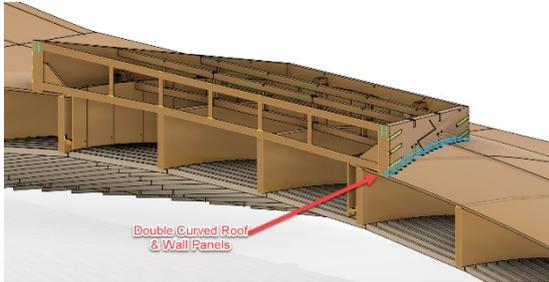


Figure 33: Installation Simulations of virtual mock ups



Figure 34: Access to the 3D model and installation animation of the complex sub-system via QR code

To facilitate the challenges faced by the team on site to install the complex skylights, there were high level of details (LOD) drawing sets created with QR codes that gave installers access to 3D models which included embedded installation animations.

Installation of the MPP panels at the skylight resulted in a perfect circle without site adjustments. This was an indicator of the success of the entire process; modelling, fabricating, and assembling with the precision of a high-detailed digital twin. Installation of the MPP panels at the skylight resulted in a perfect circle without site adjustments. This was an indicator of the success of the entire process; modelling, fabricating, and assembling with the precision of a high-detailed digital twin.



Figure 35: Comparison of the 3D and actual



Figure 36: Comparison of the 3D and actual

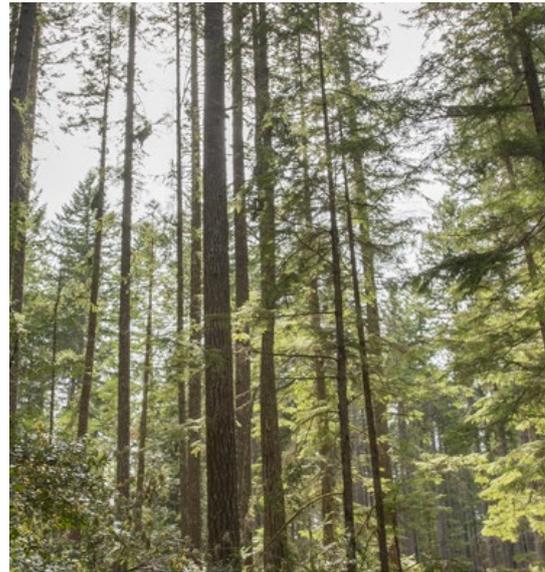
5. Sourcing

Unique in scale, the project connects 2.2 million board feet to the forests and people that grew the fiber. It stands as a North Star for what is possible when sustainable building projects intentionally incorporate positive conservation, community, and equity outcomes. The project is a tribute to the small families, Pacific Northwest Tribes, and other landowners that contributed to land stewardship and local economies across the region, within 300 miles of the airport.

The project client, Port of Portland, put forward the goal to source all the wood in a way that is better for the land and better for our local communities?

Together, the project team came up with a set of goals around sourcing:

- All the wood would come from sustainably managed forests in Oregon and Washington.
- With equity in mind, we should source from small landowners, community forests, and tribal lands all over the region.
- Just like «farm to table» cuisine, we should trace as much of the wood as possible all the way from forest to frame.



PATH 1 – Log Purchase Transparency

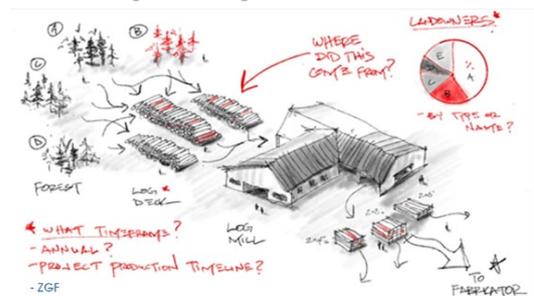


Figure 37: Paths to sourcing transparency

6. Manufacturing

The large-scale nature of the project created a unique logistics puzzle. For the manufacturing process to maintain pace with the site assembly, the manufacturing needed to start 5 months ahead of assembly start. More than half Zip-O Laminators manufacturing facility and storage were dedicated to the project for a little over a year. In addition to the space needed, the manufacturer also had set up a new area to install an arch press large enough for this project.



Figure 38: Zip-O Laminators – Manufacturing facility

The project subsequently inserted the downstream value add vendors, stain and reinforcing, into the manufacturing process, all under one roof at Zip-O. This mitigated the need for the additional handling and trucking that would have been needed under normal circumstances.

There were additional overhead cranes that needed to be installed in the facility before production would start. The additional cranes were installed just in time and made it possible to develop a new arch press, value-add, production line that could keep pace with the schedule. Manufacturing the beams in sets of 2-4 billets at a time, took approx. 7 days from start to finish.

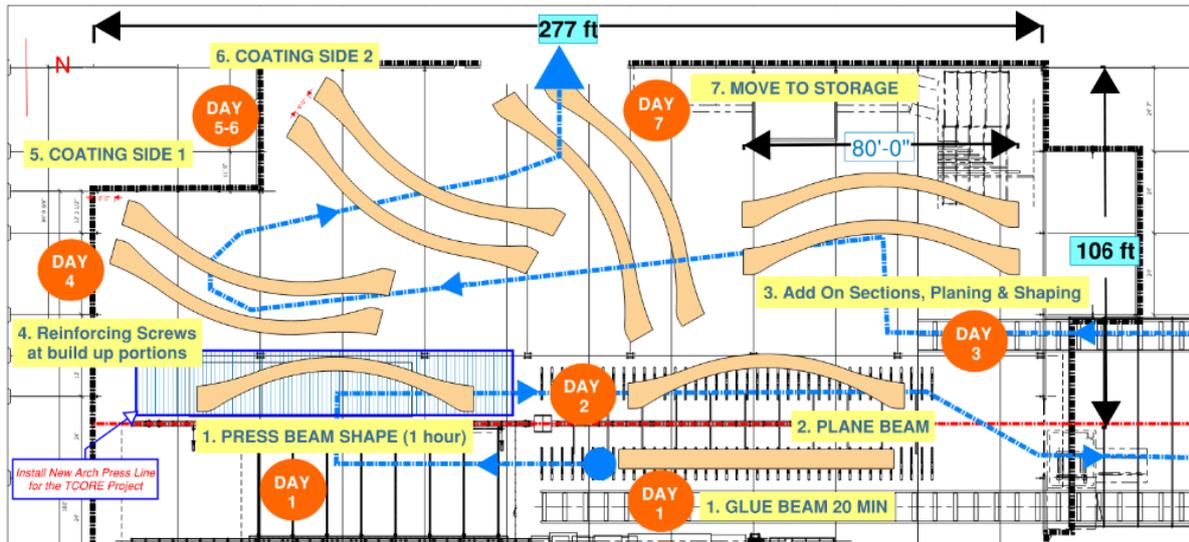


Figure 39: Manufacturing the beams in sets of 2-4 billets at a time took approx. 7 days start to finish.

For the DFMA concept to work for assembly the glulam beams needed to be accurately pressed to their shapes while maintaining very tight tolerances at any point on the arch. If done right the MPP panels will fit precisely into place on top of the glulam and lattice on the underside.

To confirm arch beam tolerances, the first beam made for each shape was point-cloud scanned and brought back into the 3D BIM model to verify its shape was within tolerance. The scanned beam was then used as the template to replicate and compare all the same shapes to. Only 2 shapes were found out of tolerance and quickly corrected.

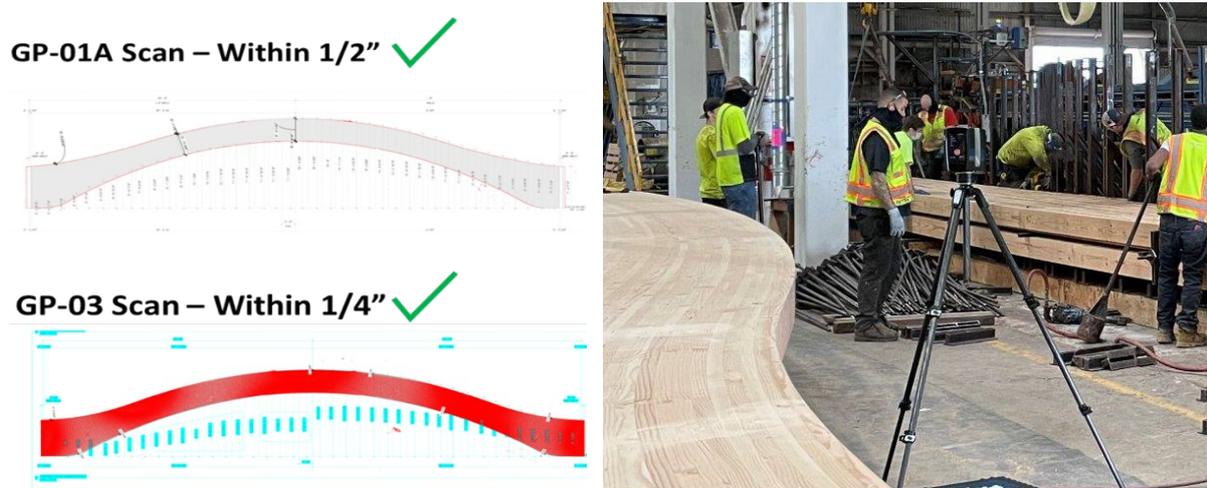


Figure 40: Results of point cloud scan overlay with digital twin (Left), Point cloud scan beam (Right).

7. Assembly



Figure 41: First beam installed – May 17, 2021



Figure 42: First beam installed – May 17, 2021



Figure 43: Assemble the skylights



Figure 44: Fasten MPP to the shape of glulam

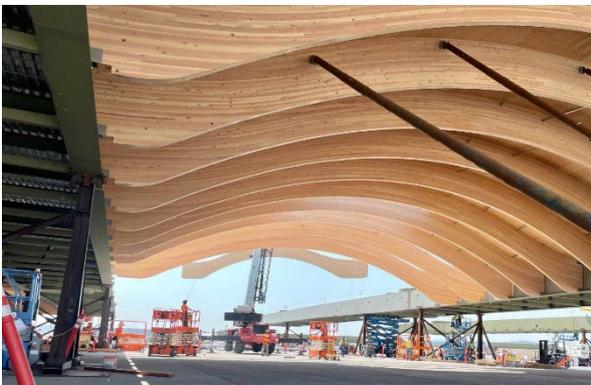


Figure 45: Install glulam and install temp bracing



Figure 46: Install vertical and horizontal lattice



Figure 47: MPP roof panels



Figure 48: Skylight MPP lattice arches