THE ROLE OF WOODEN ARCHITECTURE IN SUSTAINABLE SOCIETIES IN VIETNAM

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ABSTRACT: Constructed with sustainable materials, wooden buildings are attracting attention for their potential contributions to maintaining and preserving the environment and reducing the environmental burden. Further, raw wood material is renewable and recyclable based on sustainable forest management and can absorb and store carbon dioxide during its growth and use. The potential of wooden architecture in Vietnam is discussed from the perspectives of culture, earthquake resistance, durability, fire protection, and energy conservation, and also its contribution to the local economy.

KEYWORDS: wooden architecture, earthquake resistance, durability, fire resistance, energy saving, carbon fixation, construction.

TÓM TẮT: Thông qua việc thể hiện thiết kế và thi công trong dự án nhà gỗ mẫu IBST, chúng tôi sẽ giới thiệu cách tiếp cận trong thiết kế và thi công các công trình kết cấu gỗ ở Việt Nam và các nước Đông Nam Á khác, đồng thời thảo luận về những thách thức liên quan đến công trình kết cấu gỗ ở Việt Nam cũng như các ý tưởng để giải quyết, khắc phục.

TỪ KHÓA: Kiến trúc gỗ, chống động đất, độ bền, chống cháy, tiết kiệm năng lượng, cố định carbon, xây dựng.

1. INTRODUCTION

Vietnam's first UNESCO World Heritage Site, the Complex of Hue Monuments, and Japan's first, the Buddhist Monuments in the Horyu-ji Area (Figure 1), were both entered in the UNESCO World Heritage List in 1993. Since that year, many other wooden buildings in Asia have likewise made it onto the UNESCO World Heritage List. It has thus been 30 years since the value of the wooden


Figure 1. Complex of Hue Monuments (left) and Buddhist Monuments in the Horyu-ji Area (right)

architectural culture in Vietnam and Japan started receiving wide recognition around the world.

Of the remains that we can see today, the Boi Khe Pagoda (Chùa Bối Khê, Thanh Oai, Hà Nội), the Dau Temple (Chùa Dâu, Thuận Thành, Bắc Ninh), the Dinh Tay Dang (Đình Tây Đằng, Ba Vì, Hà Nội), and other buildings that have weathered hundreds of years of exposure to the elements can be found in various parts of Vietnam. The dinh, mausoleums, temples, palaces, clan shrines, and traditional houses that served as traditional Vietnamese community centers all used to be made of wood. It is known that not only the Viet people (Người Việt) but many ethnic groups in Vietnam have their own unique culture of wooden architecture. Vietnam is rare in a global context and has a very diverse wooden architectural culture.

While influenced by the wooden architecture of successive Chinese dynasties since ancient times, Vietnam gradually cultivated its own architectural culture owing to differences in vegetation and climate, which is a feature it has in common with Japanese traditional architectural culture. At the same time, despite the origins of wooden buildings in Vietnam and Japan from a similar civilization and technologies, there are surprising differences in architectural expression, with a relationship like that of relatives who share a common ancestor.

With the introduction of Japanese wooden architecture to Vietnam, we would like to present what has been done in this project, what we want to do, and the challenges of spreading wooden architecture in Vietnam in the future.

2. LDK'S VISION

During the reconstruction period after World War II, Japanese wooden architecture developed as an approach to providing housing, which is one of three things essential to people's everyday living: "food, clothing, and housing." Currently, 82.2% of low-rise houses with three or fewer floors are wooden constructions (according to a 2019 survey by the Ministry of Land, Infrastructure, Transport, and Tourism). Some of the main reasons for this are that there are 300,000 carpenters in Japan, there are building standards especially for wooden houses, standardized wooden construction materials are always available anywhere, and it is supported by the government as a core pillar of the domestic demand industry so that "anyone can build anytime, anywhere," while a revision of the Building Standards Act follows every major earthquake, creating a system that ensures a certain level of quality through individual building checks. The public thus knows that the wooden houses they are comfortable living in and familiar with are "safe, secure, and pleasant."

In 1966, the Japanese government formulated the first "Five-Year Housing Policy Plan," which has advanced from providing a large number of accommodations to improving housing quality in the course of eight such plans over a 40-year period. By industrializing and developing standards for earthquake resistance, durability, and fire resistance, which used to be challenges for wooden houses, a "housing industry" has been created that stimulates the economy through 22 trillion yen in housing investment and 18 trillion yen in related industries. Today, it is a sustainable industry with an extremely low environmental impact, with wooden architecture starting to spread from residential to non-residential projects as society moves toward carbon neutrality.

The circumstances differ from those described above in Okinawa, with 95% of low-rise houses being reinforced concrete structures. A major factor behind this was that the United States was in charge of the reconstruction until 1972, when the prefecture was returned to Japan. However, it currently has the highest rate of increase in wooden housing among all 47 prefectures in Japan, Japanese builders, always on the lookout for new housing markets, have begun to enter the Okinawan market, and Life Design Kabaya is one of these builders. When it comes to durability, comfort, and energy saving for Okinawan houses, the reference point is houses in subtropical regions rather than wooden houses in Japan, further expanding the possibilities to housing in humid regions around the world, including Southeast Asia.

In 2019, Life Design Kabaya established a subsidiary in Hanoi, Vietnam, as a CAD center to expand its Japanese detached housing business. Meanwhile, Life Design Kabaya started hiring Vietnamese carpenter trainees as a measure to counter the increasing average age of carpenters. However, considering that Vietnamese trainees who have completed their carpentry training in Japan work in Vietnam, as well as the prospect of decreased housing demand in Japan in the future, we realized that the essence of our Vietnam business should not lie there but in creating and fostering a new industry by utilizing advanced Japanese wooden construction technology. Vietnam, which historically has ties to the same Chinese culture as Japan, is familiar with wooden culture, so we thought that a large market can be created if engineers from both countries cooperate with each other.

In 2022, we met with the Dr. Vu Ngoc Anh, Director of the Science and Technology and Environment Department of the Vietnamese Ministry of Construction and explain about the initiatives and ideas of Life Design Kabaya. A new point of contact with IBST was created. We were given the opportunity to build a wooden model project on the IBST site. It is a joint project, with IBST handling the architectural design and Life Design Kabaya the structural design, including wooden construction only by Life Design Kabaya. We also agreed to write a guidebook on the design and construction of wooden buildings in Vietnam and to develop wood strength standards.

To give an overview of the IBST wooden model project, it involves the creation of a two-story wooden building with a total area of 195m^2, with the construction materials for the posts and beams made Japanese cedar glulam (glued laminated timber) that has treated wood conservation treatment, and Japan cedar CLT[1)] (cross laminated timber, 90 mm thick, 3 layers, 3 plies) that has treated wood conservation treatment as the roof boards (Figure 2).

In parallel with this project, we are promoting industry-academia collaboration with the Hanoi University of Civil Engineering. This study is a joint research project on the production and of wood and wooden materials used in Vietnam and an evaluation of their strength characteristics.

3. WOODEN MODEL CONSTRUCTION

3.1. Earthquake Resistance and Wooden materials

The wooden model construction, we constructed for this project used the "timber post and beam construction method." A "post and beam construction method" involves putting together a framework with elongated straight members such as posts, sills, and beams as well as fixing the bearing panel materials and braces to make a structure that resists both vertical and horizontal forces such as wind pressure and seismic forces. More than 70% of wooden houses built in Japan are built using this method, making it the mainstream architectural construction method even for large wooden buildings.

The wood used includes glued laminated timber[2)], construction plywood[3)], and CLT as specified in the Japanese Agricultural Standards, all of which are high-quality wooden materials that ensure strength and durability. The glued laminated timber and CLT were made of Japanese cedar, which is the most planted wood in Japan (Table 1).

Moreover, metal joints were used to connect wooden materials that pre-cut wood (Figure 3). The

Figure 2. IBST wooden model construction

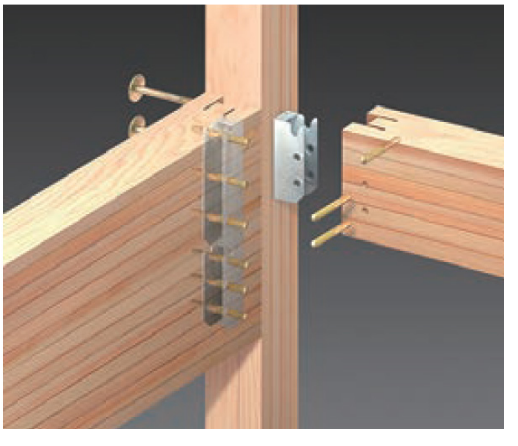


Figure 3. Example of metal joint (BX Kaneshin)

Table 1. Japanese performance values for the glued laminated timber used in the wooden mode

Tree	Standard strength "F" (N/mm^2)					Young's Modulus (N/mm^2) E_b
	Compression F_c	Stretching F_t	Bending F_b	Shearing F_s	Embedment F_{cv}	
Cedar (ungraded)	17.70	13.50	22.20	1.80	6.00	7000
E65-F255	20.60	18.00	25.50	2.70 2.10	6.00	6500
E65-F255	16.70	14.60	22.50 15.00	2.70 2.10	6.00	6500

strength of each joint is also comfirmed by Japanese performance evaluations. In addition, installing glued laminated timber, which is a new material in Vietnam, and joints using it, IBST conducted the evaluations of the strength performance of these materials and joints in order to verify their performance (Figure 4).

Figure 4. Shear failure test of metal joint by IBST

Furthermore, the wooden model was designed based on Japanese building standards4); compared to Vietnamese building standards5), 6), Japanese building standards are needed 10 times more resistant to earthquakes, while indicating essentially the same values as Japanese and international building standards when it comes to wind and vertical load resistance. Thus, the earthquake proof performance Fully sufficiently satisfy Vietnamese standards.

3.2. Durable Design

3.2.1. Moisture Control in Building Envelopes

In terms of ensuring the durability of wooden constructions, the main difference from reinforced concrete structures is ensuring wooden material dryness. Unlike concrete, excessive moisture in wooden materials induces wood decay and termite attack, significantly reducing its structural strength. As a countermeasure, it is essential to (1) not wet the wooden materials and (2) to dry it quickly if it gets wet. In particular, a double and triple fail-safe approach is adopted for waterproofing and drying, because moisture penetration into the layer of the wooden materials must be avoided at all costs.

For this wooden construction model, moisture control methods for Japanese wooden houses we are modified and incorporated by taking into account Vietnam's climate conditions.

1) Roof: A pitched roof is used to prevent rainwater from stagnating on horizontal plane, and a gutter is provided to prevent rainwater adhering to the outer surface of vertical walls by flowing down from the roof edge. By having an overhangs with a

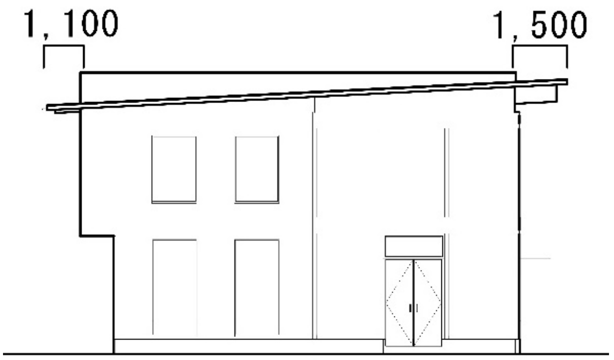


Figure 5. Eaves of the IBST wooden model

length of more than 1,000 mm, direct rain impact on the outer surface of the walls is reduced (Figure 5). For waterproofing, not only regular roof tile but also asphalt roofing with adequate sealing around fasteners is applied to the upper surface of the roof board as a secondary waterproofing layer.

2) Exterior walls: The exterior system uses a dry construction method with cement boards. As with the roof, asphalt felt is placed on the outside of the base material as a secondary waterproofing layer for the exterior wall, and double measures are taken to prevent rain penetration into the inner layer of the secondary waterproofing. A outer vented cavity is provided between the exterior and the secondary waterproofing layer to drain rainwater that has reached the back of the exterior material and to avoid moisture penetration into the inside of the secondary waterproofing layer by pressure equalization effect (Figure 6).

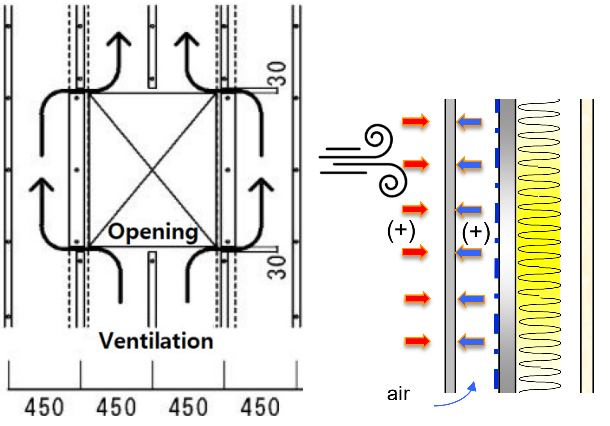


Figure 6. Example outer vented cavity

3) Measures to prevent condensation (both exterior walls and roof): Assuming use of air conditioning system (cooling device), it is necessary to prevent internal condensation caused by the installation of insulation materials on the inside of the sheathed shear wall and ceiling. For this wooden construction model, asphalt felt was used as a vapor retarder in combination with a

secondary waterproofing layer to prevent internal condensation and vapor inflow in the layer of the wooden materials, arising from moisture sources in the outdoor air. Moreover, a internal vented cavity was employed in the interior of the external walls and roof to ensure a dehumidification effect from the air conditioner (Figure 7).

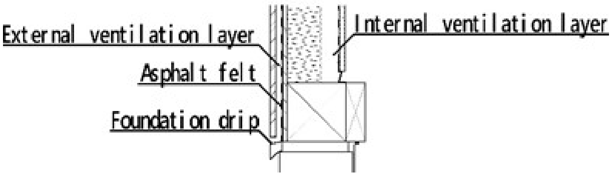


Figure 7. Secondary waterproofing layer and ventilation layer

3.2.2. Moisture Content of the Wood Material

The basic moisture content of wood is internationally established at 12%. However, since this varies depending on the environment, various performance values need to be determined based on actual moisture content. Looking at the production of glued laminated timber in Japan, the moisture content of the lamina making up the timber is about 10%, which hardly changes even when laminated, bonded, and shipped as glued laminated timber. Later, when used in construction, it is generally around 10–12%. On the other hand, considering the temperature and humidity conditions in Vietnam, the moisture content of wood is thought to be around 20%. The strength performance of wood decreases slightly as the moisture content increases, but the risk of wood deterioration rises sharply when the moisture content reaches around 26–30%. Thus, it is necessary to take measures to protect the materials shown in 3.2.1, and if treated appropriately, the increase in moisture content due to the outside air environment does not pose such a high risk. Additionally, technologies exist for chemical decay resistance treatment of wood to improve material durability involving chemical injection and application technology that makes it possible to prevent decay in the form of biodegradation and damage from termites. However, continuous treatment is required.

3.2.3. Preventing Corrosion of Metal Fittings

It is necessary to apply appropriate rust prevention measures so that metal components do not corrode. Since metal corrosion is an electrochemical reaction, increased moisture content and concomitant heightened electrical conductivity in the wood also cause an increased metal corrosion rate. This suggests that it is desirable to keep the moisture content of the wood as low as possible. It is also known that some wood preservatives for durability treatment increase the metal corrosion rate. For example, metal fittings that come into contact with chemicals containing copper corrode faster because iron has a higher ionization tendency than copper. Accordingly, it is desirable that the material of the metal fittings be stainless steel, or that a composite film made of barrier-type coating and sacrificial anti-corrosion coating be applied.

3.2.4 Demonstration of Durable Design in an Experimental Building

Before the wooden model was constructed, a wooden experimental building was installed in Hanoi in 2022 to verify the construction of the building and survey the environment inside the building for one year using wooden building thermal specifications for hot and humid regions as an environmental demonstration. Thermal specifications for wooden buildings in hot and humid climates are based on the high temperature and humidity of the region throughout the year, and the measurements were carried out to ensure that the dry state of the wood in the structural frame and a comfortable living environment are maintained indoors, where air conditioners are used. The key points of the design are: ① increasing the thermal insulation of the roof to block strong sunlight, ② completely blocking the flow of moisture from the exterior walls to the inside, ③ building a ventilation layer to keep the inside of the exterior walls dry at all times, and ④ using eaves and awnings to reduce rainfall on the wall surface to minimize the risk of water leakage into the exterior walls (Figure 8).

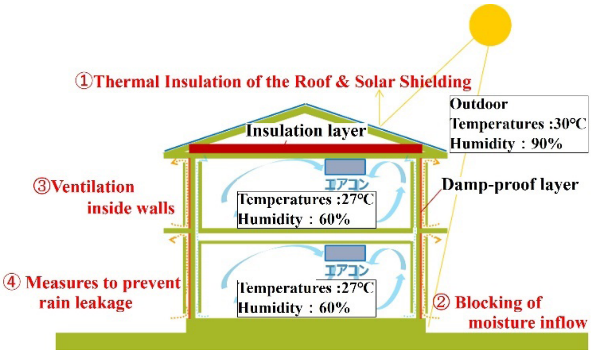


Figure 8. Image of wooden thermal specifications for hot and humid regions (modified)

The demonstration experiment was carried out at the experimental building to determine whether ② and ③ could be realized throughout the year. We installed temperature and humidity sensors outdoors, indoors, and inside the exterior walls of the wooden experimental building. The data for the south wall, which had a large temperature difference and unfavorable conditions, are presented here (Figure 9).

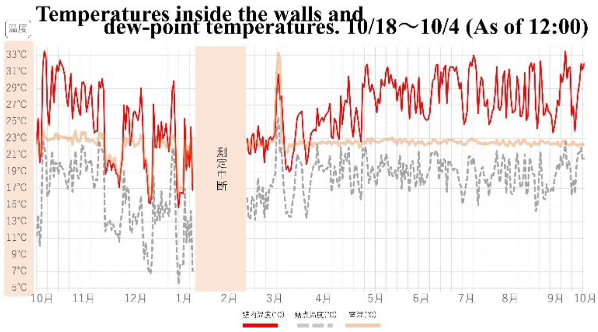


Figure 9. Temperatures inside the walls and dew-point temperatures in the wooden experimental facility building

The results showed that in the summer, with high outdoor temperatures and , the inside wall temperature never dropped below the dew-point temperature even when the interior temperature was lowered by air conditioning, which confirmed that internal condensation did not occur inside the exterior walls.

3.2.5 Wood Durability Verification

In Section 3.2.1, we discussed measures against decay and termite damage induced by wet wood, which significantly reduce the wood's structural capacity. Here, we discuss the possibility of using preservation techniques on wood grown in temperate regions for use as a building material in hot and humid areas.

In Japan, the Japanese Agricultural Standards stipulate standards for wood preservation treatment (Table 2).

Wooden buildings in Japan are covered by the Building Standards Act, which defines the performance classification of the wooden foundation in direct contact with the foundation as K3. For the IBST wooden model, all wood was treated with a K4-equivalent preservation treatment, which is a performance category defined for regions with significant decay and termite damage for materials directly exposed to the elements outdoors. However, although K4 treatment was used for safety reasons, we intend to verify whether K3 will suffice as a wood preservation treatment for use in construction in Vietnam in the future.

To this end, we conducted exposure tests in Hanoi starting in 2021 using two methods: the Japanese Industrial Standard (JIS K 1571) test for confirming the effectiveness of wood preservation treatment, and the American Wood Preservation Association (AWPA) confirmation test.

In the JIS test (Figure 10), 30 mm square cedar rods of 350 mm and 600 mm length are buried in the ground to check the degree of decay over time. In the AWPA confirmation test (Figure 11), cedar laminate 120 mm × 300 mm × 300 mm is installed

Table 2. JAS Performance Classification of Wood Treatment Agents [8)] (modified)

Perfor-mance clas-sification	Condition for use of wood	Specific content
K1	Indoors in dry conditions with no risk of decay or ant damage, and only requires insect repellent performance against dry wood pests.	Lyctus brunnerus on te starch present in the sapwood of broad-leaved trees such as lauan and oak. Therefore, co-niferous tress such as cedar wood are not subject to this treatment because they do not suffer from feeding dam-age.
K2	It can be expected to have a high degree of durability under conditions where there is a risk of decay and ant damage at low temperatures.	For building materials in relatively cold regions. For example, the evaluation method standards of the "Act on Promotion of Housing Quality Assur-ance" require that wooden foundations used in cold regions be treated to a grade equivalent to K2 or higher.
K3	A high degree of durability can be expected under conditions where there is a risk of normal decay and ant damage.	For building materials such as foundations. For example, the evaluation method standards of the "Act on Promotion of Housing Quality Assurance" require that wooden foundations used in cold regions be treated to a grade equivalent to K3 or higher.
K4	A high degree of durability can be expected under conditions where there is a risk of more severe decay and ant damage than usual.	For parts exposed directly to wind and rain out doors. It is desirable to use sawn timber of performance class K4 for construction parts in ares with severe decay and ant damage.
K5	Products that can be expected to have a high degree of durability in environments where there is a high risk of decay and ant damage.	For parts that require extremely high durability, sich as utility poles, railroad ties, and underwater use.

so that it does not directly contact the ground with a ventilated cover to prevent exposure to rain, and the degree of decay is checked over time.

In the two years since the start of the experiment in October 2021, almost no decay has been observed in the test specimens preserved equivalent to the performance classification K4 of the wooden model.

Figure 10. JIS Verification Test

Figure11. AWPA Verification Test

3.3. Thinking about Fire Resistance

Wooden buildings are considered more flammable, but the proportions of fires in wooden and non-wood construction types shown in Table 3 are 56% for wooden buildings and 44% for non-wood buildings. Thus, as far as fire cases are concerned, it cannot be concluded that wooden buildings are significantly more flammable than non-wood buildings. In other words, wood construction does not necessarily lead to a higher frequency of fires than reinforced concrete or steel constructions. Table 3 shows that the fire spread rate and the number of fire spread cases are much higher wooden structures than for non-wooden structures but, and in Japan, even wooden structures can be made quasi-fire-resistant equivalent to fire-resistant buildings, based on an evaluation of their performance in preventing the initial spread of fire, evacuation safety, and other factors. The concept of fire resistance in Japan is as follows.

The main fire-resistance performance requirements for buildings in Japan are ① performance to prevent fires from starting easily (fire prevention performance), ② performance that prevents fire from expanding and spreading quickly in the early stage (initial fire spread prevention performance), ③ performance to allow safe evacuation (evacuation safety performance), ④ performance to limit the extent of the fire and prevent collapse (fire prevention/fire resistance performance), and ⑤ performance supporting firefighting activities (firefighting activity support performance). Most of these require a certain level of fire resistance for buildings or parts of buildings according to location, scale, use, etc., due to laws, notifications, and so forth.

In terms of location, fire prevention district and quasi-fire prevention district require certain levels of fire-resistant performance from fire-resistant and quasi-fire-resistant buildings to prevent or control the spread of fire between buildings, as well as exterior walls, eaves, openings, and other "parts that

Table 3. Damage to Fire-Resistant Buildings by Fire Origin[9] (modified)

Structure type		2021				
		Number of fires		Fire spread rate (%)	Number of fire spread	Burnt floor area per incident (m²)
Wooden structure	Wooden structure	7,543	9,629 56%	31.6	2,383	76.7
	Fire preventive structure	1,826		14.4	263	31.4
	Quasi-fire-resistant Wooden structure	260		10	26	28.3
Non-wooden structure	Quasi-fire-resistant Non-wooden structure	2,209	7,659 44%	7.3	161	44.4
	Fireproof structure	5,450		1.8	100	15.3
Others, unknown		2,261		30	681	72.4
Whole of structure		19,549		18.5	3,614	50.6

** Created based on the damage status by structure of the fire source building in the 2021 Fire Service White Paper.*

** Fire spread rate is the percentage of fires that spread to other buildings other than the building where the fire started.*

** The number of fire spread is the number of fires that spread to other buildings other than the building where the fire started.*

may spread fire" having specific requirements.

In terms of scale, wooden construction is expected to be up to about four floors in height. Large buildings catching fire are difficult to extinguish and also have a significant impact on the surrounding area upon collapsing, so fire resistance and fire-resistant performance are required of the main structural parts (pillars, heights, walls, floors, stairs, roofs, and eaves) depending on the height and area of the building.

In terms of use, buildings with a large number of users such as shops and schools, or buildings such as warehouses where large amounts of combustible materials are brought in, are required to have fire resistance and fire-resistant performance for fire-resistant buildings, quasi-fire-resistant buildings, and buildings with measures to prevent collapse during an evacuation to ensure evacuation safety and minimize the magnitude of impact in the event of a fire.

Among these performance requirements, wooden buildings are recognized as quasi-fire-resistant buildings equivalent to fire-resistant buildings based on the concept of "burning space (calculation)" (Table 4). "Burning space" is a concept that takes advantage of the slow rate of burning of wood, such that even if it catches fire, the thickness of the wood ensures a predetermined amount of time until the building collapses, during which evacuation and protection of human life is possible. Therefore even wood is an excellent fire-resistant covering material. Thus, legislation is being developed to further expand the treatment of the fire resistance of wooden buildings (Figure 12).

The rate of carbonization of wood varies with the material and adhesives used but is approximately 0.75 to 1.0 mm/min (Table 4), which means that a thickness of about 60 mm is enough to secure about 1 hour for evacuation without the remaining area collapsing. Beams, columns, and other parts of such quasi-fire-resistant structures are required by law to be used after tests have been carried out to confirm the prescribed performance.

Life Design Kabaya has also obtained ministerial certification for quasi-fire-resistant structural walls used in wood-frame construction methods; an example follows.

Fire resistance requirements: Exterior walls for quasi-fire-resistant construction (45 minutes)

Structure: Wooden-frame construction method

Coating specifications: (Exterior) ceramic siding, (Interior) CLT 60 mm thick

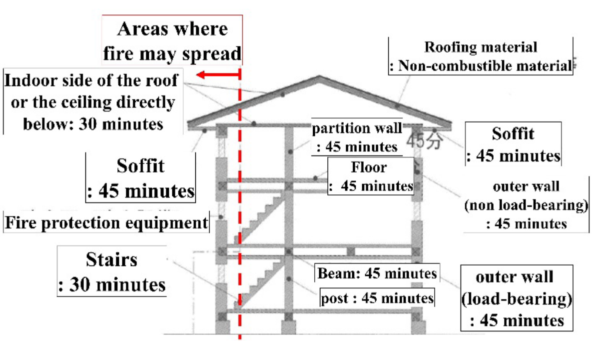


Figure 12. Overview of a quasi-fire-resistant structure [10] (modified)

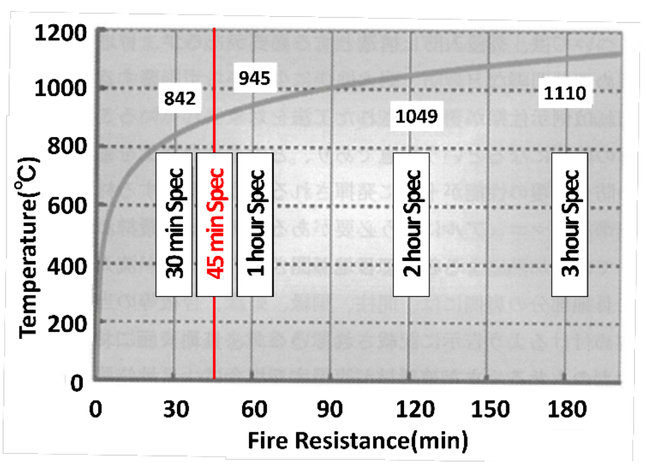
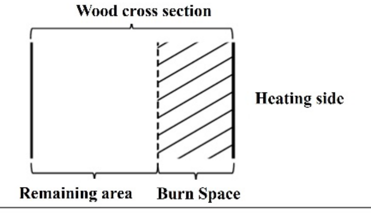


Figure 13. Standard heating temperature-time curve (modified)

Table 4. Fire-Resistance Duration and Burn Space Dimensions

Fire resistance time	Burning Space dimensions of columns and beams		Burning Space dimensions for walls, floors, and roofs (CLT etc.)	
	Laminated wood	lumber	Resorcinol phenolic resin adhesive	Adhesives other than those listed on the left
45分	30mm	45mm	35mm	45mm
60分	45mm	60mm	45mm	60mm



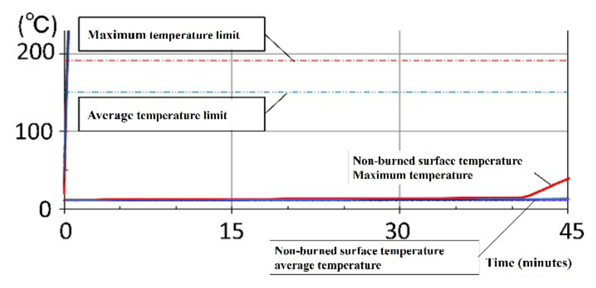


Figure 14. Test results of non-burned surface temperature

The test was performed in a combustion furnace with the heating temperature and time curve shown for the burned surface in Figure 13, and we found that the temperature of the non-burned surface did not exceed the specified values and that the structure did not collapse during the fire resistance time (45 minutes). This shows that both the average and maximum temperatures of the non-burned surface did not exceed the limit values, as shown in Figure 14, and that the structure did not collapse, as shown in Figure 15. A cross-sectional view of the specimen follows (Figure 17).

Figure 15. Non-burned surface after test

Figure 16. Burned surface after burn test

Regarding the fire resistance performance of Japanese wooden houses, it is important for the fire not to spread from or to adjacent buildings and for buildings not to collapse before enough time has passed to enable evacuation. For the wooden model, the exterior walls were made of cement boards and the adjacent building was made of reinforced concrete, so the risk of fire spreading was relatively low. Calculations for the burning space are carried out taking into consideration the burning speed of laminated wood, which burns only to a thickness of 45mm in 60 minutes. This means that by using glued laminated timber with a large cross-section, it is possible to secure time to rescue people inside while preventing the building from collapsing. It turns out that although wood is a material that burns, it takes quite some time to burn down.

3.4. Energy-Saving Design

Due to the effects of the monsoon, which is highly characteristic of Southeast Asia, Vietnamese outside air has high temperature and humidity throughout the year, with cooling energy being significant to maintain a comfortable indoor environment. For this reason, solar shading and airtightness were applied for the external walls and windows of the wooden model to prevent inflow of excessive heat and moisture from the outdoor environment. Moreover, high-efficiency facilities were introduced, because energy is consumed by the building facilities.

1) Enhancing Thermal Resistance and Airtightness in Exterior Walls and Ceilings

Thermal insulation materials were installed inside the sheathed shear wall and above the ceilings boards to reduce heat flow through the building envelopes. The building frame should be

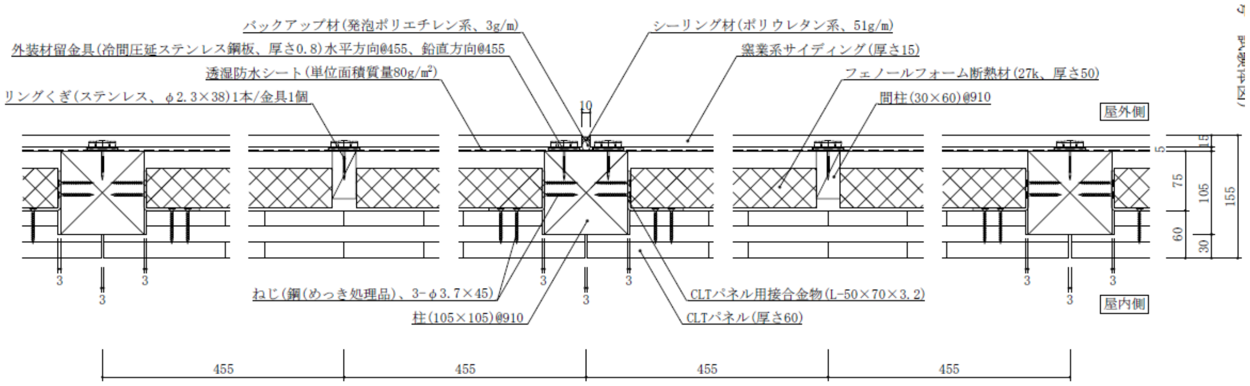


Figure 17. Cross-section of the test piece

insulated at the same time as the airtight measures are implemented, and the outside of the insulation layer should be taped or sealed to prevent the entry of high-humidity air from the outside.

2) Solar Shading for Windows

Since 70% of solar radiation into a building penetrates windows, it is essential to employ solar shading for windows. On the south side, by ensuring sufficient dimensions of the eaves, solar gain through the windows can be reduced as much as possible. As for the east and west directions, it is desirable to reduce the amount of solar gain through the windows by employing solar shading materials such as low-emissivity double-glazing and blinds.

3) Using High-Efficiency Building Facilities

Cooling system: As a cooling device, heat pump-type air conditioners are employed. In order to reduce the energy consumption of the heat pump-type air conditioners, proper model with cooling capacity and coefficient of performance (COP) should be selected. The cooling capacity is determined by cooling load of the room, which is equivalent to summation of internal heat generation and heat flow through building envelopes. As for COP, a device with higher value means better energy efficiency.

Figure 18. Wooden Experimental Building

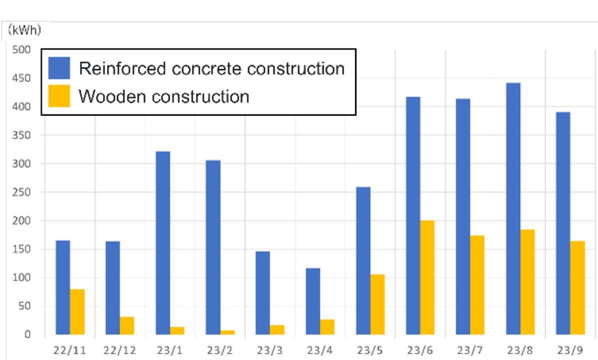


Figure 19. Reinforced Concrete Classroom

Lighting equipment: In order to save energy with the lighting equipment, it is desirable to use LEDs as the light source and to avoid unnecessary lighting by using motion sensors and timers in rooms that are only lit for short durations, such as corridors and toilets.

4) Comparing Reinforced Concrete and Wooden Constructions

We compared one room in the wooden experimental facility building with one room on the first floor of a five-story educational facility located in Hanoi made from reinforced concrete with an equivalent area. The wooden experimental building has insulation on its roof and external walls (Figure 18), while the reinforced concrete building is on the first floor, faces the outside air in three directions, and has no thermal insulation (Figure 19). The same air conditioner was installed in both rooms with the temperature set to 23°C, and the electricity consumption under normal operating conditions was compared (Figure 20). During the period of experimentation, almost no people entered or left the wooden building, while the concrete classroom saw a few. The wooden building was insulated, and the reinforced concrete classroom was not.

According to Figure 20, the wooden structure clearly consumed less electricity, and there was a large difference apparent during the relatively cooler months of the year. This result confirms that insulation of the roof and exterior walls can minimize heat intrusion from the outside and significantly minimize the energy required for air conditioning. Further, the non-insulated reinforced concrete construction saw a large amount of heat entering from the concrete of the frame, increasing the air conditioning load

Figure 20. Comparison of electricity consumption in the reinforced concrete and wooden structure

to maintain the set temperature, thus increasing electricity consumption. Therefore, it was suggested that with continuous air conditioning, insulation may yield highly energy-efficient specifications even in a hot and humid region such as Vietnam.

3.5. Environmental Contribution of Wood (Carbon Fixation and Decarbonization)

In recent years, we have been faced with the challenge of improving the total amount of carbon dioxide emitted during a building's lifetime: construction, maintenance, renovation, and demolition. As shown in Figure 21, wooden buildings store more carbon and emit less carbon dioxide during material production than reinforced concrete or steel-framed buildings. Therefore, expanding the use of wood construction can help reduce carbon dioxide emissions through the carbon storage effect of wood and its replacement with steel and concrete building materials.

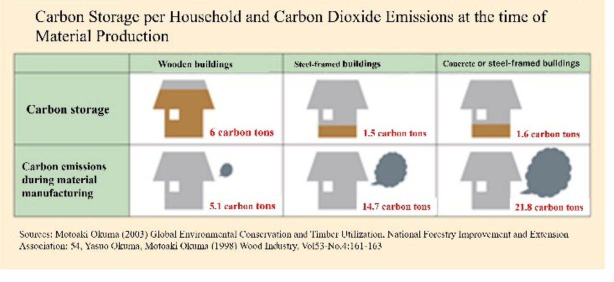


Figure 21. Carbon Storage per Household and Carbon Dioxide Emissions at the time of Material Production[11)]

Next, from the perspective of recycling resources, in order for wood used in wooden architecture to be considered a renewable resource, the life span of the wooden buildings must be longer than the time required for forest growth. That is, if wooden buildings are maintained and used socially for about 100 years, including reuse and recycle, it will enable sustainable carbon fixation based on wood that grows in 70–90 years.

In order to maintain the amount of carbon dioxide absorbed, it is necessary to harvest at the right time in sustainably managed forests meant for timber production, always followed by forest rejuvenation through reforestation. It can be said that increasing the number of wooden buildings will indirectly contribute to the forest rejuvenation and restoring the absorptive function. Further, while concrete is a finite building material that cannot be reused, wood is highly sustainable and can be repurposed to make furniture or components even after the structure containing it is dismantled.

Wooden buildings also have direct carbon storage effects. In the IBST wooden model, there is a carbon storage capacity of about 6 t-C in the 195m^2 total area, assuming that the basic unit of wood input is 0.2m^3/m^2 and the air-dry density of Japanese cedar wood used is 0.35 t/m^2. Since it has been estimated that the carbon storage capacity of 35-year-old Japanese cedar is 68 kg-C[7)], this corresponds to 87 cedar trees. In the future, when concrete buildings are replaced by wooden buildings, a considerable amount of wood and wood-bound carbon will exist in urban areas. This is why wooden buildings are also referred to as "urban forests."

4. CHALLENGES OF WOODEN HOUSING IN VIETNAM

4.1. Timber Evaluation and a Shift from Imported Timber to Domestic Timber

In considering the effectiveness of using wood to tackle environmental problems, as these are attracting worldwide attention, we believe that using domestic timber in Vietnam, which emits less CO_2 during transportation than when using overseas timber, marks an important shift. In Vietnam at present, domestic timber accounts for 60% of the total volume of timber handled, of which acacia, eucalyptus, and pine make up 56%, 4%, and 7%, respectively, of the plantation area. The most common uses of this timber are wooden furniture, plywood, pellets, and chips. We expect that adding "building material" as a use for wood will increase afforestation through economic stability, and enhance the price stability of building materials. However, these tree species need to be assessed as building construction materials in Vietnam.

The performance evaluation experiments we are conducting on wood and wood materials in collaboration with IBST and Hanoi University of Construction are crucial. This is because, in order to promote wooden architecture in Vietnam, we believe that this approach can help facilitate evaluations for the use of Vietnamese domestic wood in construction, the proposal of simple joining system, and the development of design and construction as described below.

First, as an industry-academia collaborative initiative, we predict that an early task will be the selection and evaluation of useful tree species through joint research on wood with the Hanoi University of Civil Engineering. Currently, it is important to select tree species that can be obtained continuously at a low unit price in Vietnam or from neighboring countries, evaluate their performance, and manufacture and evaluate wood face materials using these materials, especially glued laminated timber and structural plywood. It is expected that the performance of Vietnamese domestic wood will be higher than that of the main tree species used in Japan because denser tree species can be obtained.

Next is the performance evaluation and development of metal joints. Regarding evaluation related to long-term performance in consideration of vertical load, this should not differ so much from country to country, so we anticipate that the metal fittings needed will be more or less the same. Therefore, we believe it will be possible to produce metal hardware at cheaper prices and to reduce costs further by using domestic wood species with high resistance, it is necessary to develop ways to keep prices down.

For the future of domestic timber, promoting the cycle of "harvest, use in the right place, plant, and grow" will have a positive impact on the environment, including in terms of CO_2 emissions (Figure 22).

Figure 22. Forest Resources Cycle[11] (modified)

4.2. Developing a Guidebook for Wooden Architecture Design and Construction in Vietnam

When adopting the timber post and beam construction method in Vietnam, it is necessary to widely disseminate information about design and construction methods. As such, we plan to compile and provide a "Guidebook for Wooden Architecture Design and Construction in Vietnam" in the future.

As for the design methods, we are considering methods that conform to Vietnam's building standards while being based on calculation methods commonly used in Japan. Moreover, regarding durability and thermal environmental performance, we believe that it is best to adopt design methods tailored to the climate and environmental conditions of Vietnam. We would like to work together with IBST to compile such design methods.

As for the construction methods, in order to ensure durability using the timber post and beam construction method, it is essential that design and construction be used that takes into account external surface moisture control as described above, as tremendous damage may occur if this cannot be sufficiently guaranteed. As a countermeasure, in addition to the development of specifications and construction manuals that take into account climate and environmental conditions, continuous education and training regarding basic deterioration due to external forces must be provided to architectural designers and builders. Moreover, it is important to ensure the durability of wooden houses by conducting regular inspections and maintenance so that in-depth building quality can be ensured over a long period of time. The carpenters currently training at Life Design Kabaya are showing promise, so we believe that they will play a very active role in spreading Japanese wooden construction techniques when they return home.

4.3. Promotion of Wood-Construction-Related Industries and Expanding Employment

The Vietnamese government has defined four top priority categories in its National Action Plan to Implement the 2030 Agenda for SDGs prepared in 2017. If a housing policy for people's health, safety, and security is added to this and wooden houses and related industries can play a role in this, it should give great impetus to achieving the SDGs in Vietnam. The wooden construction industry is characterized by its timber supply chain. It starts with forest managers and log producers who supply wood as a raw material. This leads to intermediary companies such as lumber producers, transporters, wood processors, and pre-cutters, and finally, the construction companies, contractors, and building owners, who are the final construction providers and users. Therefore, the spread of wood construction will promote the development of the surrounding industries and help the local economy. In other words, new job as carpenter will be created and investments will be made in lumber mills and pre-cut factories. The supply, processing, and distribution of such lumber, as well as the development of building techniques, will create new employment opportunities and economic benefits.

Further, establishing standards for domestic timber in Vietnam as a building component with reference to Japanese standards and shifting from import-dependent building timber to domestically sourced timber will directly lead to a reduction in greenhouse gas emissions in the country. Establishing the infrastructure around wooden buildings will lead to increased productivity and decreased costs in the future. This will lead to an industry that offers people a wide range of healthy and comfortable lifestyles.

From the perspective of promoting industry and expanding employment expansion, wooden construction has the potential to become a major construction method in Vietnam in the next 10 to 15 *years, similar to reinforced concrete and steel construction.*

5. GLOBAL TRENDS IN WOODEN CONSTRUCTION

Against the backdrop of global environmental issues, the opinion on wooden buildings has become increasingly positive amid global environmental issues. As mentioned above, buildings make a significant contribution toward national policies to attain carbon neutrality and decarbonization. As the global trends signify, the shift to wood construction in buildings has great potential in terms of its contribution to environmental issues.

■ Gaia (Singapore) completion expected in 2023

Gaia is a six-story wooden schoolhouse of Nanyang Technological University with a floor area of 43,500 m^2 and a total length of 220 m. It is the largest wooden building in Asia by floor area. It was named after "Gaia," the goddess of the earth in Greek mythology (Figure 23).

■ Heisei Gakuen certified childcare center, Himawari Kindergarten (Japan), completed in 2020.

A two-story certified early childhood education center with a floor area of 2,982 m^2. In order to ensure light and breathability, CLT panels are assembled in a checkerboard pattern and Technology that prevents metal from being visible at joints so as to create

Figure 23. Gaia

Figure 24. Himawari Kinder Garten

Figure 25. N Company Dormitory

Figure 26. Brock Commons

high-strength walls with tenacious deformation performance (Figure 24).

■ N Company Dormitory (Japan) Construction completed in 2019

An employee dormitory for Company N, this is a 3-story building with a height of 10 m and a floor area of 1,214 m^2. The building is constructed of CLT. It has load-bearing walls at the core of the building and no walls in the other parts, allowing for a large space on the first floor (Figure 25).

■ Brock Commons (Canada) Completed in 2017

A dormitory at the University of British Columbia, with 18 stories above the ground, a height of 53 meters, and a floor area of 15,120 square meters. Mixed structure using CLT. The foundation, first-floor columns and ceilings, and elevator shafts are made of reinforced concrete, while the second floor and above are made of wood (Figure 26).

6. CONCLUSION

The widespread use of wood construction with low embodied carbon will contribute to environmental preservation and conservation on a global scale since these buildings have a small lifetime environmental impact. Furthermore, they will significantly contribute to the Vietnamese government's SDGs and carbon neutrality policies and will generate further economic benefits. They will also contribute to prosperous, healthy, and safe lives for the people of Vietnam. As a first step, the development of the experimental wooden model project by IBST is a guide for wooden building design and the creation of standards for timber. We hope that this paper will be accessed by more people of Vietnam and help raise awareness and promote the role of wooden architecture in Vietnam's sustainable society.

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