Development of Urban Timber Buildings using Glued Laminated Timber having Fire Resistance

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Abstract. In Japan med- and high-rise timber buildings have started to spread in urban areas, based on the building regulations that differ from those in Europe, the cost of timber materials, and the culture for use of timber. It is considered that the use of timber materials in med- and high-rise buildings in urban areas is essential for the environmental and economic sustainability of Japan, which is a major forest country, so we are promoting the development of technologies for use of timber materials in buildings. There are 15 projects in which the fire resistant glulam materials and CLT that satisfy Japan's fireproof standards have been applied, including those currently being designed.

1. Status of Use of Japan's Forest Resources

About 70% of the national land of Japan is covered with forest, and Japan is ranked number two in the world for forest rate of the land area after Finland. As a result of the forestry policy implemented after World War II (from about 1950), the area of planted forest for the objective of using the forestry resources for industrial use is ranked number 7 in the world, and the annual growth for planted forests only is said to be 80,000,000 m³ every year.

However, the quantity of timber required for building, etc., in Japan is 70,000,000 m³, of which 70% is imported, and the actual quantity of Japanese timber used is only 22,000,000 m³.

Also most of the forests that were planted after 1950 are approaching the age for felling, so for sustainability of the forests it is an urgent task to cycle the forests by felling and replanting.

The history of use of timber in buildings in Japan includes timber construction of traditional housing and public buildings such as temples and Shinto shrines, etc. However almost all the timber used for building is for 1 to 3-story detached housing nowadays, and with the reduction in population the size of the market for detached housing which supports the demand for timber in Japan is tending to decrease.

For these reasons there are big expectations for the use of timber in med- and high-rise buildings in urban areas in Japan, which to date have been almost completely constructed in reinforced concrete or structural steel, as a support of timber market.
Table 1. Factors promoting and factors hindering the use of timber in Japan

| Factors promoting                              | Factors hindering                                                                 |
|------------------------------------------------|----------------------------------------------------------------------------------|
| Plentiful forest resources                     | Decline of the forestry (reduction of forestry workers, low productivity)       |
| Age for felling planted forests is approaching | High timber prices                                                               |
| Traditional culture that favors timber building| Many disasters (earthquakes, typhoons)                                           |
| Important measure for solving environmental issues | Unique fire resistance regulations                                               |

2. Use of Timber in Med- and High-rise Buildings

In the amendment of the Building Standard Acts of Japan in the year 2000, basically construction in timber was enabled for buildings of any size or use provided that the required performance was satisfied. However, the strict requirements for seismic performance, the unique fire resistance regulations, and the high cost of production of timber are factors that are causing a bottleneck in its use, so at present there is no progress in the application of timber to med- and high-rise buildings of four stories and higher in urban areas in actuality.

In particular, "self-charring-stop", which is one of the performance evaluations in the fireproof standards in Japan, is not used in the overseas regulations, but it is one of the factors that makes it difficult to utilize timber in the beams and columns of med- and high-rise buildings. "self-charring-stop" is a performance that is applied only to timber as a combustible structural material. The requirement is that in the performance evaluation by furnace fire test, after completion of the required time for fire resistance the burner is stopped, then the test specimen is left within the test furnace, and the flames on the test specimen must be naturally extinguished.

In Japan, timber buildings with a total floor area of 3,000 m² or more and with four stories or more all have to be fireproof construction satisfying "self-charring-stop". In the Eurocode, flexible design methods are permitted, such as a method of calculation based on the carbonization depth of the timber material due to a fire, combination with sprinklers, etc., but in Japan these are not permitted for med- and high-rise buildings.

2.1. Fire resistant Glulam Material

The fire-resistant glulam material is developed, which satisfies the Japanese fireproof standards for med- and high-rise buildings, and has been applied to building projects. This newly developed fire resistant...
The glulam material has a 3-layer structure in the cross-section of which is embedded a heat-absorbing layer made of cement or plaster. The three layers are, from the outside: a fire allowance layer made from timber; a charring-stop layer including the heat absorbing part; and the load bearing part. The charring-stop layer is incorporated during the process of production of the glulam material at the factory, so the three layers of the cross-section are solidly integrated. It is not necessary to cover the surface of the material with a fire resistant material such as plasterboard, and this has the major advantage that designs can utilize the wood texture the Japanese prefer. There are two specifications, 1 hour- and 2 hour- fire resistance, in accordance with the Japanese fireproof standards.

![Figure 2.](image)
The surface of the timber is not covered with a fire resistant coating, and this has the advantage that the wood texture can be utilized in designs.

2.2. Utilization of CLT in med- and high-rise buildings in Japan
Since the enactment of the Building Standard Acts for CLT (Cross Laminated Timber) in 2016, CLT has come to be commonly used as a timber material in buildings in Japan. Eight companies are supplying motherboards of up to a maximum width of 3 m, length 12 m, and thickness 450 mm. In Japan CLT was expected to be the key to increasing the use of timber materials, but the fire resistance regulations and high cost inhibit the propagation of CLT constructions. We are also proceeding with the application of CLT to med- and high-rise timber buildings, through the development of floors and walls that combine fireproof covering and CLT, and the development of low-cost connection technologies.

![Figure 3.](image)
**Figure 3.** Rationalization of construction using the CLT panel method

![Figure 4.](image)
**Figure 4.** Connection that enable high-efficiency stress trans-mission
3. Introduction to Med- and high-rise Timber Building Projects

"Urban Timber Buildings" such as med- and high-rise buildings using fire resistant glulam and CLT in cities has been constructed since 2010 in Japan. 11 projects including those currently being planned has been built with the same type of fire resistant glulam previously explained. Four projects of "Urban Timber Buildings" are introduced here.

Figure 5. Examples of "Urban Timber Buildings" in Japan

3.1. Osaka Wood Brokers Office (2011)

Summary of Building:
- Total floor space / 1,032 m²
- Stories / 3F
- Structure / Fire-resistant GLT, RC
- Main use / Office

Figure 6. Exterior view

Figure 7. The interior has been designed with a combination of various Japanese timber species.
3.2. Ariake Nishi Gakuen School (2018)

Summary of Building:
- Total floor space / 24,480 m²
- Structure / Fire-resistant GLT, RC
- Stories / 5F
- Main use / School

**Figure 8.** Hybrid reinforced concrete and timber structure

**Figure 9.** View of line of Moen-Wood columns

3.3. Hyogo Forest Owners C.A. (2019)

Summary of Building:
- Total floor space / 1,565 m²
- Structure / CLT, Steel
- Stories / 5F
- Main use / Office

**Figure 10.** The design utilizes the wood texture of CLT. CLT shear walls are used in combination with structural steel.

**Figure 11.** During an earthquake only the horizontal forces acting on the building are resisted by the CLT shear walls, so fireproof coating is not required.

3.4. Flats Woods KIBA (Scheduled for 2020)

Summary of Building:
- Total floor space / 8,969 m²
- Structure / Fire-resistant GLT, CLT, RC, Steel
- Stories / 12F
- Main use / Dormitory

**Figure 12.** Twelve-story housing complex having the first structural steel and timber hybrid structure in Tokyo

**Figure 13.** The interior finishes utilize the wood texture.
4. Significance of Promotion of Med- and high-rise Timber Buildings
As the significance of and initiatives in connection with sustainable development goals (SDGs) spreads among Japan's local governments and private companies, initiatives for the utilization of domestic timber materials have an important position in satisfying several of these development goals.

Based on the Paris Agreement (2015) adopted in COP21, Japan has promised to reduce CO₂ emissions by 26% by 2030, by 80% by 2050, and to balance emissions by increasing CO₂ absorption by forests. The initiatives for med- and high-rise timber buildings assist in achieving these sustainable development goals.

Figure 14. CO₂ absorption by forests is anticipated in Japan’s CO₂ emissions targets in the Paris Agreement.

In cases comparing the CO₂ emissions of an office building model using the fire resistant glulam with a reinforced concrete model, it was calculated that the CO₂ emissions were reduced by about 20% during construction (for a total floor area 3000 m², with a hybrid structure in which 50% of the floor area was built with the fire resistant glulam). In med- and high-rise timber construction, a large CO₂ reduction effect can be expected, even with timber construction in combination with reinforced concrete or structural steel.

Figure 15. By utilizing timber materials in med- and high-rise buildings, a double CO₂ reduction effect can be expected due to the CO₂ accumulated in the building as timber material, and the CO₂ absorbed by the newly planted trees.

As a result of the development of fire resistant technologies using timber material such as the fire resistant glulam and CLT, it is technically possible to construct office buildings in Tokyo that are 99% or more constructed of timber. Using timber material grown in all Japanese cities as a replacement for steel and concrete that are currently mainly used in the Japanese construction market whose value
exceeds $250 billion will have the major economic effect of investing urban money into the local areas and encouraging local development and environmental conservation. By using locally produced timber materials in urban buildings profits to the local communities and forestry, activities to re-afforestation by planting young trees after a forest has been felled have commenced as a part of the construction projects.

5. Summary
By the development of technologies for use of timber materials in construction, the use of timber materials in med- and high-rise buildings in cities is indispensable for sustaining the Japanese environment and economy. In particular, the utilization of domestic timber materials is effective for regeneration of local economies and for conservation of forest resources. Med- and high-rise timber buildings have started to spread in urban areas in Japan, based on the building regulations that differ from those in Europe, the timber cost situation, and the culture of use of timber materials.

References
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