WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

DESIGN AND FABRICATION OF A WOODEN PAVILION USING UNDERUTILIZED LUMBER, AND PROPOSAL FOR CONVERSION

Ayano KODERA[1], Natsuki HORIE[2], Kazumi KUDO[3], Yuya TAKAIWA[4]

ABSTRACT: Against the backdrop of aging planted forest resources, declining managerial population, and the fact that usable wood as building material can be turned into chips or fuel, we developed a wood pavilion that uses unused wood. In this context, we propose a method of converting wood pavilions and a forest circulation system created by building pavilions. Bending loading tests were conducted to obtain Young's modulus and allowable stress, and finite element analysis was performed using the results obtained to calculate allowable stress and evaluate structural safety. The validity of the model was confirmed by comparing the analytical results with the tensile loading test results of the pavilion, and it was confirmed that the model could be safely created from off-specification sizes and species of wood.

KEYWORDS: Unutilized wood, Circular economy, Forest circulation, Japanese traditional wooden structure, Recombinable

1 – BACKGROUND AND OBJECTIVES OF THE STUDY

Many of Japan's forest resources are aging, and forest care is not keeping pace with the aging population [1]. In consideration of the environment, wood chips, laminated wood, paper materials, and other materials are processed into wood chips, laminated wood, and other materials that cannot be used as products. In artificial forests managed by private forestry enterprises and residents, the processing of large-diameter timber is difficult with current facilities, requiring the introduction of new machinery, and its use has not progressed. Currently, wood that cannot be utilized and is difficult to use is left unattended. [2] In this study, we propose the creation of a reusable pavilion made of wood that is not used as building material, a method of conversion, and a circulation system by creating a state in which universities equipped with various facilities can participate in the circulation of unused wood, and universities, towns, and companies can collaborate.

2 – THE STATE OF THE FORESTS - FORESTS ON THE UNIVERSITY CAMPUS AND IN THE NEIGHBORHOOD

2.1 FOREST ON THE KAWAGOE CAMPUS OF TOYO UNIVERSITY

The Kawagoe Campus of Toyo University owns a forest that used to be a thicket in the village and is now called "Komorebi-no-Mori" and serves as a route to school for students. The forest used to be part of the residents' forest and was used as firewood and fertilizer for their fields, but the university has no way to utilize the trees, and because the trees have not been thinned out for a long period of time, they are dying due to the effects of woodlice that prefer large-diameter wood. When trees die, they must be felled and disposed of to prevent the woodworm from dispersing. In addition to the danger of falling trees, this causes the problem of costly disposal. Photo 1 shows a forest scene and Photo 2 shows a dead tree.

Photo 1. Komorebi forest

Photo 2. Underutilized lumber

[1] Ayano KODERA, Master's Student, Course of Architecture, Graduate School of Science and Engineering, Toyo University, Saitama, Japan, kodera.toyo@gmail.com

[2] Natsuki HORIE, Master's Student, Course of Architecture, Graduate School of Science and Engineering, Toyo University, Saitama, Japan, s36f02400175@toyo.jp

[3] Kazumi KUDO, Professor, Department. of Architecture, Faculty of Science and Engineering, Toyo University, Mr. Eng, Saitama, Japan, kudo@toyo.jp

[4] Yuya TAKAIWA, Associate Professor, Department. of Architecture, Faculty of Science and Engineering, Toyo University, Dr. Eng, Saitama, Japan, takaiwa@toyo.jp

https://doi.org/10.52202/080513-0008

2.2 FORESTS NEAR THE KAWAGOE CAMPUS OF TOYO UNIVERSITY

About 70% of Japan's land area is covered by forests, and about 40% of these forests are planted forests. The majority of these planted forests were once planted to restore mountain areas devastated by excessive logging during and after the war in Japan and to meet the increased demand for lumber during the period of rapid economic growth. The demand for these timbers is decreasing every year, and the number of trees that are not cut is increasing. In addition, with the decrease in the number of forestry classes, there has been an overall increase in the number of large-diameter trees. The market demand for large-diameter timber is decreasing and is not being utilized. Sawmills that are unable to handle large-diameter lumber are turning the wood, which can be used as furniture or structural lumber, into chips or forest fertilizer. Even when processing is possible, the sawmills cut out offcuts that will never become products in terms of wood chips. The problem of how to utilize and where to store such unmarketable or pre-marketable timber is seen. The cost of logs is generally highest for lumber and lowest for chips [1]. It is therefore extremely important for the utilization of forests to convert logs to high-value uses without simply turning them into chips [3].

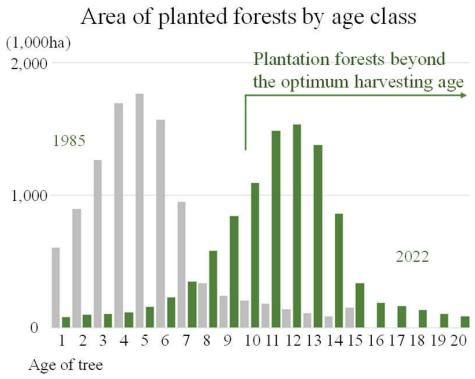


Figure 1. Increase in large diameter lumber [1]

Photo 3. Storage of scrap wood

Photo 4. Scrap wood to be made into wood chips

3 – BACKGROUND AND OBJECTIVES OF THE STUDY

3.1 SCHEME FOR CIRCULATION

In order to promote the utilization of forests, we propose an intervention of activities in the forest cycle based on the relationship between the university and the town. One of the factors that contribute to the lack of problem solving for underutilized timber is the difficulty in introducing sawmilling machinery, as well as the inability to determine the performance and material properties of the timber, which makes it difficult to ensure safety. Therefore, this study proposes a scheme to solve the problem by collaborating with universities equipped with the laboratory equipment necessary to investigate the following material properties. By collaborating with universities in designing, ensuring safety, and investigating material properties, we can promote the utilization of unused wood and add value to wood that has previously been processed into wood chips. The scheme for circulation is shown in Figure 2.

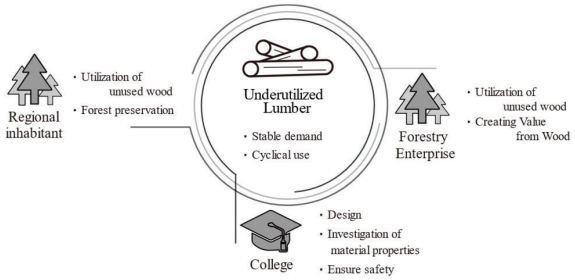


Figure 2. Scheme for Promotion of Forest Circulation

3.2 DESIGN OF FOREST CYCLES

We propose a forest cycle that takes into account the circular economy through a pavilion production activity using unused wood. We will discover wood that can be utilized before it is disposed of or turned into chips and find a way to utilize it through manufacturing. As the amount of large-diameter timber is expected to increase in the future, it is important to create demand for large-diameter timber. Although it has been considered in a wide range of fields in the past [4], it has not yet led to a stable demand. The design of the manufacturing process based on the relationship between the university and the town should take into account the flow of energy conversion. The design of forest circulation is shown in Figure 3.

https://doi.org/10.52202/080513-0008

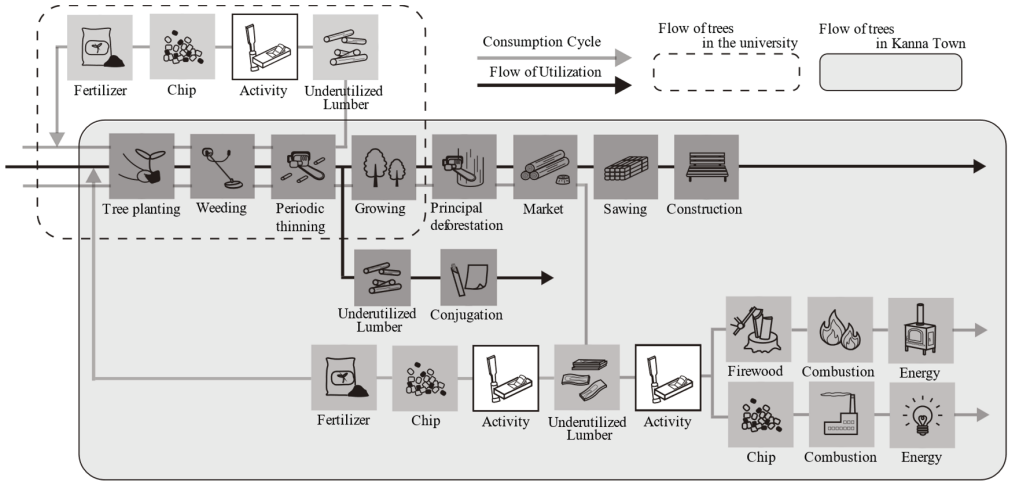


Figure 3. Design of forest cycles

4 – DESIGN PLAN

4.1 PROPOSAL FOR RECONFIGURABLE DETAILS FOR CIRCULATION

We have been participating in forest conservation activities for some time and have been learning about the state of the forest. Photo 5 shows a forest conservation activity. During the activities, we found that various species of trees will have to be thinned and felled in the future to maintain the forest cycle. Considering that the above-mentioned timbers will continue to be collected and will need to be utilized in the future, the design adopted a finish that allows partial replacement of materials in anticipation of deterioration over time. In addition, in order to facilitate the future processing of wood chips and paper materials, yatoi and hanasen were adopted as an easy dismantling method. When two pieces of lumber are joined together, the method of cutting them into a convex-concave shape and joining them together is called a "hozo" joint, a member with a convex-concave groove is called a "yatoi" a wooden wedge driven along a post to prevent the member from falling out of the post is called a "hanasen," and a piece of wood driven to join two members is called a "komisen. Since the joint detail is made up of these three repetitions, the design can be freely transformed by changing the length of the member or other elements as the demand for the pavilion changes. Detail for circulation is shown in Figure 4 and the method of joining is shown in Figure 5. Although woodworking requires a certain level of skill, these pavilions provide an opportunity for people to experience woodworking in response to the declining population shortage of carpenters. In addition, pavilions are temporary structures and are often discarded or left in storage after use. Therefore, the pavilion is designed to be used for events and as furniture for daily use, regardless of time and place.

Photo 5. Forest Conservation Activities

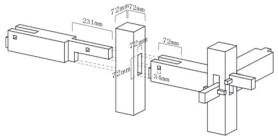


Figure 4. Detail for circulation

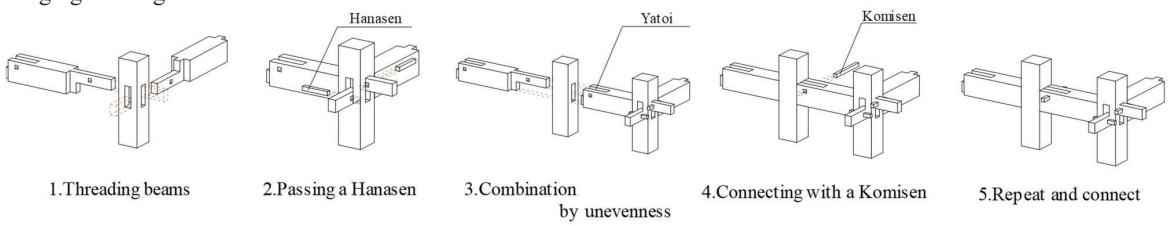


Figure 5. Joining Methods

https://doi.org/10.52202/080513-0008

4.2 MATERIALS AND DIMENSIONS

The structural members are made of 75 mm-square *Sugi* (Japanese cedar), the roof timbers are made of *Hinoki* (Japanese cypress), and the stopper is made of *Kashi* (oak). The design of the structure is composed of three elements: the structural material, the lumber for the roof, and the stopper, which allows the use of various species of trees. The overall dimensions are 4320 mm wide, 975 mm deep, and 2000 mm high. The entire structure consists of cubes of various sizes in 303 mm modules, which are combined to create a space for a resting area, a desk space, and a chair space, creating a place to stay. These spaces promote the circulation of wood of various sizes and species, and at the same time, allow for the incorporation of a variety of human activities. Figure 6 shows a plan view of the pavilion and Figure 7 shows a cross-sectional view.

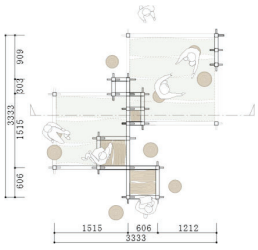


Figure 6. Plan

Figure 7. Cross-section

4.3 DRYING AND DIVERSION TO THE NEXT YEAR

The reason why the processing of large-diameter lumber is not widely available due to the aging population is not only the lack of machinery and manpower, but also the lack of drying areas and the lack of stable demand. The pavilion was designed to function as a place for human activities by using logs for drying and planks from large-diameter lumber. The planks do not require special machinery and can be produced by the machines generally owned by sawmills [5]. The materials to be dried are intended to be used in the future, and by encouraging the continuous use of the materials, a stable demand necessary for forest conservation is created. Photo 6 shows the pavilion being used at a university festival, and Photo 7 shows it being used as furniture at an exhibition.

Photo 6. Exhibition at the University Festival

Photo 7. Exhibition at the Business Arena

5 – CONSIDERATION OF AVAILABLE STRENGTH LUMBER

5.1 PURPOSE OF THE EXPERIMENT

The pavilion is constructed with a four-way piercing with a mortise and tenon stopper as shown in Figure 3 above. The wood is designed to be ungraded. On the other hand, the strength of wood is expected to be higher than that of ungraded wood. Therefore, a parametric study using material tests and static analysis was conducted to determine the appropriate Young's modulus of the wood for this joint detail

5.2 MATERIAL TESTING

The purpose of this test was to determine the strength and Young's modulus of the material and obtain values to be used in the analysis. Figure 8 shows the dimensions of the material to be tested, the distance between the support points and the equipment used. A vertical hydraulic jack was used to perform a push-off trisection four-point bending test at a loading speed of 0.25 mm/sec. The distance between the fulcrum points was determined based on the-tests' manual for structural wood [6] provided by the Japan Housing and Wood Technology Center. The test results of the specimens are shown in Table 1. Due to the small number of specimens, the lowest Young's modulus value of 7.34 kN /mm², and the lowest strength value of 20.40 N/mm² were used as reference values.

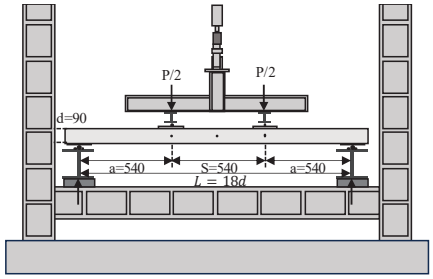
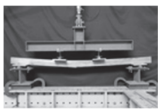


Figure 8. Fulcrum-to-fulcrum distance of a Vertical hydraulic jack

Table 1. Experimental Result of Specimen

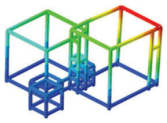
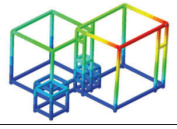
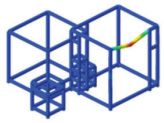
Specimen	1	2
Young's Modulus (kN/mm²)	8.32	7.34
Bending Strength (N/mm²)	44.67	20.40
Destruction Mode		

https://doi.org/10.52202/080513-0008

5.3 COMPARISON OF FULL-SCALE LOADING TEST AND STRUCTURAL ANALYSIS

Three directions (X, Y, and Z) were defined for the pavilion, and the deformations were compared when an arbitrary point was subjected to human force in the X, Y, and Z directions and when a load was applied using finite element analysis. For the force test, a digital hanging scale and a digital angle meter were used to measure the applied load and deformation angle. The model was created using the finite element analysis software midas iGen, and static analysis was performed. The pavilion model was created using beam elements, and the wood species was cedar with a specific gravity of 0.39. Table 2 shows a full-scale loading test and analytical simulations of displacement under loads in the X, Y, and Z directions, and Figures 9, 10, and 11 show graphs comparing deformation in each direction. The stiffness of the pavilion is considered to exceed the analytical value due to the accuracy of the horizontal tension in the experiment, and it was confirmed that the experimental and analytical values corresponded well in the relationship between load and displacement.

Table 2. Experimental Result of Specimen

Z Y X	Photo of tensile testing	Deformation (Analysis)
X-direction		
Y-direction		
Z-direction		

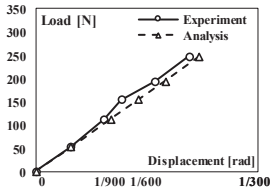


Figure 9. Load-displacement graph of X-direction

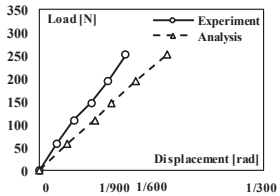


Figure 10. Load-displacement graph of Y-direction

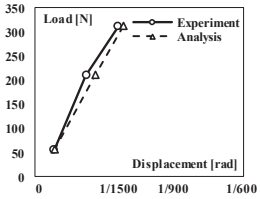


Figure 11. Load-displacement graph of Z-direction

5 – CONCLUSION

This study proposed a circulation system, a pavilion that can be dismantled and reassembled, and a conversion method using wood that is not used as building material. By doing so, the project contributed to the circulation of forests, and at the same time, it created a place for people to be, regardless of time and place, as it was used and made known to many people through exhibition opportunities. When considering the design of circulation, we believe it is important to create added value. Since it is necessary to verify material properties and safety as a structure when considering a circulation system, the necessity of participation by research institutions such as universities was reaffirmed in order to realize this circulation system. It was also suggested that a society that is sustainable and can respond to changes can be created by having local organizations work together to address issues. The issue of unused timber is one that has arisen over the course of history, and it is necessary to consider what is necessary not only for the present, but also for the future, as we consider how to utilize forests.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Takashi Ayabe of Ayabe Corporation, Mr. Teppei Ikezawa of the Kannagawa Forestry Association, Professor Hiroyuki Ose and Ms. Tamae Fujino of the Komorebi-no-Mori Satoyama Support Team for their generous cooperation in this research. We would like to express our gratitude to them.

REFERENCES

[1] Rinyacho : REIWA 5 NENDO SHINRIN RINGYO HAKUSYO, 2024 (in Japanese) (accessed 2025-01-28) (https://www.rinya.maff.go.jp/j/kikaku/hakusyo/r5hakusyo/attach/pdf/zenbun-38.pdf)

[2] Seiji IWANAGA, Masato HAYAHUNE, Wataru TANAKA, Yuji IKAMI : REALITY AND CHALLENGES OF DOMESTIC LARGE-DIAMETER TIMBER UTILIZATION IN

JAPANESE SAWMILL INDUSTRY, Chubu forestry research, No.68, pp.57-58, 2020 (in Japanese)
DOI 10.18999/chufr.68.57

[3] Yumiko MATSUMOTO : CURRENT STATUS OF PLANTATION FORESTRY IN PRIVATELY OWNED FORESTS AND EFFORTS FOR EFFECTIVE USE OF LARGE DIAMETER LOGS, Boreal Forest Research, Vol.70, pp.5-8, 2022 (in japanese)
DOI https://doi.org/10.24494/jfsh.70.0_5

[4] Kazuki MIYAMOTO : INTRODUCTION TO SPECIAL ISSUE: HOW SHOULD WE COPE WITH AGING OF CONIFER PLANTATIONS IN JAPAN ?, Journal of the Japanese Forest Society, Vol.97, pp.169-170, 2015 (in Japanese)
DOI https://doi.org/10.4005/jjfs.97.169

[5] Hideki AOI : THE POSSIBILITY FOR FINDING OUT THE POTENTIAL DOMESTIC WOOD DEMAND ON ARCHITECTURAL FIELD BY USING WOOD BASED CONSTRUCTION MATERIAL MADE FROM BOARD, Journal of the Japanese Forest Society, Vol.97, pp.208-213, 2015 (in Japanese)
DOI https://doi.org/10.4005/jjfs.97.208

[6] Japan Housing and Wood Technology Center : Tests manual for structural wood, 2011 (in Japanese) (accessed 2025-01-28)
(https://www.howtec.or.jp/files/libs/1828/201712121507021978.

https://doi.org/10.52202/080513-0008