Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Limitations in the use of reclaimed wood on spatial structures in a carpentry workshop; a field study

Wolfgang SCHWARZMANN*,

*Liechtenstein School of Architecture,
Fürst-Franz-Josef-Strasse, 9490 Vaduz, Liechtenstein
wolfgang.schwarzmann@uni.li

Abstract

This paper focuses on the construction of spatial structures primarily made from regional resources and reclaimed wood. To facilitate a later reuse of the raw materials, the structure has been optimised for the highest possible degree of deconstructability and clean separation. Designed as a small, mobile sauna, the structure was presented at the 'Handwerk+Form 2023' exhibition in Andelsbuch, Austria and judged by an independent jury. As part of this approach, we were able to document and evaluate still existing limitations regarding the implementation of reclaimed wood in an everyday working process with a carpentry workshop. To ensure that the construction materials will later be separable by type, the following parameters were defined as the ultimate goals: Implementation of regional available materials and technology, optimization for a later separation and disassembly, substitution of fresh wood in the process with reclaimed timber and an optimization of the material cross-sections. While the first four aspects have proven to be feasible, the last two points, the implementation of reclaimed wood and the optimization of cross sections, proofed to be more challenging. As the results show, the integration of reclaimed wood on CNC joinery robots is still a major challenge, although this aspect is of great importance regarding future constructions of large-scale shells and spatial structures.

Keywords: reclaimed wood, CNC-machine, wood-only construction, field research, 1:1 case study, digital fabrication, circular construction, timber construction, deconstructability,

1. Introduction

Shell and spatial structures are mainly characterized by their extremely material-efficient construction, whereby they generally carry more weight than they weigh themselves [1]. When working with reclaimed wood, i.e. wood from a demolished building, a high degree of diversity in the raw materials has to be taken into account [2]. Planks, beams, and rafters from a single demolished building usually have different dimensions, qualities and strengths. This complexity in the available raw materials is further increased by the variety of different building standards, historic eras and architectural styles of each construction.

Based on these considerations, the horizontal piling of beams on top of each other more generally known as log construction, can be regarded as a material-efficient construction. This construction enables a construction method compensating the variation in the raw material that would otherwise have been simply been discarded which in turn contributes to multiple use and thus an efficient material utilization.

1.1. Background and context

Depending on which approach regarding material, construction and innovation is pursued, a number of fascinating concepts can be considered. The work by Fivet and Brütting, shows how steel profiles that previously functioned as electricity masts can also be used in other load-bearing structures [3]. Based on the software solutions, the construction materials are transferred to a new use with minimal waste. This method is well suited for power masts or similar technical constructions since a very precise blueprint of the construction is available and can be used as a basis. If these blueprints are not available in the appropriate quality, technologies such as LiDAR scanners enable the rational and efficient logging of materials that are already in use. The resulting digital database forms a repository for the subsequent planning processes [4]. Due to the inherent natural growth of wood and the associated material inhomogeneity, the variations in the raw material, such as a branch fork, can bring added value to the construction. In the case of the 'Wild Wood Gridshells', the integration of technologically complex developed nodes compensates for the variance of naturally grown branch forks resulting in a particularly rigid connection [5]. This is a particular advantage in the case of these naturally grown branches, which is usually solved with steel parts or glued joints. The increasing amount of glue and such additives also raises health concerns for inhabitants, which emphasizes glue-free solutions such as log construction or dowelled wood connections. Solid wall elements manufactured by dovetail joints can provide a glue-free and therefore ecologically safe solution [6].

1.2. Log construction as a proven concept

Log construction is one of the oldest construction techniques in timber construction. Due to the relatively straightforward construction and the small number of tools required, log construction can be realized with minimal resources [7]. Whereas in a post-and-beam or timber-frame-construction the timber is used in a vertical orientation, in log construction the individual beams are laid horizontally one over the other [8]. At the corner points, the adjoining beams are interlocked with each other. This clever, dovetailed construction allows the individual layers to function both as load-bearing and space-creating elements. While in the earliest times such constructions were made from round, simply hewn tree trunks, over time the cross-sections of the beams were adapted to a more rectangular shape [9]. As the example of the '*Red House'* (German meaning: *'Rotes Haus'*) in Dornbirn, Austria, still reveals, tapered and conical beams were used back then (Figure 1). The construction of this log house, which was built in 1639, is still visible today and was now partially documented with a LiDAR scanner for this research project. The red marked beam measures 200 cm in length and is 32 cm tall at [02] Measure A and 28 cm tall at [03] Measure B. The beam therefore tapers by 4cm on a length of only 200cm.

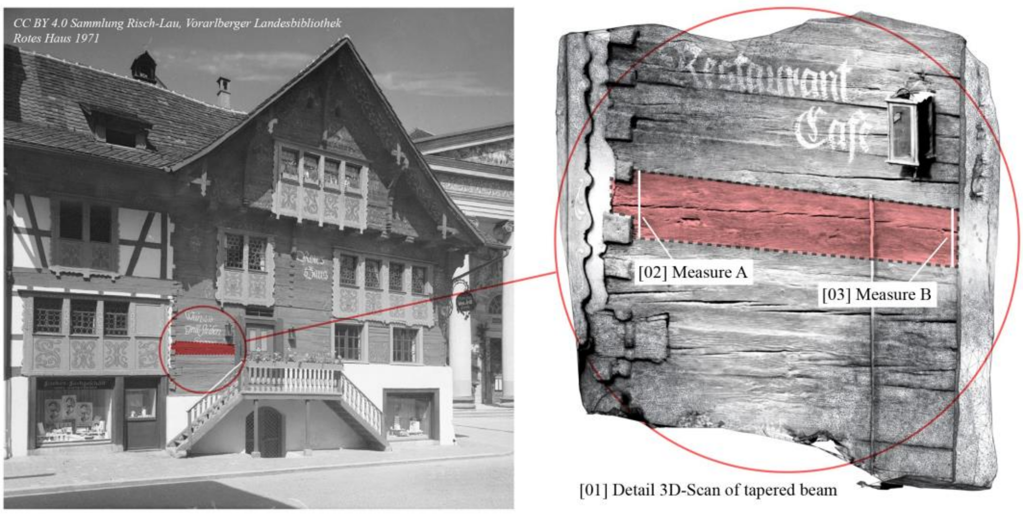

Figure 1: Built 385 years ago; the tapered beams of the 'Red House' are plain to see and were digitized with the 3D scanner. [left image: *Sammlung Risch-Lau, Vorarlberger Landesbibliothek, 1971*]

With the increasing mechanization and the comparatively high costs for manual labour, the natural proportions of the individual trees were no longer considered for later structures. The beams were sawn over their full length in a uniform cross-section, which in turn resulted in larger quantities of offcuts, but at the same time also enabled rational and efficient processing, as all beams had the same cross-sections. **It can be said that previously existing material characteristics were 'straightened' in favor of a faster and more efficient workflow which, however, contributes to a greater offcut of the raw material.**

1.3. Log construction vs. CLT construction nowadays

A further significant step in the field of solid timber construction was made at the end of the 1960s - 1980s when CLT and LVL were ready for wide applications [10]. While solid timber beams have technical limitations in terms of dimensions and the resulting structural properties, engineered wood products achieve a constant and efficient uniformity. The required timber cross-sections can be produced just in time, in the required dimensions, while material weaknesses are cut out and will be replaced by glued joints [11]. In addition to these advantages, CLT is characterized by its possibility of large panel dimensions and its relatively uncomplicated application, which are major advantages in comparison to individual wooden beams. These advantages generally require correspondingly large production facilities and the use of modern adhesives [12]. However, in today's discussion on circular timber construction and the resulting construction materials, several unique characteristics can be mentioned regarding block construction.

Strengths and challenges of log construction [7, 8, 9]:

+ No glue/only wood: The interlocked corners and wisely cut-out struts mean that a building can be constructed from 100% wood. Further structural rigidity is provided either by wooden dowels, corner chamfering or mortised posts

+ Easy to dismantle: due to the construction principle of horizontal interlocking of beams, the building can be dismantled in reverse order. A proper log construction requires no screws, no glue and, in fact, no other building materials except wood. The wood does not need to be treated, glued or coated and can therefore be reused at a later date.

+ Large material dimensions: Most of the timber beams used are utilized in their grown structure. This means that a large proportion of the beams remain as full cross-sections for later re-use. This ensures a variety for subsequent applications.

+ Simple to manufacture: In principle, log construction does not require particularly large production facilities and can also be handled by a small-scale workshop with a conventional joinery machine. This means that it is possible to work with regional raw materials and available regional infrastructure over short transport routes.

However, log construction also has certain challenges that need to be considered:

- Swelling and shrinkage: As a natural material, wood will swell and shrink depending on the ambient climate. Consequently, joints and grooves must be considered with a tolerance.

- Cross grain warping: Wood installed horizontally can shrink again in its cross-section over the first few years. At a room height of approx. 280 cm, it will 'shrink' by up to 4-6 cm in the first few years

- Elaborate construction (when done by hand): Due to its design, many individual logs must be joined when building a log house. When done by hand, as was common in the past, this means an immense amount of labor. However, this point can be streamlined and automated using new joinery machines.

- Large quantities of wood: Since all components in log construction are made from solid wood, a very large quantity of wood is required.

1.4. Log construction in the digitized age:

The principles of log construction have also been transferred to digital manufacturing technologies and contemporary architecture. Due to the possibilities of robot-supported production in workshops a limitation of time-consuming manual labour can be achieved [13]. The rational and automated production of customized beams is no longer time-consuming manual work. Joinery robots became affordable for craft businesses at the end of the 1980s and their application is configured for the needs of each individual company [14]. The 'Leis house' designed by Peter Zumthor illustrate how log construction can be translated onto a contemporary design approach. The beams were produced on a joinery robot and all have the same cross-sections (Figure 2).

Figure 2: Manufactured by machine, assembled by hand: The Leis houses by Peter Zumthor are designed as a log construction. [© Walter Maier]

Based on this context of raw materials, technology, the design principles and the subsequent construction, the research question can be framed as follows:

To what extent can we implement the principles of circular timber construction with joinery robots in a log building and what are the key challenges experienced in the process?

2. Method

The combination of technologically applicable solutions and existing traditional construction principles prompted us to develop a 1:1 prototype.

2.1. The prototype as a research object

As part of the 'Handwerk + Form 2023' competition, a craftsman and a designer have to team up, to jointly realize an object. As part of this challenge, a collaboration with the carpentry firm Harald Berchtold in Vorarlberg, Austria, was established. As a small-structured craft business (6-8 employees) in Vorarlberg, the company owns a carpentry robot (Hundegger Robot). Within the framework of several workshops, the construction and design for a small sauna made of 100% wood was developed (Figure

3). The collaborative process to develop the construction and design was limited to six months. The final object, a sauna with a wood-burning stove for 4-5 people, measures 292x192x223cm (l/w/h). All beams have a continuous wall thickness of 6cm. The dimensions of the building are chosen in such a way, so it can later be transported on a car trailer. It has a single square window at the front to provide light for the interior and a wooden door on the opposite side. The floor, walls, ceiling, and roof are made of 100% wood. The beams are designed with an elongated groove to interlock with the underlying beam.

Figure 3: Collaborative development: The ideas, principles and possible solutions were brought together in several workshops. The process was documented in a project book.

In addition, some wooden dowels have been inserted according to structural requirements (Figure 4). The door and the window frame have a longitudinal sliding groove to enable later settlement in the wood. As a matter of principle, we tried to completely avoid using metal fasteners such as screws and nails in the project. However, since the building must be transported with a car trailer, it was not conceivable for the carpenter to fully eliminate screws. The slightly pitched roof consists of individual boards with small strips of sheet metal inserted in the gaps to drain off the water.

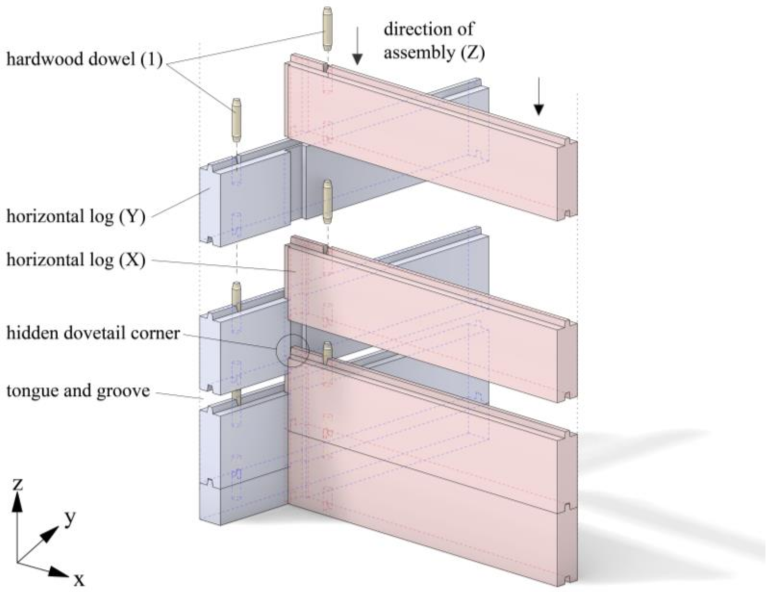

Figure 4: Piece by piece, the building was put together from bottom to top. In addition to the very precise corner joints, hardwood dowels were also installed in the construction, resulting in a very stable design.

2.2. Assessment table for evaluation

As described at the beginning, there are numerous advantages to log constructions with solid timber beams. To clearly structure our analysis and better categories the results, we compiled a table listing the relevant aspects in this context (Table 1). As listed in the table below, the key objectives for us were

1. **Implementation of regional available raw materials:** To minimize transportation costs an resulting CO2 emissions, a focus on regional available raw materials was given.
2. **Regionally available technology:** Design principles and the necessary manufacturing steps shall be manufacturable with regional available machines. The design should be feasible with existing technologies at a local craft business
3. **Built for (later) dismantling:** No screws and nails or other steel parts should be used in the construction. Timber cross-sections should be kept at a large dimension for subsequent use
4. **Built for (later) separation**: No glue, no adhesives, no silicone sealing; all materials should later be 100% separable and separated,
5. **Reduction of fresh wood in the process**: Use of reclaimed wood from a demolished building
6. **Optimization of timber cross-sections**: Avoid unnecessary planning work, reduce cut-offs and trimming as far as possible

Table 1: Evaluation table of the timber construction: The goal (A) should lead to the solution (C) through the approach (B). The points (D) indicate how successful the corresponding approach was.

	A	B	C	D
	Goal	Approach	Solution	points achieved
1	buildt from regional available resources	Non-engineered Wood, less than 40km,	work only with solid wood Fir, Spruce, Ash etc.	10/10
2	buildt with regional available technology	accessible technology of the region; small scale CNC-Joinery Robot	Possibility for complex and detailed solutions	8/10
3	build for (later) disassembly	few screws + nails; keep large cross sections	push-fit connections; interlocking corners, wooden dowels etc.	7/10
4	build for (later) 100% separation	No glue, no composite materials, easy separable	reversible wood joints, logic and visible construction	9/10
5	reduction of fresh wood in the process	implementing reclaimed wood	Using reclaimed beams from an old building	1/10
6	optimise the available timber cross-sections	reduction of straightening losses during surface preparation	construction with loose tongue and groove	2/10

Subsequently, we documented the design, construction and completion process of the building via a variety qualitative methods. In addition to interviews with the craftsmen, numerous photo and video documents were taken and the built structure was analysed in detail. The resulting data and a joint reflection provided the basis for evaluating Table 1 while using a points system. Each of the 6 'Key Objectives' listed in Table 1 can be awarded 1 to 10 points, with 1 point for a very unsatisfactory performance and 10 points for the best possible fulfilment. These points and the findings obtained, are then combined to frame the results of this work.

3. Results

It can be said that the construction principle of log construction already offered many advantages in this process. Since log construction involves working with individual beams, it was possible to work with regional timber in the entire process. No industrial processed timber was required (like LVL or glue laminated timber). As the process has shown, the expertise of the craftsman is of particular importance, as solid wood tends to deform more during processing and assembly compared to glued laminated timber. The carpentry workshop has a joinery robot and could therefore also build on experience in log construction. Building on this technological basis and the craftsmanship knowledge, the components could be produced efficiently and precisely with the joinery robot.

In principle, a later dismantling process should be straight forward. However, due to the need for transportation of the building, the carpenter wanted to use screws at some specific points. In addition, the dowelled timber connections are made very precisely, if not to say too precise. As a hammer was used during assembly, it might be difficult to disassemble the logs piece by piece, which will certainly complicate easy disassembly. However, cutting with a saw at specific points should not be a problem as no steel parts have been used in the walls.

Basically, the entire building was made of wood and no glue was used. The inserted metal strips in the roof construction can simply be pulled out at a later point. Due to limited availability, a coated aluminium sheet was used, whereas the initially intended copper strip would have been ideal in terms of future reuse (Figure 5).

Figure 5: Made from 100% wood: The small sauna, was ultimately made from spruce wood. However, as the process revealed, the implementation of reclaimed wood was still too challenging for the craft business.

Besides these comparatively good achievements, the points *(5) Reduction of fresh wood in the process* and *(6) Optimisation of timber cross-sections* particularly raised our attention as a major challenge.

It was planned to construct the building with reclaimed wood right up until the very last moment of manufacturing. The required timber beams had already been collected from a demolished building, were cleaned and ready for processing. However, at one of the last moments, the company considered the risk for working with reclaimed wood to be greater than expected. Despite proper inspection and cleaning of the beams, the risk of a hidden stone or an unseen screw was too great for the craftsman. **As explained by the carpenter, any machine damage to the milling head would be far more profound than the cost of buying clean timber.** In addition, the smallest impurities such as old dust or even small amounts of sand were described as a significantly negative factor that cause excessive wear to the milling head or the drill (Figure 6). As a result, the previously processed and prepared timber was discarded and replaced with new timber on the spot. This observation is also in line with Lebossé *et al.* [15] observations on the issues and the real value of reclaimed wood.

Figure 6: Screws, stones, sand and dirt: While metallic contaminants can be localized and removed with a metal detector, this is not possible for sand and stones. The risk of machine damage when using reclaimed wood on the joinery robot was ultimately too great for the carpentry company.

In addition, the optimization of the timber cross-sections proved to be a greater challenge than originally assumed. While the project was planned with a loose tongue and groove connection, the wood savings could not prevail over the necessary additional costs for the craftsmen. Whereas with conventional connections, both the groove and the tongue are milled out of a full timber cross-section, with the 'external tongue' only a groove has to be milled into the timber beam. In order to ensure the necessary interlocking later on, a suitable wooden lamella is inserted into the milled groove. It is made to fit exactly and thus transfers the forces from one beam to the other. The advantage of a loose tongue is a 3%-5% reduction in material loss during planning and shaping work. For the craftsman, however, these planning losses were marginal, so that the joists were ultimately joined using a standard tongue and groove joint.

4. Discussion and conclusion

Although shell and spatial structures are generally characterized by their performance and lightness, log construction may also be considered as an option in terms of the efficient use of materials using reclaimed wood. The provided case study and the discussed goals show that log construction is suitable for the integration of regionally available resources and technologies. In principle, the buildings can be designed in such a way that they can be dismantled at a later point and deconstructed into separate materials. However, the implementation of reclaimed wood on a conventional joinery machine has proven to be the greatest challenge. As it turned out, the construction was ultimately made from new wood after all. To be able to efficiently realize large-scale shell and spatial structures with reclaimed wood in the future, we are currently considering three further consolidations:

- **Clean raw material:** The raw materials (reclaimed wood) have to be refined to a quality that does not pose a risk to the machines and craft businesses in subsequent processing.
- **Specialized machine:** The design and equipment of the machines must be optimised so that possible material impurities (sand, single stones or even nails) do not pose a substantial threat to the machine

- **Extended sensor technology:** The machines must be supplemented with additional detection mechanisms and sensors in order to be able to localize defects in the wood by themselves and, if necessary, remove them with a trimming cut, for example.

Acknowledgements

This conference paper is part of the FFF-funded project *'Double the wood; twice the resources from one tree'* at the University of Liechtenstein.

References

[1] International Association for Shell and Spatial Structures. "Why Shell and Spatial Structures?" Accessed: Mar. 20, 2024. [Online]. Available: https://iass-structures.org/

[2] S. Wood, "Richtlinien für den Rückbau in Portland, Oregon," in *Besser - Weniger - Anders Bauen: Kreislaufgerechtes Bauen und Kreislaufwirtschaft: Grundlagen - Fallbeispiele - Strategien*, D. E. Hebel, Ed., De Gruyter, 2022.

[3] C. Fivet and J. Brutting, "Nothing is lost, nothing is created, everything is reused: structural design for a circular economy," *STRUCT ENG*, vol. 98, no. 1, pp. 74–81, 2020, doi: 10.56330/LXAH1188.

[4] M. Gordon, L. von Zimmerman, O. Haradhun, D. Campanella, M. Bräutigam, and C. de Wolf, "Digitising Building Materials for Reuse with Reality Capture and Scan-to-BIM Technologies," in *A Circular Built Environment in the Digital Age* (Circular Economy and Sustainability), C. de Wolf, S. Çetin, and N. M. P. Bocken, Eds., Cham: Springer International Publishing, 2024, pp. 41–55.

[5] T. Cousin, L. Alkhayat, N. Pearl, C. B. Dewart, and C. Mueller, "Wild Wood Gridshells: Mixed-Reality Construction of Nonstandard Wood," *Technology|Architecture + Design*, vol. 7, no. 2, pp. 216–231, 2023, doi: 10.1080/24751448.2023.2245725.

[6] H. Emre Ilgın, M. Karjalainen, and O.-P. Koponen, "Review of the Current State-of-the-Art of Dovetail Massive Wood Elements," in *Engineered Wood Products for Construction*, M. Gong, Ed., IntechOpen, 2022.

[7] H. Phleps, *Der Blockbau: Ein Fachbuch zur Erziehung werkgerechten Gestaltens in Holz*, 1942nd ed. Karlsruhe: Bruderverl., 1989.

[8] T. Herzog, J. Natterer, R. Schweitzer, M. Volz, and W. Winter, *Holzbau Atlas*. De Gruyter, 2003.

[9] K. Zwerger and V. Olgiati, *Das Holz und seine Verbindungen: Traditionelle Bautechniken in Europa, Japan und China*, 2nd ed. Basel: Birkhäuser, 2012.

[10] G. Du and X. Zhou, Eds. *Wood Industry - Past, Present and Future Outlook*. IntechOpen, 2023.

[11] A. Wagenführ, "Die Holzverwendung im Wandel der Zeit: Evolution oder Revolution," in *Holz: Stoff oder Form: Transformation einer Konstruktionslogik*, M. Rinke and J. Schwartz, Eds., Sulgen: Niggli, 2014.

[12] H. Blumer, "Das Holz und seine Wege," in *Holz: Stoff oder Form: Transformation einer Konstruktionslogik*, M. Rinke and J. Schwartz, Eds., Sulgen: Niggli, 2014.

[13] W. Schwarzmann, "Traditional Knowledge on Modern Milling Robots: How CNC-joinery machines promote a renaissance to lost techniques in the profession of a carpenter.," in *Anthropologic: Architecture and Fabrication in the cognitive age - Proceedings of the 38th eCAADe Conference*, Berlin, L. Werner and D. Koering, Eds., 2020, pp. 579–604. [Online]. Available: http://papers.cumincad.org/cgi-bin/works/paper/ecaade2020_297

[14] Hans Hundegger AG. "Hundegger, Die Unternehmensentwicklung." Accessed: May 2, 2022. [Online]. Available: https://www.hundegger.com/de-de/unternehmen/unternehmensentwicklung

[15] M. Lebossé, F. Besancon, G. Halin, and A. Fuchs, "VALUES OF RECLAIMED TIMBER," in *World Conference on Timber Engineering (WCTE 2023)*, Oslo, Norway, K. A. Malo, A. Q. Nyrud, and K. Nore, Eds., 2023, pp. 3608–3617, doi: 10.52202/069179-0470.