Summary

Examination of the progress of timber multi-storey building in four European countries and in Japan indicates that increase in such building in both regions show different trends. In the European countries, for reasons of national economy and ecology, timber building is progressing as regards building performances, construction methods, building cost, various types of buildings and diffusion. In Japan, economical advantages of timber multi-storey building, as compared to steel and reinforced concrete buildings, support the progress. These advantages are largely generated by the compatibility of the timber building features with the building environment in the large cities of Japan. Buildings types and overall constructed square meters, however, are limited and for the most part, are divided between 4-storey detached single-family buildings and small apartment buildings for low-income rental.

1. Introduction

The purpose of this paper is to compare the progress of timber multi-storey apartment building between four European countries, namely, Austria, Finland, Sweden and Switzerland, Japan. [1] It is part of a larger research on confirming the best applications of timber multi-storey apartment building for the middle-rise building environment in Japan. The grounds for the comparison are similarities in both the period of constructing timber multi-storey buildings and, to some extent, the background and environment of timber construction. An important factor is that unlike North America, in the European countries, as well as in Japan timber multi-storey building is a new type of construction.

2. Similarities Concerning Timber Multi-Storey Building

Similarities between the European countries and Japan, with regards to timber multi-storey building, concern the environment of timber building and the revision of building laws.

2.1 Environment of Timber Building

2.1.1 Having considerable land covered with forest and timber is a natural resource.

Fig. 1 Land Covered by Forest, percent of total land area of a country

<table>
<thead>
<tr>
<th>Country</th>
<th>Austria</th>
<th>Finland</th>
<th>Sweden</th>
<th>Switzerland</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47%</td>
<td>72%</td>
<td>66%</td>
<td>30%</td>
<td>67%</td>
</tr>
</tbody>
</table>

2.1.2 Having valid “know-how” regarding construction.

2.1.3 Constructing high percentages of detached houses with timber: Finland 90%, Sweden 90%, Japan 80%. [2][3]
2.1.4 Constructing a marginal percentage of multi-storey buildings with timber.
2.1.5 Shared histories of severe fires in old wooden towns that resulted in heavy casualties and damages.
2.1.6 Building laws prohibited construction of multi-storey buildings with timber.
2.1.7 Timber-building technology, as a consequence of the laws’ prohibition, was not developed for many decades.

2.2 Revision of Building Laws

Revision of building laws in the European countries and in Japan allowed for timber construction on a large scale and of tall buildings. After many years during which fire regulations form the main obstacle to timber multi-storey construction, laws were revised in the mid 1990’s. The detailed requirements of building products and structures from the past were changed to performance-based code. That is to say, new building laws emphasize safety criteria and the examination of the real behaviour of buildings in case of fire. One of the main differences between the countries is the number of floors with timber structure allowed. [4]

Fig. 2 Number of Storeys with Timber Allowed and Year of Law Revision [5]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2001</td>
<td>4</td>
</tr>
<tr>
<td>Finland</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
<td>∞</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2005</td>
</tr>
<tr>
<td>Japan</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1998</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

3. Timber Multi-Storey Building in the European Countries

3.1 Reasoning for Construction

Timber multi-storey building in recent years has gathered momentum in the European countries. Construction of the first experimental buildings was completed and today the trust in new timber building is growing. The number of projects, quality and importance, as well as the rising interest from different groups and customers indicate this movement. The reasons are two: economy and ecology. Governments of forested countries with considerable wood industries, encourage construction of timber multi-storey buildings from viewpoints of national economy, employment, exportation and ecology. [6] The goal is enhancing the use of wood, and middle-rise building with timber is a new field for consuming wood that matches the objective. The growing diffusion of timber multi-storey building is an outcome of cooperation between construction and forest industries, and research institutes and governments.

3.1.1 Economy

In Finland, for instance, national wealth is based on wood. General exports equal almost one-third of gross domestic product, and in recent years forest industry products have accounted for some 30% of Finnish exports. Today forestry and the forest industry make up about 8% of the country’s GDP. The forest industry is the third largest industry and provides work to many people. The Finnish government supports the use of wood by several national programmes and projects. The national objective has been to promote the use of wood in Europe and to raise the degree of refinement timber construction products, with the vision of making wood Europe’s primary housing construction material. [7]

In Sweden, another example, 11% of total exports in 2006 originated in forestry and forest industry. Forest industry, with approximately 95,400 employees, accounts for some 12% of manufacturing industries and 2.7% of total GDP. Here too, the Swedish government supports using wood for the
national economy and it also suggests that further developed building systems for multi-storey (higher
than 2 storey) buildings will act as catalysts for increased industrialization in housing, and help reduce
costs in housing construction. [8] The high potential of industrialization of timber multi-storey buildings
is recognized as economical added advantage of timber multi-storey building.

3.1.2 Ecology

Ecological advantages of timber favour promoting wood for construction instead of other intensive
energy-consuming materials, as well as, for being a renewable material. The governments and the public
in Europe are aware of the sensibility of using wood for construction, and environmental aspects are
added values for the timber multi-storey building in support of its diffusion.

 Fig. 3 Fossil Energy Consumed in the Manufacture of Building Materials [9]

<table>
<thead>
<tr>
<th>Building Material</th>
<th>Fossil energy consumption MJ/Kg</th>
<th>Fossil energy consumption MJ/M³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawn timber</td>
<td>1.5</td>
<td>750</td>
</tr>
<tr>
<td>Steel</td>
<td>35</td>
<td>266,000</td>
</tr>
<tr>
<td>Concrete</td>
<td>2</td>
<td>4,800</td>
</tr>
<tr>
<td>Aluminum</td>
<td>435</td>
<td>1,100,00</td>
</tr>
</tbody>
</table>

In Austria, for instance, demand for timber multi-storey apartment buildings is becoming perceivable.
Between 5 and 10% of customers of the largest social housing company in Austria, the Sozialbau AG,
call for innovative and environmental housing solutions, with timber as a preferred construction material.
[10]

3.2 Building Systems in Use

At the first phase, multi-storey apartment buildings were constructed with (light) timber frame systems
similar to the North American ‘two by four’ type. The system was adopted for its economical
performance and uncomplicated construction method. But because of customer demands, building
culture, chain of supply of products and services and building code requirements, new building systems
have developed for residential buildings and for other buildings types such as offices or public buildings.
[11] Today, with regard to apartment building, the Massive Timber Panels System (or, Solid Wood
Panels System) is in more common usage. The building system is used solely, or, together with timber
frame system, mostly for walls, as often practiced in Switzerland. In Finland, however, the timber frame
system was further developed. All Finnish timber multi-storey apartment buildings are built with the
advanced timber frame system, named the ‘Timber Open Construction System’. Customers in European
countries require high standards of acoustic performance. These demands are more complicated and
expensive to meet with slabs of timber frame system, but possible solutions do exist. [12]

High performances timber multi-storey apartment buildings are achieved with both, the advanced
Finnish timber frame system and the massive timber panels system. But it seems that countries with
productive forests are more likely to construct their multi-storey apartment buildings with massive
timber system than with timber frame system, for providing better economical grounds to their forests.
An average building with massive timber system required three times more wood than a building with
timber frame system. [13] High wood consumption supports forest and forest industry.

 Fig. 4 Ratio of Built Area to Volume of Wood by Building System

<table>
<thead>
<tr>
<th>Built Area</th>
<th>Finnish Timber Frame System</th>
<th>Massive Timber Plates System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m²</td>
<td>0.1 m³</td>
<td>0.3 m³</td>
</tr>
</tbody>
</table>

Note: The Timber Frame’s figure includes wood structure, wood façade and interior wood finishing.
The massive timber’s figure includes wood structural panels for walls, floors and roof.

The example of Finland is evidence that the reason for using - solely or mainly - one building system
and not the other is more complicated. Additional factors are obviously taken into consideration when
prioritising a building system. How well the timber frame system is established in a country before introducing the new massive timber system is, for example, a factor, as modifying building systems required extensive funding; or the size of a country, in terms of population and the number of potential buildings to be built, since the required network of factories and transportation costs for massive timber buildings may result in too costly a system for low-populated country.

3.3 Current Situation

Austria, Finland, Sweden and Switzerland each completed the construction of pilot projects, all are apartment buildings. The well thought out, invested and published projects were an important phase in gaining the trust of construction industry, local governments and general public. These projects also help in spreading the information concerning the possibility of timber multi-storey construction. After years of prohibition, many remain unaware of building laws revisions and of actual feasibilities. Timber multi storey buildings currently continue to be constructed in various types of projects. Succeeding timber multi-storey projects challenge the first buildings for size, height, engineering solutions and construction method.

Additionally, in Finland, since 1997 densely populated modern wooden towns, 2 to 3-storey timber houses have been promoted by a national program, in the objective of creating a pleasant and exemplary new living environment. In 2006, construction of modern dense timber city with 8-storey, ground floor with reinforced concrete, timber buildings was begun in the city of Växjö, Sweden. Swedish objectives include energy efficiency and the development of timber technology. The modern timber town gains momentum these days as Finland, Sweden, Denmark, Iceland and Norway undertake the ‘Northern Wooden Town’ project.

3.4 Costs of Timber Multi-Storey Apartment Building

The success of timber multi-storey building requires competitive cost and yet, cost-efficient production of timber multi-storey apartment building in European countries is still in a learning phase. There is not much direct profit in structural costs of apartment buildings; experts, however, see high potential in reducing overall construction cost in careful layout design of load-bearing walls, prefabrication and construction methods. Few cost studies have yet been conducted, but existing data indicates that timber multi-storey apartment building costs 8 to 12% more than reinforced concrete building. A case study form Sundsvall, Sweden, conducted in 2006 showed that advanced construction of massive timber building has the potential to be 5 to 7% cheaper than reinforced concrete building. [14] This data does not include the Finnish timber frame buildings.

**Fig. 5 Cost of Timber Compared to Reinforced Concrete for Apartment Building**

<table>
<thead>
<tr>
<th>Building System</th>
<th>Cost Compared to R.C.</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive Timber with Timber Frame</td>
<td>&gt; 10%</td>
<td>Switzerland</td>
</tr>
<tr>
<td>Massive Timber</td>
<td>&gt; 8 - 12%</td>
<td>Austria</td>
</tr>
<tr>
<td>Massive Timber - advanced method</td>
<td>&gt; 9 - 10%</td>
<td>Sweden, Sundsvall</td>
</tr>
<tr>
<td>Massive Timber - advanced method</td>
<td>&lt; 5 -7%</td>
<td>Sweden, Sundsvall</td>
</tr>
</tbody>
</table>

4. Timber Multi-Storey Building in Japan

4.1 Reasoning for Construction

In Japan, the number of constructed timber multi-storey buildings higher than 3-storeys increases every year. Since the first building constructed in 2005 until December 2007, 26 timber buildings of 4 to 5-storeys obtained building permits. Examination of the built projects with regards to type, size in square meters, as well as quality and level of importance, indicates that the overall timber multi-storey building in Japan is progressing in a different direction than in the European countries.

In Japan, as in Europe, ecological reasons for constructing timber multi-storey buildings are considered valid and global warming and its effects on energy consumption a relevant issue. Japanese customers
today are thus more aware of environmental aspects than in the past. There is, however, a radically
difference between the European countries and Japan in economic considerations. Forest productivity, a
highly influential factor relating to national objectives and motivation for constructing tall buildings
with timber in European forest countries, has no influence on the progress of timber multi storey
building in Japan; other economical factors or advantages justify the construction of the new timber
building here.

Fig. 6 Productivity of the Forest of Japan [15]

<table>
<thead>
<tr>
<th>Land Covered by Forest</th>
<th>67%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preservation</td>
<td>66%</td>
</tr>
<tr>
<td></td>
<td>16,299</td>
</tr>
<tr>
<td>Domestic Supply</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>17,176</td>
</tr>
<tr>
<td>Imported Supply</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>68,681</td>
</tr>
<tr>
<td>Productivity:</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>0.72 m³/ha</td>
</tr>
<tr>
<td>Europe (except Russia)</td>
<td>1.8 m³/ha</td>
</tr>
</tbody>
</table>

The forests of Japan are not profitable. With no forest economical grounds the country’s motivation for
promoting the enhanced use of wood for the benefits of nation’s economy does not exist. In Japan
timber has no priority in national programmes over other construction materials. Likewise, selling more
wood, in the form of multi-storey structures, is not a national objective. In fact, except one building in
Kanazawa city, all the timber 4 to 5-storey buildings, in Japan, were constructed with imported wood.
With no governmental umbrella, the construction industry in Japan takes a key-role in the development
and diffusion of timber multi-storey building in the country. One effect is that in Japan the focus is on
selling more timber houses, rather than on selling more timber. The distinction is slight but makes a
difference.

4.2 Economical advantages

In Kanazawa city, Ishikawa Prefecture, one 5-storey building with timber-based hybrid structure,
ground floor with reinforced concrete, was constructed. The special hybrid structure was the result of a
single governmental research project, from 1999 to 2005, for developing timber multi-storey building.
Except this building, all other timber multi-storey buildings in the country were constructed with timber
frame system, similar to the North American type of ‘two by four’, and were supported by ‘Japan 2x4
Home Builders Association’.

In 2004, Japan 2x4 Home Builders Association, together with COFI, the Council of Forest Industries
from Canada, received approval for 4-storey fire resistive timber frame structures from the Ministry of
Infrastructure, Land and Transportation (MILT). Since then until recently, the 2x4 Association issued
building certificates to twenty-five 4 to 5-storey timber frame buildings, in practice about 20 buildings
were built by the end of 2007.

Japan 2x4 Home Builders Association endeavours to promote and diffuse timber frame buildings in the
country. Their mission is approaching builders, emphasizing the most effective factor for constructors,
which is economical advantage of constructing with timber over construction with concrete or, steel.
Small builders’ companies (< 100 houses per year) are encouraged to compete with the new timber-
frame multi-storey building in the free market for the cost advantages. Both timber material and timber
frame system have economical advantages in the construction environment of Japans’ cities.

4.2.1 Foundation Costs. Because of its being located in a seismic zone, costs of foundations in
Japan are relatively high in comparison to non-seismic countries. Lightweight timber
buildings reduce the high expense of foundation work. Results of a questionnaire conducted
by the first author in 2007 between several constructors of 4-storey timber buildings in
Tokyo show that one of the main reasons for choosing timber is lowering foundation costs.

4.2.2 Site Conditions. In the construction environment of Japan’s cities, sites can be of very small
dimensions and surrounded by narrow access roads, sometimes of less than 2 meters. These
conditions are difficult for construction of concrete and steel buildings that need cement
trucks or cranes, and may result in costly building. For such sites, the timber frame system,
constructed on-site is often the only reasonable economical solution. In the questionnaire
mentioned above, site conditions, along with foundation costs, was the first or second reason for constructing 4-storey building with a timber frame system.

4.2.3 Other Advantages. Other economical advantages for constructing middle-rise buildings with timber are as valid for Japan as for other countries, the rapid and dry construction process, for instance. About 70% of the timber frame multi-storey apartment buildings in Japan are for rental purposes. Shortened construction periods, obviously, help bring tenants in earlier. Another reason is the systematic application of the timber frame systems to simplify the construction process. Builders of 4 to 5-storey buildings are often already experienced in timber frame system construction of low-rise houses.

4.1 Characteristics of the Entire Buildings

Twenty-five timber-frame 4 to 5-storey buildings’ certificates were issued by Japan 2x4 Home Builders Association in the 3 years between January 2005 and December 2007. Two projects were cancelled; the remaining 23 projects were built or will be completed during 2008 (no other cases were noted). [16]

22, (96%) are with 4-storey; 1 project is 5-storey; ground floor with reinforced concrete. 18, (78%) projects are located in Tokyo Metropolitan Area, which includes the Prefectures of Tokyo, Kanagawa and Chiba. 22, (96%) are various forms of Housing; 13 (59%) various Apartment Buildings, 9, (41%) Single-family Houses, 1 is an elderly house (rest home) in the Shimane Prefecture.

The Elderly House differs from the rest by the function, and exceptional in its size; about 12,900 m², which is almost 20 times bigger than the second larger project; apartment building in Hokkaido, and similar to the size of the FMO office building (13,300 m²), in Espoo, Finland.

4.2 Characteristics of the Apartment Buildings

13, 4 to 5-storey timber frame projects include 2 or more housing units and therefore can be considered as apartment buildings.

Fig. 7 Timber Frame Apartment Buildings by Floors, Fire Zones, Scale, Location and Structure

<table>
<thead>
<tr>
<th>Slvcsys</th>
<th>Fire District</th>
<th>Scale of Project</th>
<th>Location</th>
<th>Structure</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-storey</td>
<td>5-storey</td>
<td>Fire Zone</td>
<td>Fire Zone</td>
<td>Other</td>
<td>No. Units</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

◎ Housing with Other Functions (Shops, Medical Clinics, Studios etc.)
■ Other / Multi Family Housing
Number of Storeys: 1 of the 13 apartment buildings is 5-storey building, in Kanagawa Prefecture, the rest are 4-storey buildings.

Fire Zone: 9, (69%) buildings are located in Fire Protection zones, 3 (23%) buildings are in Quasi Fire Protection zones.

Location: 11, (85%) buildings are in the Tokyo Metropolitan Area. The 2 larger buildings (B, D), with floor area of over 600 m² per each, are located in Hokkaido and Gifu Prefectures.

Size of Apartment: No clear data was given for the size of apartments, or, size of “other functions” (Project I-L). Assuming that the public area of stairs, corridors and entrance hall, in a modest apartment building, are about 15% of the total area, we can roughly guess the size of an apartment in the projects.

2 Apartment buildings, A, D, have no indication on number of apartments.
5 Apartment buildings, C, F, G, H, M, are with apartment sizes between 20 to 25 m².
4 Apartment buildings, I, J, K, L, are with apartment sizes of less than 30 m².
9 Apartment Buildings or, almost 70% of the buildings have less than 30 m² and fairly suggested that these are rented apartments for low-income population.

Summary of Timber Frame Apartment Building's Analysis:

The majority of the timber frame apartment buildings in Japan are concentrated in the Tokyo Metropolitan Area (85%), built or planned for small-size units for rental purposes and targeting low-income tenants (70%). The projects are of a basic quality, in keeping with their size, and with no special attention for issues such as acoustic solutions. Additionally, in appearance, Japanese timber frame apartment buildings are similar to the concrete or steel buildings; no special attention is given to differentiate timber multi-storey buildings.

5. Conclusions

European timber multi-storey building is progressing as regards building performances, construction methods and building costs. It is becoming increasingly widespread, and the number, quality and types of constructed buildings indicate progression towards its becoming a common construction practice in the middle-rise building environment of European countries. In Japan, timber multi-storey construction is progressing differently. It occupies a narrow market niche of small builders, and until now, did not benefit from clear enough an image or publicity. The buildings are of mainly two types of housing projects; one is tall (4-storey) detached single-family homes, and the second is apartment buildings with small units for low-income rental. These timber buildings answer certain needs generated by the building environment of Japan's cities, and are therefore important. However, various types of timber multi-storey buildings, with higher building performances that will apply to different clients for expanding the building’s market, are missing.

The European experience shows that buildings with high performances project a good image more easily, and attract customers and publicity that support their diffusion. It also indicates the important connection between high-production forests and the progress of timber multi-storey building; when wood contributes in significantly to a country’s wealth, the timber buildings are benefited. In Japan, the economical factor, of forests that boost the progress of timber multi-storey building, is absent. Yet the country needs to recognize the economical potential of its forests, and shift the discussion from ‘Trees’ and ‘CO2’ to ‘Lumber’ and ‘Timber Technology’. Realizing the country's natural resources will support national wealth, environment and the progress of the timber multi-storey building in Japan.
6. References

[1] The Term ‘European countries’ in the paper refers to four counties; Austria, Finland, Sweden and Switzerland, only.


[10] Zechner W., Socialbau AG, Interview, Vienna, AUSTRIA, November 30, 2006


[16] Data by Japan 2x4 Home Builders Association, January 2008

7. Acknowledgement

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