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Natural form and industrial building: Two case studies

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ABSTRACT: This paper considers the means and methods by which the complex natural properties and forms of trees can be deployed in the construction of buildings. The authors consider the structural and aesthetic potential of so-called whole timber elements in relation to processes of design, fabrication, and assembly. Tracking the development of experimental building projects, two case-studies are presented in detail, and particular attention is given to methods of selection, harvesting, processing, modelling, transport, and prefabrication.

1 INTRODUCTION

In most traditions of vernacular building, the evaluation of standing trees is essential to the process of design and construction. The straightness of trunks, location and quantity of knots, dimensions, color, density and hardness are central to the selection of building components from available forest stocks. Identifying these differences is an essential task for foresters and carpenters, but at the expanded scale of industry, such variations are antithetical to the production of homogeneous products. As a result, the chemical, biological and morphological differences that emerge naturally between trees and species are often suppressed in favor of standardized products.

Recently, some researchers have challenged this tendency toward homogenization through developed surveys of whole timber, which assess the historical traditions, structural characteristics, and potential applications of such components (Bukauskas et al. 2019). Numerous other studies have pursued the use of these components in experimental structures (e.g., Mollica & Self 2018). The research here considers if and how such components might fit within a more conventional framework of construction. To assess the combination of whole timber and standard wooden structures, the research team traced the design and construction of a public building in partnership with academic and professional actors over three-years. Scots Pine (Pinus sylvestris) trunks were used as architectural and structural elements in two case study buildings, both of which were realized within the practical constraints of full-scale construction projects. From transport to assembly and structural design, the study was pursued through an open-air pavilion and fully enclosed event facility. In each project, logistics and expediency were balanced with a desire to preserve and make use of the unique characteristics of individual trees.

2 CASE STUDIES

The study centers around the design and construction of a temporary event facility in central Helsinki. Finlandia Hall, the landmark building by Alvar Aalto is currently undergoing a three-year renovation and a temporary building was constructed adjacent to the hall to host events and gatherings during the period of closure. Following the renovation, the temporary structure will be disassembled and relocated to a second site for use as a school or kindergarten.
The project was organized by Aalto University, the City of Helsinki and the operators of the Finlandia Hall convention center. Initial work began with a graduate-level design studio held at the Aalto University Department of Architecture. Over the course of one semester, 18 students developed individual design proposals for the building site and at the conclusion of the term, the proposal by student Jaakko Torvinen entitled “Finlandia Forest” was chosen as the basis for development of a feasible design for construction. The winning proposal was based on a grid of natural pine columns enclosed in a simple rectangular volume, which could be built from standard wooden structural systems of massive CLT panels, hollow-core roof elements and glue laminated beams. The untreated pine trunks – with branches intact – were meant to serve as the primary load-bearing system for the building in order to enliven the interior and create a surprising counterpoint to the otherwise conventional components and box-like form. Scots pine trunks were selected for two primary reasons: first, because they could be sourced from nearby forests, second, because they remain a potent symbol of the national romantic tradition of Finnish architecture and design.

The shape and structure of the building were clear from the initial proposal, but the feasibility of this method of construction remained uncertain. To study the proposed method of construction, students from the Aalto University Wood Program were assigned the task of designing a prototype structure to explore the feasibility of harvesting, processing and shaping whole trunks for use in construction. The knowledge and information from this experimental process was then used to develop the detailed design for construction of the larger building, realized the following year.

2.1 Katve pavilion

Katve (meaning ‘shade’ or ‘cover’ in Finnish), was initiated in January of 2020. A team of eleven students developed various plans for the 64 m² roof canopy using glu-laminated beams for the horizontal structures and a series of whole timber pine columns to carry vertical loads. The pavilion was developed as a proof of concept for the structural system and a functional event space for an urban space in central Helsinki. Due to the Covid pandemic, the pavilion could only be partially constructed. A 4 x 4 m section was built using two columns and a lattice wall to support the roof.

Development of the architectural design for the pavilion was carried out simultaneously with experimental studies for the selection, processing, and fabrication of the column-trunks. As the logs would not be sawn or kiln dried, it was necessary to carefully manage their harvest, transport and seasoning from forest to building. By harvesting in mid-winter, the trees could be expected to have a moisture content of 35-40%, from which they would be dried to a moisture content of about 18-20% for use in the building. A careful plan for harvesting, de-barking, transport and storage was necessary to ensure the visual and structural integrity of the trunks.

Initially, a batch of small logs (diameter of 200 mm) were harvested from a forest in Vantaa in January 2020 and transported to the Aalto University building workshop then de-barked using various methods devised in consultation with industry partners specialized in carpentry and log construction. Physical tests were carried out on this batch of logs to determine a method for peeling that effectively removed the outermost layers of bark and cambium while retaining the consistent, smooth surface of the wood below.
Test logs were subjected to various methods of mechanical scrapping and pressure washing to determine an optimal sequence. The most effective method was to position the logs horizontally and spray them using a high-pressure flow of water from a hand-held lance and rotary nozzle. Operating at 250 bars (25 MPa) with a flow rate of approximately 18-20 liters/minute, the nozzle was moved continuously along the length of the trunk at a 45-degree angle to remove both the bark and cambium layer at once. Additional passes were made as necessary to remove debris and stubborn areas around knots and crevices, but care was taken not to overwork the surface. While pressure and flow rate could be varied with minimal consequence, the angle of incidence and rotation of the nozzle were essential for removing the cambium layer without cutting or damaging the visible surfaces of the wood beneath.

After peeling, the trunks were transferred to a climate-controlled facility (18-20˚ C, RH 40%) and positioned vertically. While drying in a controlled setting, the trunks were monitored for cracking and moisture content on a weekly basis. Five trunks were cut using various techniques to control cracking and relieve internal tensions developed during drying. After one month, the tests showed that all specimens in the group were subject to similar degrees of cracking. No single method of relieving stresses proved to be superior to the control specimen in visual or structural terms. More importantly, certain methods of cutting the trunks with deep and continuous grooves adversely affected their structural integrity. The research team concluded that the process of cracking could be more effectively controlled by slow drying than mechanical treatment.

Apart from cracking, other visual changes to the trunks proved challenging. The bleeding of resins to the surface of the trunk began immediately after de-barking and led to a tacky, adhesive surface that easily collected debris and visual imperfections. In addition, the application of tape or labels lead quickly to the development of blue stain and visual blemishes. These concerns were addressed with an initial drying cycle after de-barking to harden the surfaces resins and a careful avoidance of non-adhesive tags to keep the surface free of labels. These measures proved essential in the larger project to identify columns while maintaining their visual integrity.

In March, 2020, the design and research team initiated a partnership with the Evo forestry unit of the Häme University of Applied Arts (HAMK) and The Finnish Forest Administration to harvest trees for the prototype pavilion from a carefully managed forest in central Finland. Initially, the trees were to be scanned in-situ to evaluate the geometry of each specimen for preliminary design and analysis. However, it became clear after consultations that scanning in this early phase was practically difficult and somewhat ineffective. Using a laser scanner to produce a point-cloud scan from multiple angles made it difficult to scan a single tree in the dense forest as other trees often obscured parts of the scan. Moreover, the presence of snow on the crown and branches limited the amount of detail possible from an in-situ scan, and movement due to wind further limited the detail of the final point cloud.

As an alternative to in-situ laser scanning, a field survey of twenty specimens was conducted according to a four step process: (1) identifying trees with a number tag (2) marking their location on a map with a matching number (3) measuring the diameter of each trunk at a height of 150 cm (4) photographing each tree from three angles at a distance of 780 cm with a scale reference ruler and number tag visible in the photo. This system of documentation allowed for a detailed evaluation of the specimens in the design studio, and finally six trees were selected for harvest according to criteria including straightness, trunk diameter (30-35 cm) and presence of one to three sturdy branches in the mid-section of the tree.
On site, felling was carried out under the supervision of HAMK forestry instructor Martti Kolkka. Initially, a nylon cargo strap was fixed to each tree at a height of approximately 450 cm using a ladder. This strap was then connected to the boom of an adjacent crane to stabilize the tree while it a base cut was executed using a chainsaw. This method was meant to limit mechanical damage to both the trunk and branches as they fell to the ground, however, testing proved the system to be unworkable. Neither the position of the strap nor the carrying capacity of the crane were sufficient to suspend the full weight of the tree vertically as it was cut. Positioning the strap higher on the trunk required special lifting or climbing equipment, and a larger crane would not be able to navigate the dense forest without damaging the surrounding trees and soil.

![Harvest and transport from Evo forest to Otaniemi. Aalto University Wood Program.](image)

In consultation with the forestry team, an alternative method was devised and each tree was directed to fall into the canopy of an adjacent tree. This method slowed the fall of the tree to the ground and was faster than supporting the trunks with straps. It proved to be sufficient in preventing mechanical damage to branches, however it also caused unnecessary damage to adjacent trees and made it difficult to extract the trunks after they had fallen. Eventually, it proved most effective to simply guide each tree into a clear area of soft snow.

After felling, each specimen was lifted using cargo straps and transported to the Aalto University building lab to be peeled and set for drying according to the methods devised earlier. After the trunks had been stripped of their bark and placed in the workshop, laser scanning could be carried out in a controlled environment with few obstructions for the laser scanner to navigate. The team partnered with researcher Juho-Pekka Virtanen (Aalto Department of Built Env.) to undertake the scanning work using a Leica BLK360 3D laser scanner. In the controlled conditions of the workshop, it was possible to scan multiple trunks at the same time from multiple positions to collect the necessary information and separate the specimens in working files after scanning. The laser scanning process produced a high-density point-cloud which needed to be down sampled in order to produce a triangulated mesh that could be edited in a NURBS modeling environment (Rhinoceros). The high-density precision of the models produced by the laser scan allowed for extremely accurate visualization of the columns in development of the spatial design. More importantly, they gave

![Translation of 3-d point cloud scan to NURBS mesh. Aalto University Wood Program.](image)
precise dimensional information that could be used to study the connection of the columns to the roof, which was planned according to the position of the supporting trunk and branch. The resolution of the scan geometry exceeded the level of information that was required for fabrication; however, it was essential in establishing the exact vertical axis of each trunk so that machining could be carried out in the correct position. At the base of each column, a 60mm boring was made to receive a steel pipe affixed to a 50 x 50cm foundation plate. At the top of each column, a simple tapered dovetail crown is compressed between the carrying members of the roof. The columns were machined using a 5-axis router at the Aalto University workshops.

2.2 Pikku Finlandia event center

Pikku or ‘little’ Finlandia was built as a 2 700 m² (14 000 m³) temporary event facility to host activities during the three-year renovation of Finlandia Hall. Following the renovation, the building is to be disassembled and moved to a new location for use as a primary school or kindergarten. The building measures 123 x 25 m and is organized on a regular, orthogonal grid with 95 pine columns. More than half of these (56) serve as vertical carrying members while the remainder are designated as non-bearing. 36 columns are located outside of the building, forming a colonnade along an exterior canopy and terrace.

The workflow and design solutions for the earlier Katve pavilion were refined and developed to accommodate the increased scale and quantity of components in the Pikku Finlandia building. Within this real-world context, adjustments were made to ensure that harvesting, peeling, finishing, transport and assembly could be conducted within the strict constraints of the project schedule and budget. In January 2021, 120 trunks were selected for harvest from three forest stands in Loviisa (on the southern coast of Finland). The trees chosen for harvest ranged in age from 40 to more than 100 years. The selected pines were felled by local foresters with the direction of fall intended to protect selected branches on each tree. The order of harvest was coordinated in advance so that each tree would not damage or be damaged by the next. The timing of the harvest proved fortuitous as a fresh 50 cm snowfall helped to soften the fall of each tree to the ground and minimize damage to the branches.

In the field, the trunks were cut roughly to a length of 7-8 m with final cuts made in the workshop according to the position of each column in the building. The freshly cut columns were transported to Timberpoint where they were peeled and dried under the supervision of Marko Suonpää in a large open hall following a similar workflow to the one developed earlier. During the drying period (February and March), 95 pines were selected from the 120 cut trees based on anticipated structural performance as defined by trunk diameter. Dimensions of the columns were defined in accordance with Eurocode requirements for a structural grade of C24, following the standard definition for wooden components that have not been subject to grading due to their unique properties. Specimens were thus categorized in three categories: load-bearing P2 (diameter of 300 to 450 mm), load-bearing P3 (diameter of 200 to 300 mm) and non-bearing P.

In accordance with the earlier process, these trunks were intended to be scanned, however this was unfortunately not realized. Although the individual forms of each tree were important for the architect, a precise model of each individual column was not required by the structural engineer or
constructor. A comprehensive BIM model with information for each trunk could not be achieved by the research team in the time available, and so the 95 selected trunks were instead inventoried using drawings and photographs. Following this method, the approximate shape of each trunk was included in the construction documents so as to locate each element with respect to structural capacity (defined by diameter) as well as visual quality. The orientation of the columns was adjusted to avoid visual repetition and intersections with other structural and technical components. In practice, this process proved to be laborious and would have likely been expediated by the originally planned method of 3-D scanning developed in the earlier research.

Figure 13. Pikku Finlandia first floor plan with structural elements highlighted. Drawing by Jaakko Torvinen.

Apart from the pine columns, the building utilizes mostly on business-as-usual solutions. The outer walls and stabilizing walls are built from 120 and 180 mm thick CLT panels, which provide lateral stability. The column grid is based on a length of 480 cm and a width varying from 330 to 550 cm. Nine transverse GL beams support the insulated roof slabs, and are supported by the pine trunk columns, CLT-walls or GL columns depending on their location. The GL columns (380 x 380 mm) and CLT-walls take the loads of the longest (11.3 m) span, which is located at the opening between the three large halls. At this location, the double GL beam dimensions grow to 2 @ 1215 x 190 mm, but at all other points dimensions are more modest.

The walls of the large open spaces were made of prefabricated CLT made from Norway Spruce (Picea abies) and produced in Kuhmo, Finland by Crosslam. The roof and floor slabs were built from insulated hollow core slabs constructed from LVL, 16 to 17 m long and varying in width from 360 to 620 cm. These box-like elements span between the GL beams to carry the loads of the roof. The uninsulated roof of the exterior terrace and colonnade are slightly narrower (380 cm) and built using a prefabricated wooden truss. The construction of the building is based on a combination of prefabricated planar and volumetric elements that facilitate easy assembly and disassembly. Certain technical spaces such as the kitchen and service rooms were sufficiently low to be fully outfitted in the factory and transported to the site as complete volumes, but most spaces in the

Figure 14. Pikku Finlandia structural system. Drawing by Jaakko Torvinen.
building were too tall to be transported in this manner. For most of the structure, the trunk-columns were pre-installed into volumetric units and transported to the site where roof beams and insulation panels were set onto the open structures to complete the building enclosure. The exterior columns of the colonnade were shipped individually and installed on-site.

Figure 15. Tree-columns were pre-installed in volumetric modules by FM Haus. Helsinki, 2021.

Figure 16. Columns which were not pre-in-stalled in the volume elements were in-stalled on site. Helsinki, 2021.

2.3 Connections

The final design of the joints was based on a draft by the structural engineer and developed by the architects with input from the fabricator. The design follows a long-established principle best summarized by Professor Hermann Kauffman as, ‘A builder develops a design to be feasible, an architect ensures that it does not become banal.’ In principle the use of scanning technology and NC machining allowed for a wide range of options in crafting the upper and lower trunk connections, however the size of the trunks and presence of the branches made positioning and tool access difficult on the cutting rig. With many columns to be machined, the aim for the design of the joints was made as simple as possible to avoid complex operations in machining or transport. In principle, the joints could be easily cut with a chain saw, but the use of a Hundegger PBA2 workstation insured consistency and precision across a large number of varied components.

At bottom, each trunk is cut flat and a square plate of LVL is fixed using 12 screws (6 x 160 mm). Each plate is screwed first to the column and then to the beams of the floor slab using another 12 screws of the same dimensions. A circular steel collar, painted black, finishes the joint at the point that the column meets the floor.

At top, the interior pine columns use two 20 x 500 mm threaded steel rods inserted into the glulam beam and one longer 1000 mm rod, which passes through the entire beam. The rods are welded to a steel plate which sits between the pine column and the beam. Below the plate, a single rod slides into a hole on top of the pine trunk. The upper connection thus allows for any torsion that may develop from twisting of the trunks as they continue to dry. The exterior pine columns use a slightly simplified version of this joint, with only one rod (Ø20 x 450 mm) passing through the GL beam and into a hole on top of the pine trunk. The non-bearing pine trunks, replace the steel joint with a simple LVL plate, similar to the bottom connection.

2.4 Finishing

At each phase, permeability of protective layers proved critically important. During transport, the use of protective plastics led quickly to mold growth on some columns and even thin transparent wrap or adhesive tape resulted in uneven coloring, marring the uniform surface in a short time.

Interior columns were finished with a water-borne wood preservative in the factory. This treatment is typically used in log buildings to create a thin, breathable film that protects the column surfaces from dirt and to slow drying by evaporation. In this way, the logs should dry more predictably until they reach a moisture content comparable to the building interior. Exterior columns were treated with a solvent-borne primer and finished with a transparent coating similar to that used on the interior. Outdoors, the colorless preservative slows the absorption of moisture from the humid exterior air and prevents the spread of blue stain. However, finishing is intended only to reduce the changes of pine tree columns, cracks, gradual color changes and greying will inevitably occur and emphasize the natural character and age of the trunks.
3 CONCLUSION

Standardization persists as the prevailing logic of industry, but this fact has far-reaching impacts on the energy, ecology and economics of wood construction. Issues of bio-diversity and forest resilience may seem to be distant concerns for architectural designers, but the demands of the building industry and the management of forests are intimately related. Trees and species that do not fit easily into existing workflows or production pipelines are often designated as low-value and put to use in biofuels or pulp production, which yields less economic benefit for forest owners. This chain of valuation further incentivizes the cultivation of homogeneous forest stands in which single species are planted and harvested in mass (Takala et al. 2022). Ultimately, such silvicultural practices may be detrimental to the long-term health and resiliency of our forest ecosystems. Finding potential uses for a broader range of tree types may have potential to intervene in these cycles of management and use.

The non-standard characteristics of whole timber are often assumed to be difficult in an industrial process, but the research here suggests that with careful planning, this aspect of the construction is one of the simplest parts of the building process. Common challenges of scheduling, coordination and document delivery caused more substantial difficulty than the use of unique building components. Nevertheless, questions about the structural behavior of these elements remain to be investigated. Previous studies have demonstrated that unsawn timbers have higher bending strength than comparable sawn elements [Wolfe 2000], however the schedule of this project did not allow for individual assessment of each specimen. Further research could be directed at incorporating the unique behaviors of these elements not only spatially, but also structurally.

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Katve Design Team

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