MASTERARBEIT

TIMBER AS A CONSTRUCTION MATERIAL IN MIDDLE- AND HIGH-RISE BUILDINGS

The aesthetics, merits and future of using wood considering fire regulations and safety instructions, comparing Japan and Austria/Europe

ausgeführt zum Zwecke der Erlangung
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unter der Leitung von
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PREFACE

This thesis is written in English because it was part of a research during an exchange program in Tokyo - Japan, from October 2009 to October 2010, with the University of Tokyo (supervised by Prof. Koshihara Mikio).

The sources the thesis is based on (authored in Swedish, Japanese, German and Italian) were translated by the author and combined into the content of every section; an accurate and detailed list of references for every single chapter and its subchapters can be found on the last pages of the thesis; citations are marked with footnotes. In case they were not available in English, descriptions in figures and plans were also translated by the author.

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ABSTRACT

This paper illustrates not only the merits of wood and its influence in our everyday life and shows realized timber projects in Europe and Japan; it also promotes future ideas and visions for middle- and high-rise timber constructions. It shall depict possibilities and solutions to construct multi-storey buildings made of wood, which can offer the same security standard as “common” concrete, steel and reinforced concrete constructions.

Every kind of wood offers different impressions and possibilities, not only when utilized as a construction material but also for interior design like furniture, flooring,….
Wood sounds good, feels good, smells good and creates a good and balanced atmosphere. Wood designed spaces always appear warmer than they actually are. This reduces heating costs and increases well-being.

The aim of the Kyoto Protocol is to reduce the six most important greenhouse gas emissions [carbon dioxide ($CO_{2)}$, methane (CH4), nitrous oxide (N2O), fluorinated hydrocarbon (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF6)] of developed countries to 5% below the level they were in 1990 for the period of 2008-2012.

Wood as a renewable resource provides a non-negligible contribution to the protection of the environment. The fabrication of most wooden products requires less energy and natural resources than other building materials commonly used in Europe. In the course of their growth, trees bind carbon from C02 and emit oxygen to the atmosphere. As a tree matures, less carbon is absorbed and if the tree is not used and dies, it’s stored carbon is released again. If wood is manufactured and utilized for further use, the carbon is removed from it’s natural circulation and stored for many years - the building industry is therefore of effective use.

Since the existence of man, wood has been developed for utilization. Wooden constructions can survive for centuries. And broken parts are easy to find and replace, unlike brick or concrete. Changes can be made easily, quickly and inexpensively.
But despite it’s eminent properties as a construction material, it has been pushed into the background through the nowadays in middle Europe commonly used materials.
Strict conditions and safety regulations as well as building laws in consideration of fire safety are to blame for the reasons why many architects shy from developing “higher” projects, as the current law allows only an average of 4-5 storey timber constructions.

In this paper you will find an overview of the aesthetical and technical aspects of wood, fire regulations in Europe and Japan as well as middle-rise projects that already exist and ideas to overcome the “fear” of using wood for high-rise buildings.

An existing building – the *Mode Gakuen Cocoon Tower*, located in Shinjuku, Tokyo (Japan) was remodelled as a timber construction by recalculating the main structure (using a table of forces based on the steel structure) to get an approximate overview for the prospective dimensions a high-rise building would need for construction using timber.

If fire regulations would allow this height, there would be no question about the safety or structural analysis – the interesting part of a project like this then would be the consideration of the deformation properties of wood and how to connect the immense members of diagrid frames, beams and columns. As the case study of the *Mode Tower* is only scraping the surface of the theme “high-rise timber constructions”, it has not gone into detail about joints.

ZUSAMMENFASSUNG

Diese schriftliche Arbeit zeigt nicht nur die Vorzüge von Holz, seinen Einfluss in unseren Alltag und realisierte Holzprojekte aus Europa und Japan, sondern fördert auch Zukunftsvisionen und Ideen für Mittel- und Hochhaus-Holzkonstruktionen. Sie soll darstellen, welche Möglichkeiten und Lösungen es für mehrstöckige Gebäude aus Holz, die den gleichen Sicherheits-Standards wie "gewöhnliche" Beton-, Stahl- und Stahlbetonkonstruktionen bieten, bereits geben oder noch erforscht werden.

Jede Art von Holz bietet unterschiedliche Eindrücke und Möglichkeiten, nicht nur, wenn es als Konstruktionsmaterial benutzt wird, sondern auch im Innenausbau.
Holz klingt gut, fühlt sich gut an, riecht gut und schafft eine angenehme und ausgeglichene Atmosphäre; Holz lässt Räume viel wärmer wirken, spart Heizkosten und steigert das Wohlbefinden immens.

Das Ziel des Kyoto-Protokolls ist es, in der Zeit von 2008 bis 2012 die sechs Treibhausgasemissionen Kohlenstoffdioxid (CO2), Methan (CH4), Distickstoffoxid (N2O), Fluorkohlenwasserstoffe (H-FKW/HFCs), Kohlenwasserstoffe (FKW/PFCs) und Schwefelhexafluorid (SF6) der Industrieländer um 5% aus dem Jahr 1990 zu reduzieren.
Holz als nachwachsender Rohstoff stellt einen nicht zu vernachlässigende Beitrag zum Schutz der Umwelt dar. Die Herstellung der meisten Produkte aus Holz benötigt weniger Energie und natürliche Ressourcen als andere Baustoffe, die heute in Europa verwendet werden. Im Laufe ihres Wachstums binden Bäume Kohlenstoff aus Kohlenstoffdioxyd (C02) und emittieren Sauerstoff in die Atmosphäre. Je älter ein Baum wird, desto weniger Kohlenstoff wird absorbiert und wenn der Baum nicht genutzt wird und demzufolge stirbt, wird der gespeicherte Kohlenstoff wieder freigegeben. Wenn Holz genutzt und weiterverwendet wird, wird der Kohlenstoff dem natürlichen Kreislauf entzogen und für viele Jahre gespeichert - eine effektive Nutzung ist daher die Bauindustrie.

Seit Anbeginn der Menschheit wird Holz für Nutzung entwickelt. Holzbauten können über Jahrhunderte bestehen bleiben. Gebrochene Teile sind leicht zu finden und zu ersetzen im Gegensatz zu Materialien wie Stein oder Beton. Änderungen können leicht, schnell und kostengünstig vorgenommen werden. Doch trotz seiner hervorragenden Eigenschaften wurde es durch die Materialien, die heutzutage in Mitteleuropa gerne genutzt werden, als Baumaterial in den Hintergrund geschoben.
Strenge Auflagen und Sicherheitsvorschriften sowie Baurecht unter Berücksichtigung des Brandschutzes sind Gründe, warum viele Architekten sich nicht über die derzeit 4 bis 5 Etagen erlaubter Holzkonstruktionen wagen.

Diese Arbeit bietet einen Überblick der ästhetischen und technischen Aspekte von Holz, Brandschutzbestimmungen in Europa und Japan sowie bereits bestehende Mittel- und Hochhaus-Holzkonstruktionen und Ideen, wie man die „Angst“ vor Holz als Baumaterial überwinden könnte.
Ein bestehendes Gebäude – der „*Mode Gakuen Cocoon Tower*“ (Shinjuku, Tokio - Japan), wurde durch Neuberechnung der Hauptstruktur (mit Hilfe einer Tabelle von Kräften, die auf der Stahlkonstruktion basiert) als Fallstudie herangezogen, um einen ungefähren Überblick über die zu erwartenden Abmessungen der Bauteile zu bekommen, wenn das Gebäude aus Holz gebaut werden würde.

Wenn Brandschutzbestimmungen es erlauben würden, so hoch zu bauen, wäre es weniger eine Frage der Sicherheit oder Statik – der interessante Bereich an einem Projekt wie diesem wäre, dass man einerseits die Deformierungseigenschaften von Holz in Betracht ziehen muss und auch, wie man die gewaltigen Dimensionen der diagrid frames, Träger und Säulen miteinander verbinden könnte. Da diese Fallstudie nur an der Oberfläche des Themas „Holzhochhäuser“ kratzt, wurde diesbezüglich nicht ins Detail gegangen.

CONTENT

1. CONSTRUCTION MATERIAL TIMBER

1.1 Why use timber to construct tall buildings?

1.1.1 Merits of timber

1.1.1.1 Technical properties

- From a technical point of view, timber can compete with all other construction materials; a fir wood cube with a 4cm edge length can bear 4 metric tons.

- Although, since wood is biodegradable, this can only happen in a moist milieu. As long as it's the right wood, treated with care, utilized with know-how and therefore shielded from moisture, wood's endurance is almost unlimited.

- Wood is highly resistant to acids, bases, salts and other chemicals.

- Ventilation is important; it avoids the penetration of humidity, allows surface water to drain off and assures quick drying due to air circulation.

- Right angled to the grain, wood has 100 times less tensile strength than along the grain, and it swells and shrinks – depending on humidity. These problems can be solved with derived timber products. Plywood panels for example neither swell nor shrink and show a constant strength. In general, the used wood should never exceed 20% moisture content.

- Metal constructions deform rapidly under the influence of heat. A wooden beam however, keeps its stability for a longer period. This is because even dry wood contains water that has to vaporize. Until then, the temperature of wood ranges around 100°C. At around 270°C, combustion starts with a burning velocity of around 1mm/min – It's fire resistance can be calculated (pinewood ~0.76mm/min; hardwood ~0.5-0.6mm/min). Even at 1000°C temperature wood stays unharmed 1cm under the charred surface and the residual cross section is still stable. Steel, on the other hand, loses it's stability at around 450°C; at 650°C the compression strength of concrete is reduced by two-thirds.

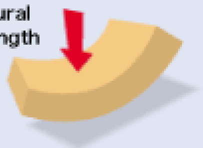
Material	Timber	Concrete	Steel
Specific gravity(kn/m³)	0.40	2.00	7.66
Tensile strength 	2250	10	509
Compressive strength 	950	100	445
Flexural Strength 	2800	7	182

Fig 1.1.1.a – Material strengths [kgf/cm²]

1.1.1.2 Long-lived, natural construction material is eco-friendly

- The lifetime of a timber building is remarkable: timber frame houses often have to be renovated after they are more than 300 years old, but still they don't need more care and effort than other buildings.

- Wood grows again; fossil raw materials of unlasting resources are being preserved. And due to the emergence of construction material wood, the environment is supported. Trees only need water, earth and air; from air, they even extract the harmful CO_2.

- CO_2 emission for the production of different construction materials [kg/m³][1]:

Wood………	16
Concrete…..	120
Steel……….	5 300
Aluminium…	23 000

- Since the transport route of regionally grown material is short, it saves energy, complicated further processing and 100% of the material can be used (no wastage).

- Low use of energy for manufacturing[1]:

Timber house………………..	930 MWh
Vertical coring brick house…	6 210 MWh

1.1.1.3 Easy to handle

- Timber constructions are flexible. Modern timber frame constructions save space and therefore, lead to more leeway for individual floor plans.

- It can be used multifunctionally which lends itself to other materials like concrete, glass, stone and metal. Also, because it is lighter than other materials, a stronger foundation is unnecessary. (e.g.: a timber house's weight: ~ 26 tonnes; a brick house's weight: ~ 160 tonnes[1]).

- A building should be built for several generations, but still – requirements change. Timber constructions are flexible as they can be easily reconstructed at reasonable prices.

- Short construction periods (prefabrication not subject to changes in weather) and no waiting times like when using concrete = immediately capable of bearing.

1.1.1.4 Net weight

Steel : Concrete : WOOD = 17 : 5 : 1

Fir/Spruce 460kg⁄m³ < Beech⁄Oak 710kg⁄m³ < Concrete 2 300kg⁄m³ < Aluminium 2 702 − 2 700 kg⁄m³ < RC 7 500kg⁄m3 < Steel 7 700 − 7 840kg⁄m3 < Low carbon steel 7 870kg⁄m3

- When a single material is used as the primary structural system, timber is always the lightest.

- The steel-timber combination and all-steel systems have about the same mass.

1.1.1.5 Natural climate regulator

- Wooden rooms offer a natural balanced ambience and a self-regulated humidity, offering some merits to it's occupants: allergy causing dust mites hardly exist; inside it's cooler in summer and there are no real lapse rates; no drafts – the climate is comfortable.

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[1] see http://www.proholz-stmk.at/desktopdefault.aspx/tabid-426/652_read-2027/ (Accessed: Feb 13th, 2011)

- Timber houses are already insulated by nature: out of the load bearing construction materials, wood has the best damping properties - the better the insulation, the lower the heating costs.

- As wood is used dry, no noteworthy humidity develops. Later (with for example gypsum fibreboard), covered wooden parts develop a natural buffer property. They absorb air humidity and dispense it again when the climate is drier.

- Because building parts are constructed multi-layered and decoupled among each other, they don't transmit sound. Therefore, noises from outside as well as inside the house are damped.

- Wood has the best insulation + heat storage ratio: 10cm wood = 51cm brick = 160cm concrete.

1.1.2 Demerits of timber

In general, there are a few disadvantages although most of them can be prevented by skilled manufacture.

- Wood is open to insects, fungus and bacteria. Thus, it can be damaged at a fundamental level.

- On a long-term basis UV radiation can harm wood. Hereby, the lignin reacts and can be washed away by rain. Also it's natural colour changes to a dull grey like concrete. However, the impact of sunlight on the outer layers of wood can be limited with varnishing.

- It's hygroscopic property is a big problem when working with wood – it's humidity adjusts to it's surrounding climate and these changes are followed by shrinking and swelling, depending on the three basic anatomic directions of wood (e.g. wood swells mostly tangentially).

Still, all these "disadvantages" can be avoided by constructive timber proofing. To prevent wood being attacked by fungus or bacteria, it is important to keep it and the construction dry.
Though wood has a general content of moisture (it should never exceed 20%) modern timber elements (e.g. gluelam) have about 15 +/- 3 % or less.

The timber construction market in Europe is not yet as big as it could be due to the lack of construction companies who have enough knowledge in using wood efficiently as a construction material.

1.1.3 The Kyoto Protocol

In 1988 at the earth summit in Toronto, the western industrial states were advised to minimize their emissions of greenhouse gas to slow down the progress of the climate change.
Then in 1997, at the climate protection conference in Kyoto, international legal binding aims to reduce the emission of greenhouse gas were constituted.

The "Kyoto Protocol" indicated that during 2008-2012 the six most important greenhouse gases (CO_2, CH4, N2O, H-FKW, P-FKW, and SF6) must be reduced by 5%, according to the data of 1990.
The heightened concentration of CO_2 in the atmosphere is a fundamental reason for the increasing greenhouse effect, leading to a change in the climate and therefore, global warming[2].

In this regard, wood is a beneficial material, as every tree during the process of growing binds CO_2 out the air. Carbon (C) is used for the buildup of the organic substance; oxygen (O^2) is released into the atmosphere.

A 25 metre high beech daily releases the amount of oxygen that three people need for breathing. But as a tree matures, it' growth slows, and less CO_2 is absorbed. As time goes by an uncut tree dies and the bound carbon will be released again – as CO_2.

On the other hand, if the tree is "used", e.g. as a construction material for buildings, it's carbon will remain bound tied over decades, maybe even centuries.

[2] cf. http://unfccc.int/resource/docs/convkp/kpger.pdf (Accessed: Feb 13th, 2011)

1.2 Timber in Austria (Europe)

1.2.1 Stock of wood by numbers

World wide, approximately 3.6 billion m³ wood is harvested every year, with more than half being used to produce energy: 1/5 is used to produce paper and cardboard; 1/4 is used for furniture, construction and the packaging industry.
Even when wood is compared to cement, steel, aluminium or plastics, it is a principal material and therefore one of the most important natural raw materials considering both weight and mass:

Material	*Billion tonnes*	*Billion [m³]*
Wood	2.2	3.6
Cement	2	1.8
Steel	1	0.125
Plastics	0.25	0.22
Aluminium	0.03	0.01

Tab 1.2.a.: Approximated annual production worldwide[3]

Per capita consumption of wood [m³/year]	
1.05	Finland
0.68	Sweden
0.68	Austria
0.66	Canada
0.24	USA
0.23	Japan
0.23	Czech
0.22	Germany
0.20	Switzerland
0.17	France
0.15	Italy
0.29	EU15

Tab 1.2.b.: According to Fachverband der Holzindustrie, 2009[4]

Forest area [%] of territory	
Finland	75%
Sweden	68%
Austria	47%
Slovakia	41%
Czech	33%
Italy	32%
Germany	31%
France	30%
Hungary	19%
EU:25	34%

Tab 1.2.c.: According to UNECE/FAO[5]

Concerning Austria, 47% of its total area is covered with forest and makes it one of the European leading countries concerning the stock of wood.

About two-thirds of lumber, paper, flake- and fibre boards and other wooden products manufactured in Austria are exported; main trading partners are countries of the EU.

Austrian wood exports [%]	
Italy	58%
Germany	8%
Slovenia	8%
Japan	5%
Czech	1%
Greece	1%
Others	19%

Tab 1.2.d.: According to Fachverband der Holzindustrie, 2008[4]

[3] see http://www.lignum.ch/holz_a_z/holz/ (Accessed: Feb 13th, 2011)
[4] see http://www.proholz.at/wald_holz/wald_zahlen.htm (Accessed: Feb 13th, 2011)
[5] see http://www.proholz.at/wald_holz/unternehmen_holz.htm (Accessed: Feb 13th, 2011)

1.2.2 The Kyoto Protocol regarding Austria

Austrian wood stores around 800 million tons of carbon, which approximately matches the 40-fold amount of its annual greenhouse gas emission.
Within the last few decades more wood has grown in Austrian forests than has been used, so the pool of increased carbon is ongoing. Regarding the last 15 years, growth comes up to 15% of the greenhouse gas emissions.
A relevant question is to what extend can wood be used to store carbon, especially the "times for conversion" (meaning the time from binding the carbon within the tree due to photosynthesis and its disposal to the atmosphere due to decomposition or burning)? The use of wood as a construction material can extend these times for conversion.

On June 18th 2002, the Council of Ministers enacted the "Kyoto Measurement" and Austria committed to reducing it's greenhouse gases to 13% from 2008-2012[6].

1.3 Timber in Japan

Japan is the world's largest importer of wood and paper products; about a third of exported logs from Russia and Malaysia are delivered to Japan, Indonesia delivers plywood, from Chile sawn wood and most of Japan's woodchip comes from Australia and USA.

66% of Japan's area is covered with forest, making it one of the most heavily forested countries in the world. But the self-sufficiency rate has decreased after liberalizing timber import in 1960 (from 86.7% down to 19.9% in 1990.
Today about 70 million m³ forest grows annually, but wood production is only 19 million m³ (less then one third of annual growth).

[6] cf. http://www.umweltbundesamt.at/aktuell/presse/lastnews/newsarchiv_2005/news050216/ (Accessed: Feb 13th, 2011)

2. THE AESTHETICS OF WOOD

2.1 Wood in the European culture

2.1.1 Manufacturing and utilization

2.1.1.1 Wood as a building material

Timber is used as solid wood, glulam or as derived timber products, as a constructive or isolating material or as a cladding material. Because of the constant development of manufacturing techniques and information about timber, it is possible to realize uncommon wooden constructions.
Due to wood's lower density, it is used to produce thermal isolation materials; wooden fibreboards with a higher density have a good acoustic insulation.
In the thirties, there were several AM transmitters constructed in timber since the material is electrically non-conductive.
Furthermore, timber is used for formwork boards, for bins and silos to store aggressive salts, and earlier it was used in the mining industry to backup lugs (because of its "alarm" (cracking) when it came close to collapse).

2.1.1.2 Wood as a construction material

Apart from semi-manufactured products like boards, battens, chipboards, … wood is used for/as:
- carpentry products like furniture, stairs, windows, doors;
- tone wood for musical instruments;
- handles of tools;
- material for a multiplicity of sports equipments;
- boat building;
- pallets and crates for transportation and storage facilities.

2.1.1.3 Wood as a furnishing material

When using wood as a furnishing material, it's aesthetic aspects are the most important ones. There is a broad list of types of wood distinguished by colour and pattern when speaking about parquet or wood panelling. Exotic wood, in particular, is used. Therefore, these products are much more expensive, so they are mainly used as veneers. Wooden floors have to be resistant to abrasion, so the most common kinds of wood for floors are hardwoods.

2.1.1.4 Pulpwood

Wood is a very important material in the pulp industry where excorticated wood is mechanically shredded or chemically solubilised.
For the production of pulp, as much as possible lignin must be extracted. For the production of base materials for boards and low class papers, lignin doesn't have to be extracted.

2.1.1.5 Recycling and Energy

Wood can be disposed of by composting or combustion, the latter also offering a production of energy.
Matured timber is used as fuel in biomass power stations to achieve CO_2 – neutral energy.
High temperature carbonization is another recycling method. Using this method, chemical base materials can be produced out of wood and other organic materials that replace fossil sources.

Furthermore, "recycling" can be done by burning wood and using the smoke for preservation of food, as a base material for brandy or as a raw material for chemical products like tar.

2.1.2 Classification

2.1.2.1 Types of wood

In general, wood is classified into two groups: *softwood* and *hardwood*.

Softwood:
Most softwoods have spiky leaves and are coniferous (e.g. pine and fir). About 80% of the world's timber production comes from softwood. North America, Scandinavia and Russia are the main sources.

Hardwood:
Hardwoods have broad flat leaves and come from angiosperm trees (e.g. oak) and have a more complex structure than softwood. Hardwood joinery tends to be more expensive compared to softwood.

Although both types of wood can be used in all kinds of fields (construction, furniture, utensils,…), due to it's density, hardwood is mainly used for musical instruments and furniture.

Furthermore there are species where you can classify wood as *heartwood* and *sapwood*.

Heartwood:
Heartwood is more resistant to decay due to the genetically programmed process called "*tylosis*". Once its formation is complete, it is dead. There is no vital importance to the tree; the name "heartwood" is derived solely with regard to it's position.


Fig 2.1.2.a – Sapwood and heartwood

Sapwood:
Sapwood is the outermost wood, which leads water from the roots of a tree to its leaves; it is the "living" wood.

2.1.2.2 Criteria

The main criteria when speaking about wood are:

a) Hygroscopic properties
- The tendency to absorb moisture from it's surrounding.

b) Anisotropy
- Wood shrinks unequally when drying. Out of the middle European kinds of timber, there is maximum shrinkage of axial 0,3%; radial 5%; tangential 10% - wood shrinks tangentially about twice as much as radially, which can lead to radial cracks.

c) Density
- Density fluctuates with the moisture of wood. Because wood is a viscoelastic material, it's properties are subject to time. The load duration and the type of load (static or dynamic) have to be considered. Out of the different building materials, the tensile strength of wood is the one with the best data. And although the tensile strength of steel is about 5-6 times higher than of wood, wood is 16 times lighter in weight.

d) Acoustic properties
- Acoustic velocity is influenced by: density, elasticity, fibre length, moisture content, knobs and cracks. Because of its good acoustic properties, wood is used for musical instruments, but also for products for acoustic insulation.

e) Thermal properties
- Wood is a bad heat conductor and therefore suitable for insulation products. Heat conductivity increases with the moisture of wood and it's raw density.

f) Biological properties
- Wood is a biodegradable substance and therefore prone to biotic varmints. Decay and decomposition due to bacteria and fungi are only possible at a high grade of moisture.
E.g. resistant heartwoods decompose very slowly; their resistivity is classified into groups 1 - 5 (DIN EN 350-2).

g) Optical properties
- Colour and structure are considered aesthetically pleasant aspects, while knobs and irregular changes in colour are wood defects.
UV radiation harms wood surreptitiously where *lignin* is reduced and washed out due to direct outdoor exposure – the surface then looks grey and dirty. Finishing can help prevent this change of appearance.

2.1.2.3 Common types of wood in Europe

a) Alder
A pale reddish yellow to orange colouring, soft but firm wood, with a moderate tendency of shrinking.
Use – Solid wood is used for imitations of exotic woods for furniture, musical instruments, etc…

b) Ash tree
Sapwood is a whitish grey/ whitish yellow colour. Hardwood has the same colouring which darkens as a tree matures; a linear fibre structure with a rough texture; very elastic wood with good mechanical resistivity.
Use – Solid wood is being used for sports equipments, furniture, parquet, etc…

c) Beech tree
Pale yellow to a pinkish brown coloured wood; darkens only slightly under the influence of light; hard and dense surface.
Use - Solid wood is being used for stairs, office furniture, school furniture, parquet, tools, toys, etc…

d) Cherry tree
Sapwood is a reddish white colour, and thin but firm and hard. Heartwood is a slightly darker light reddish brown colour; a moderate tendency of shrinking with a pleasant smell but not weather-resistant; prone to fungi and insects as well as crooks.
Use – Solid wood is used for high quality interior design, furniture, musical instruments, etc…

e) Elm tree
Sapwood is slim and light yellow to brown, heartwood is a reddish brown and darkens after exposure to air; it's hard, has moderate elasticity, very pressure resistant and has little tensile strength; very decorative wood.
Use – Solid wood is used for furniture, parquet, sports equipment, etc…

f) Larch tree
Sapwood is a light yellowish brown. Heartwood is reddish brown coloured; very resinous with a small tendency of shrinkage, resistant to fungi and acids.
Use – Solid wood is used for windows, gates, parquet, furniture, etc…

g) Maple tree
Almost white or yellowish white medium hard wood with very fine annual rings like vessels.
Use - Solid wood is used for high quality interior design, furniture, musical instruments, parquet, etc… Veneer is used for decor of every kind.

h) Oak tree
Sapwood is yellowish white, and the heartwood is a greyish brown to brown; a very rough and linear fibred texture; very elastic, heartwood has good strength.
Use – Solid wood is used for railway sleepers, furniture, parquet, etc… Veneer is being used for decor of every kind.

i) Pear tree
Heartwood is a light rose colour; medium heavy, dense and without clarity but a fine texture; one of the finest woods.
Use – Solid wood is used for furniture, musical instruments, etc…

j) Pine tree
Sapwood is a rosy white, heartwood is a yellow to rosy brown; a soft wood with a slight tendency of shrinkage.
Use – Solid wood is used for windows, doors, furniture, parquet, etc…

k) Spruce
White, yellowish white to a reddish white; good strength properties, good resistivity against acids but only slightly weather resistant.
Use – Solid wood is used as carpentry material, mine timber, for poles, etc…

l) Walnut tree
Sapwood is white, heartwood is a brownish grey; grains and textures in different tones that makes an impressive veneer; easy to handle and polish.
Use – Solid wood is used for chairs, small furniture, carving work, parquet, etc… Veneer is used for decor of every kind of furniture, pianos, etc…

m) Yew tree
Sapwood is thin and a yellowish white, heartwood is brown, reddish brown or orangey brown coloured; a very decorative wood, elastic, tough, homogeneous.
Use – One of the oldest types of lumber; used for period furniture, luxury accessories, small furniture, etc…

2.1.2.4 Engineered wood

Since it is not naturally grown but manufactured it is also called "*man-made wood*" or "*composite wood*". To achieve a product that meets national or international standards, the strands, particles and fibres are bound with adhesives to form an engineered wood (e.g. plywood).
Wood waste is used for wood composed of particles or fibres, while whole logs are used for veneers.
Because engineered wood is man-made, it has some advantages over "natural grown wood":

- It can be designed to meet specific requirements regarding it's performance;
- No matter how small in diameter the trees are, large panels can be manufactured from their fibres;
- Wood with defects can be used.

On the other hand, demerits are:

- They require more energy for manufacturing;
- The used adhesives may be toxic;
- These products are more prone to absorb humidity than solid lumber.

Types of engineered wood:

Log based:
Glued laminated timber (Glulam)
Multilaminar veneer
Plywood
Laminated veneer lumber (LVL)

Particle based:
Wafer board
Chipboard

Fibre based:
Fibreboard
Parallel strand lumber (PSL)
Wood-plastic composite

2.1.3 The use of wood in Europe

2.1.3.1 The use of wood in general

These days when speaking about wood, for most people the first things that come to mind are the technical facts and properties. You'd think that its "natural beauty" might not be important enough. In fact, example crooks and variations of colour are pointed out as an abnormality; its "aesthetic" properties are not considered as a criterion. But in the past, massive wood of select quality became a status symbol, in Europe and in Japan as well. Joints, being the smallest architectonical device, were a discernible indicator for the always changing ideals of "beauty"; later the successful blurring of the display of a building's constructive body were considered "beautiful".

When looking at ancient timber constructions (i.e. temples, halls, churches, etc…), even if most of them seem to be overdimensioned, these dimensions are not only chosen to disburden the timber but also to give the constructions a good proportion, to make them look more aesthetic. Another way for showing off the aesthetics of wood is showing the construction. In the Nordic countries (i.e. Norway), you can still find houses that seem to be isolated into their components due to their construction (i.e. groove and tongue). The bond between wood and its fabricator starts in the forest – back in time, the farmer (builder) searched for the material he wanted to work with. Naturally grown wood – the singularity of each and every tree – made it possible to construct unique houses and buildings just because of the chosen material.
Back in time the use of bent wood was widely accepted (and later even artificially manufactured) and used for constructional solutions like a drain outlet of a rain gutter.

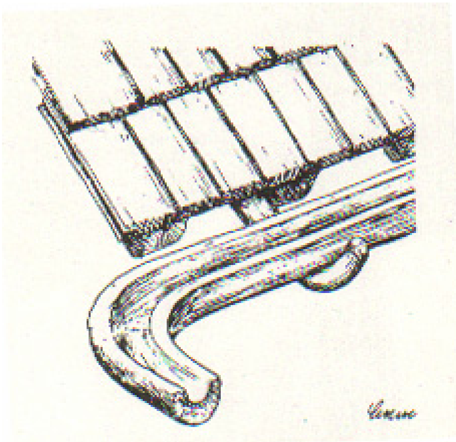


Fig 2.1.3.a – Bent wood used as a drain outlet

a) Wood as a construction material
Within the last years, the percentage of timber houses doubled due to the realization of the merits of timber as a construction material. Handled carefully, timber doesn't need any chemical treatment; modern timber structures are protected due to constructive solutions. Wood has low thermal conductivity and therefore good insulation properties. But not only does this lower heating costs, but even at a lower room temperature, the resident still feels comfortable, since walls and floors don't feel as cold. Plus, due to the natural permeability of wood, air humidity is always constant. Therefore mould fungus, which is the main reason for allergies in rooms, can't arise.

Although nowadays rarely considered, the place of location of a tree should have an influence over utilisation due to atmospheric conditions a tree is exposed to. The heart of a tree can dislocate and create an uneven density of the wood. An experienced builder can use this knowledge (and use a tree with a dislocated heart for example, by applying it as if it is "prestressed").
Not all trees are created equal – grown in a narrow formation, trees have disadvantageous conditions and therefore might grow thicker than others, or depending on the location (south sided/ north sided). In general, softwood appears in weaker branches when growing under extreme conditions. For the restoration of the Yakushi-ji in Nara for example, the master builder Nishioka Tsunekazu ordered wood from south facing slopes for the southern part of the temple, from north facing slopes for the northern part, and so on.

b) Wood as an everyday material
For years it has been said that chopping boards made of plastic are more hygienic than wooden boards. In 1993, scientists from the University of Wisconsin discovered that microorganisms (like salmonella or listeria) were still viable on the plastic boards as opposed to the wooden ones[7]. After leaving the boards exposed to the air at room temperature overnight, the next day the bacteria on the plastic boards had increased; however there were no bacteria shown on the wooden boards.

[7] cf. http://www.treenshop.com/Treenshop/ArticlesPages/SafetyOfCuttingBoards_Article/CliverArticle.pdf (Accessed: Feb 13th, 2011)

Even in Germany, scientists realized that domestic wood disposes antibacterial properties, especially the wood of pine trees, but also oak or larch. However, beech or poplars behave like plastic. Cooking spoons as well should preferably be made of wood since they don't interfere with the taste of the food.

c) Wood and art
South German wood carvers of the 15th and 16th century solely used basswood for their work, not only because of their technical properties but also for religious and traditional reasons. Cabinetmakers of the 19th century though, preferred wood with especially marked colours and structures. Root veneers were used as well as walnut wood and all kinds of fruit trees, especially cherry tree wood.

2.1.3.2 Moonwood

Moonwood is wood traditionally cut in winter depending on the moon phase. According to tradition[8], wood has special technical properties if it is cut at a certain time of the year and even nowadays some people prefer this type of wood for certain pieces of art like special furniture or musical instruments.

Lumber:
The best time to cut lumber is said to be during advent during a waning moon phase. The tree top has to be kept on the bole for some time in order to get rid of the moisture.

Non-shrink wood:
To prevent a change of volume, the 21st of December is said to be the best date to cut this wood.

Saw logs, planks:
The best time to cut lumber is the period of the waxing moon in the Pisces (between September and March), since the wood then is said to be resistant to vermin.

Tear resistant wood:
Used for furniture, it is said to be cut a few days before the new moon in November.

Non-fouling, hard wood:
This wood is said to be cut within the last two days of March, during a waning moon phase.

Wood for pile foundations or footbridges in water:
It should be cut on warm summer days during a waxing moon phase and be used immediately.

Non-flammable wood:
The first of March is said to be the date to cut this wood, after sunset, during any type of moon phase. Many houses were made out of this type of wood to "ensure", that the houses would be fire proof.

Wood for furniture:
Wood cut during the first eight days after December's new moon in the phase of Pisces or Aquarius is said to stay firm, won't distort and will keep its mass.

2.1.3.3 Furniture and accessories

Biedermeier

The manual quality of the production was of great value. The most common types of furniture were chests, davenports or table tops; Also padded sofas with fitting chairs and a round table made of cherry or walnut veneer. The use of domestic wood (cherry, birch, walnut) instead of using mahogany amplified the simple impact of this furniture.

Bugholzmöbel (Bentwood furniture)

In 1856, Michael Thonet managed to outfox the natural properties of wood and it's limits by influencing the effect of the process of bending after a certain time of soaking and steaming and forming the wood

[8] see http://www.mond-holz.de/Downloads/AufDenRichtigenZeitpunktKommtEsAn.pdf, *noted by Josef Schmutzer on December 25th, 1912* (Accessed: Feb 13th, 2011)

using moulds. Wood cut in the direction of growth and bent into massive pieces made it possible to combine ease and strength with grace and elasticity.

Musical Instruments

For the express purpose of making musical instruments, only wood of the highest quality is chosen.
It must be pure solid wood, light but not soft with a steady structure, have thin annual rings and no spiral growth. The sonic speed has to be high compared to the density, whilst also having high sound absorption. The most famous kind of wood that offers these kinds of characteristics is the European spruce, found in higher places (1 000m a.s.l).

2.2 Wood in the Japanese culture

2.2.1 The definition of aesthetic

2.2.1.1 Religious influence

Even in present-day Japan, a common belief is that trees have a soul (according to one of the two biggest religions - "*shintô*" (神道); the first sign, "*kami*", means god(s); "*kami*" are numerous, unlimited and can take the form of people, animals, things or other abstract beings), but also wood; it's soul appears in its beauty. This deep bond to wood in Japan even has its own word: "*kodama*" – the spirit of trees.
The Japanese aesthetic ideals though are more influenced by "*Buddhism*". In Buddhism, nature is not seen as being perfect or complete but considered as a dynamic whole. This valuation is the foundation of many Japanese cultural elements.

2.2.1.2 Wabi-sabi

Wabi-sabi (侘寂; the first sign, "*wabi*", means "*the beauty to be found in simplicity*"; "*sabi*" means "*elegant simplicity*" – combining these two symbols a definition evolved (which is untranslatable) that became the benchmark for Japanese evaluation of arts.) respects three realities: nothing lasts, nothing is finished and nothing is perfect, including characteristics like asymmetry, simplicity or modesty.
Life should be in complete harmony, but not perfect; be clean, but not sterile; symmetry is considered too static, while asymmetry challenges people's interest; items which seem incomplete are a symbol for the dynamic of life. And: less is more – "*One blade of grass is enough to determine the direction of the wind*." (*Suzuki*)

Wabi-sabi can be found in many Japanese genres, for example:

Ikebana (侘寂 – "living flower")

While in the "western" part of the world, the number and colours of the flowers and only the blossoms are considered important. The emphasis of *Ikebana is* on the aspects of the arrangement, including the vase, leaves, branches and stipes.

Japanese Gardens

A Japanese garden is planned down to the last detail where every stone, moss, expanse of water and tree has been accurately chosen and placed. It offers every visitor countless discoveries when walking along the paths. Due to asymmetric and decentred composition, the viewer receives different impressions depending on the point of view.

Japanese Tea ceremony (茶道 – “chadô“; the way of tea)

Attending a real Japanese tea ceremony, the guest is a participant in a kind of performing art. It has a “choreography” based on more than 400 years of tradition, and only the finest tableware and the best tea are chosen by the host.

2.2.2 The use of wood in Japan

I’ve asked people in my area – hardly any of them are very interested in it’s culture or are familiar to the country – about the first things that come into their minds when thinking about Japan. The most common answers were *Geisha* (芸者; the first sign meaning “arts, crafts”, the second one “person”); *Sushi*; funny Japanese *TV-Shows* like “Takeshi’s castle”; *earthquakes*; and: *wood*.
Only a few knew the real “work” of a geisha; that sushi has its origins in china. And almost no one knows about the tradition of wood in Japan. Their knowledge was very basic and superficial, however, it was known that carpentry and the use of wood has a long history in this country.

Houses were built using wood because of the high number of earthquakes, and as time went by carpentry had evolved into art, but so many more genres carefully choose, treat and use this material because of it’s beauty.

While the heart of a western timber frame home is that it’s frame is firm and significant a Japanese house could be described as a large piece of furniture consisting of it’s frame and numberless smaller members that put together form a unified whole. Hundreds of different types of joinery can be found in a medium sized tea house or a home, a result of a tradition that is more than 1 000 years old.

The grid system of the traditional house structure was greatly influenced by tatami straw mats. These mats have a certain size (about 90x180cm per mat) and cover the floor surface of houses. This also influences the placing of doors, windows and even leads to streets of houses of old towns with the same rhythm along their facades.

2.2.2.1 Common types of wood

a) Hinoki (Japanese Cypress)
A light rosy brown colour; straight grained and rot-resistant.
*Use –U*sed for building temples, shrines, palaces, masu (box for measuring rice), etc…

b) Kaya (Japanese Nut yew)
A light yellowish gold colour; very strong and firm with a good sonic quality.
Use – Was used for the construction of Go Boards (Japanese board game) but is now protected.

c) Katsura (Cercidiphyllum)
A light coloured wood; very strong.
Use – Is in use as veneer.

d) Keyaki (Japanese Zelkova)
A light coloured wood; highly resistant to Dutch Elm disease; close-grained.
*Use – U*sed for furniture, interior design, etc…

e) Kiri (Paulownia)
A pale white coloured wood; very light and fine-grained, soft, good sonic quality; extremely fast growing.
*Use –U*sed for the construction of wooden surfboards, body material for guitars, chests, geta (Japanese clogs); burned wood is used to make charcoal for sketching.

f) Matsu(Japanese Pine)
A light yellow coloured wood; very firm and strong.
*Use – U*sed for all kinds of construction work (beams, columns,…)

g) Sakura (Cherry)
A dark red coloured wood; easy to polish, not very resistant against insects;
Use – Used for accessories, interior design, furniture, etc…

h) Sugi (Cedar)
A pale reddish pink coloured wood; very light but firm and resistant to decay;
Use – Used for all kinds of construction work, panelling, interior design, etc…

2.2.2.2 Japanese colour woodcut

The Japanese colour woodcut is a kind of print formed in the second half of the 18th century. Its characteristics are the lack of light and shadows, the use of clear and fluent lines and either completely filled or empty areas. The artwork displays the character of a creature, there is no importance to be as close to real life as possible.
The centre of production of colour woodcuts was Edo, but also Ôsaka.
Since the beginning of the 20th century, it's common to call all woodcuts 浮世絵 (Ukiyo-e; "pictures of the floating world"), but it's not the correct term when speaking about kacho-e and meisho-e, special types of prints.
The material for the wooden board is mainly cherry tree wood and Indian bean wood. The paper used for the prints was obtained from fibres from plants, which made it a tough and robust material. The tools for printing were all handmade and the materials were carefully selected.

2.2.2.3 The tea ceremony

For the tea ceremony the tea house itself can be seen as one of the tools for the whole ceremony where every element is thoughtfully arranged to offer a particular atmosphere for the guests. The deeper meaning of a tea ceremony is to clear the soul and mind and stimulate them in a harmonious way. The harmonisation isn't complete with only drinking the tea; visually, a guest is stimulated by the displayed art (the flower arrangement and scroll painting); incense is used for the sense of smell.

Regarding growth abnormalities for example, unlike in Europe where nowadays they are considered to be not really useable, they are carefully chosen for the interior design of Japanese houses. An example is the wood of the "*Kitayama Sugi*" (*Kitayama Cedar*); this wood is widely used for *Migakimaruta* ("peeled log") which again is used as an alcove post ("*Tokobashira*"), especially for Japanese tea houses.

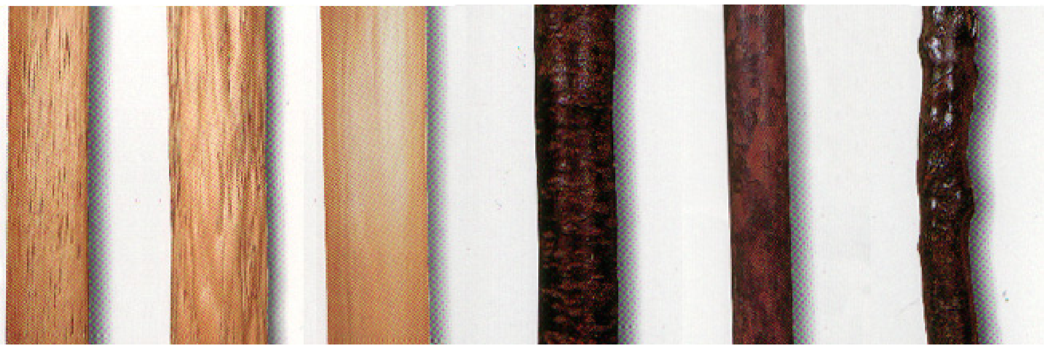


Fig 2.2.2.a – Examples for Tokobashira (from left to right: a) Kitamaya cedar, three types; b) Japanese white birch; c) Japanese red pine; d) Plum;)

Every tool used for the ceremony (here only a small selection of the most important and mostly wooden tools) is a high quality piece of handcraft:

Fig 2.2.2.b –Tea ceremony equipment

Chabako (茶箱) – This box contains a set of utensils for the tea ceremony and is used when the host is asked to hold a tea ceremony somewhere other than his own place. It is made of light wood for ease of transport.

Chaki (茶器) – The container for the powdered green tea (macha)

Fig 2.2.2.c – Choice of chaki

Daisu (台子) –A double shelved display stand for the utensils of a tea ceremony which is usually lacquered in black. It can easily dismantled for easy since in traditional Japanese carpentry the use of nails is avoided because it can cause rust and the metal can corrode which might damage the wood.

Hana-ire (花入) – A flower vase often made of bamboo.

Kouboku (香木) – Aromatic wood as a scent for the ceremony room; pieces are placed on the fire and burnt.

Kuromoji (黒文字) – Natural wooden chopsticks to hand out the sweets served at the ceremony from a tray to the guests.

Chashaku (茶杓) – Bamboo tea scoop to portion the matcha.

Chasen (茶筅) – Tea whisk

Tabakobon (煙草盆) – Tobacco tray

Fig 2.2.2.d – A selection of tabakobon

Even today many contemporary architects try to reinvent the theme of the traditional tea house, which may be because of it's limiting restrictions in scale and concept that inspires the search for new inventions and possibilities.

2.2.2.4 Furniture and accessories

Tansu / Dansu

Since furniture has always been reduced to a minimum in traditional Japanese houses, there are only a few types that are very famous. It was common to "hide" all personal belongings behind sliding doors or objects that seem to be essential parts of the room itself.

In Europe, a very famous type of Japanese furniture is the "*tansu*" – a chest, cupboard or drawer. There are different types of designs.

One design that can be found in several Japanese family houses is the "*kaidan dansu*" or "*step chest*" – futon, covers and/or temporarily used accessories were kept in the drawers while the chest itself were the stairs to get to the second floor.

Fig 2.2.2.e – "Kaidan Dansu"

"*Mizuya dansu*" were placed in the kitchen where they were used as storage for utensils, plates or food and designed with a mixture of drawers and sliding doors.

"*Kusuri dansu*" were found in pharmacies and designed with lots of drawers to store all the herbs and medicine.

"*Katana dansu*" were chests to store swords and therefore had a long and low shape. The type of wood used was Kiri, to prevent the swords from rusting.

The iron fittings and details of the tansu can help identify where it was created – different patterns and shapes, prints of animals are characteristics found unique in every part of Japan.

Kabazaiku

A traditional art of handcrafting tea boxes and small woodwork items out of cherry tree wood. This wood acts as a natural insulator against humidity and keeps the moisture levels constant, which is essential for storing tea and tobacco leaves. The boxes are made by shaping the wood itself into the desired form, the bark is then reapplied.

Fig 2.2.2.f – "Kabazaiku" tea box

Go Boards and bowls

Go is a very old and in East Asia still very popular board game; in Japan there are about 10 million active players. Boards are usually made from the wood of the Kaya, being superior in colour and hardness, but they can also be made out of Katsura (Japanese Judas Tree) or Spruce. The bowls for the stones can be made out of mulberry, keyaki, sakura or chestnut; depending on the board they are used with, it is essential to choose the right and aesthetic colour.

Fig 2.2.2.g – Go board with bowls

3. HISTORY OF TIMBER CONSTRUCTIONS

3.1 History of timber constructions in Austria (Europe)

3.1.1 Overview

Until the 16th century, mainly timber constructions were used in middle Europe. They were displaced by the usage of clay and stone constructions:
On one hand because of the increasing need of wood for the purpose of heating as well as for producing charcoal for the iron industry. On the other hand because the Mediterranean technique (constructions made of stone) was chosen in preference of duplications.
The use of timber within Europe varies a lot – Norwegians probably developed their timber stave churches and log constructions (that can be found even in northern Russia) by copying Western European constructions; In the Alpine regions (and therefore because of the geographical conditions), log constructions were preferably used. In contrast to this, Central Europe preferred timber framed constructions filled with straw, cob or clay bricks.

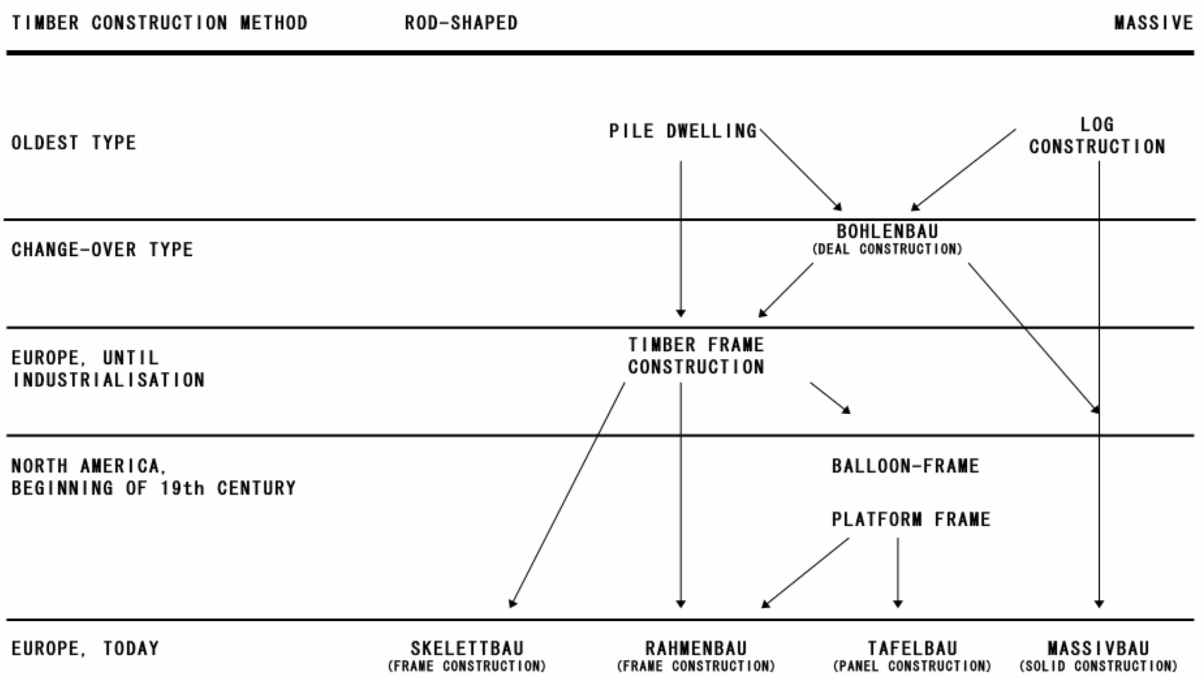


Fig 3.1.a – Development of timber constructions

3.1.2 Type of constructions

The most commonly used timber structures in the 19th century were timber frame and log constructions. They were developed further in America to "*balloon frame*" and "*platform frame*"; the timber frame constructions have been reimported to Europe, adjusted for European standards and have become the basis for the common timber frame constructions used today.

3.1.2.1 Timber frame constructions

The timber frame house was the ruling style from around Central Europe to England between the Classical Antiquity period until the 19th century. The supporting elements are made of timber, the blanks filled with a combination of wood and clay or bricks.

The typical cross section of the lumber ranges from 10x10 to 18x18cm. Connecting parts are mortised and secured with tree nails. These constructions can be dismantled and rebuilt from the ground up and single parts can be replaced.
The construction of sole plates, posts, beams and struts is erected storey-by-storey and struts should be placed at the corners of the building to transfer wind forces directly to the sole plates.

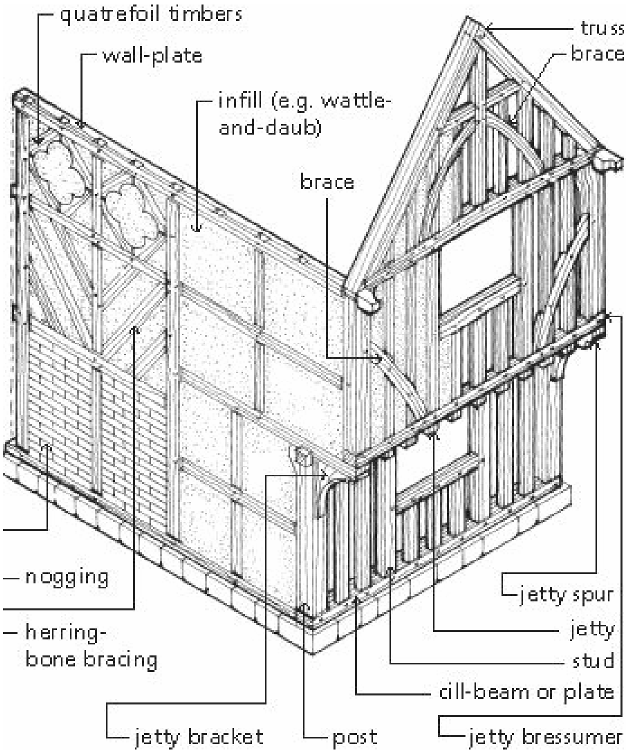


Fig 3.1.b – Timber frame construction

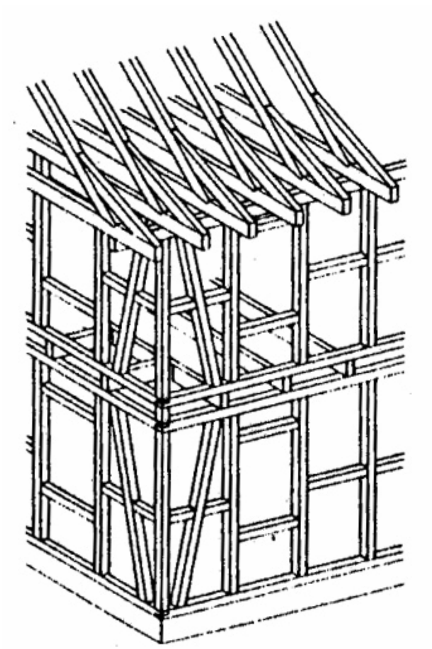


Fig 3.1.c – Traditional timber frame system

Fig 3.1.d – Timber frame house; Lucerne, Switzerland

Fig 3.1.e – Timber frame house; Springe, Germany

3.1.2.2 Log constructions

Although associated with North America, log construction has its roots in Scandinavia and Eastern Europe from around 3500 BC. It is one of the oldest timber building systems used not only for houses but also for towers, churches and other buildings (up to five storeys high). With its better insulating properties, solid wood has an advantage over timber frame constructions.
Over the years, although the traditional joints have survived and are still in use they were developed and technically matured, so that they can now be made more precisely.

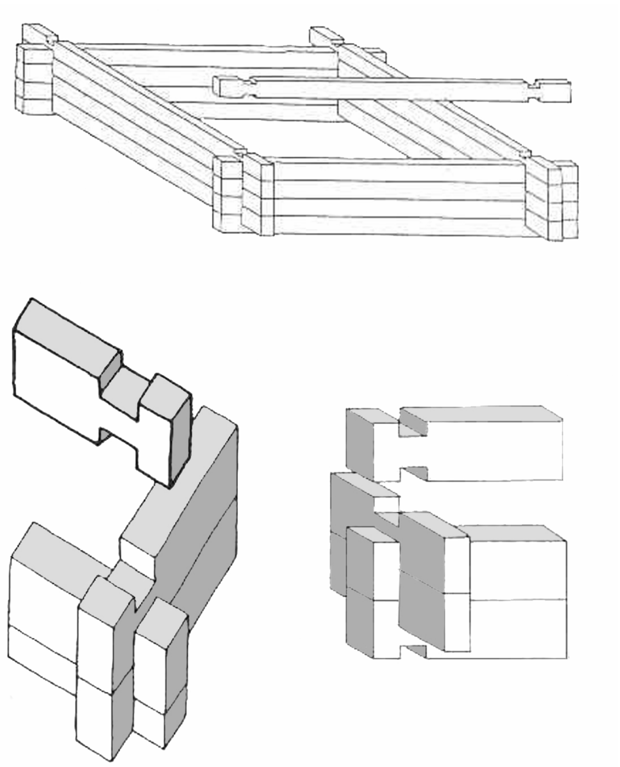


Fig 3.1.f – Log construction – Joints

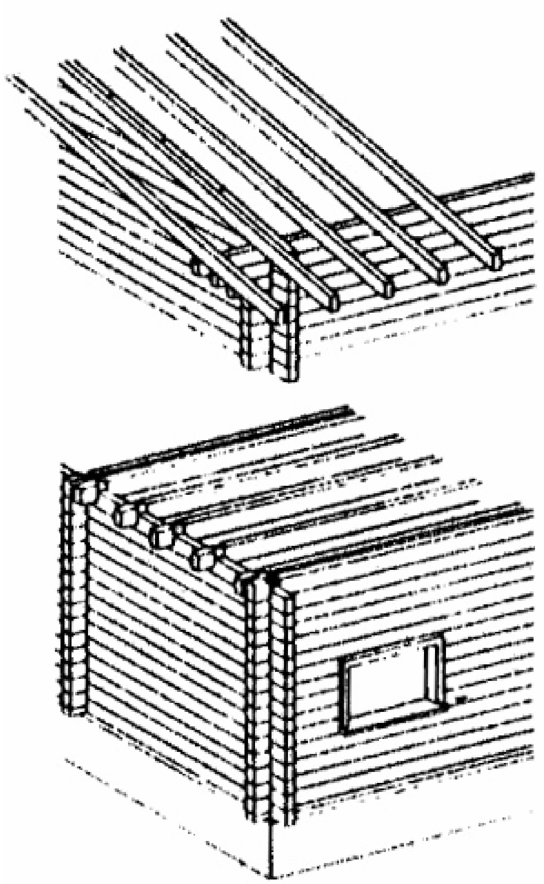


Fig 3.1.g – Log construction - system

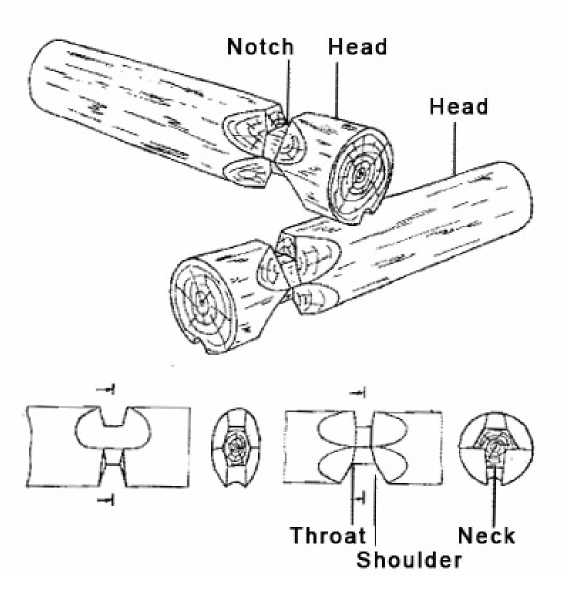


Fig 3.1.h – Log construction; Joints - Norwegian Style

Fig 3.1.i – Log cabin; Germany

3.1.2.3 Panel constructions

Panel elements – also using the frame building principle – are prefabricated. They are fitted on site and are therefore a time saving construction method. They are usually produced to the size of a wall and are insulated.

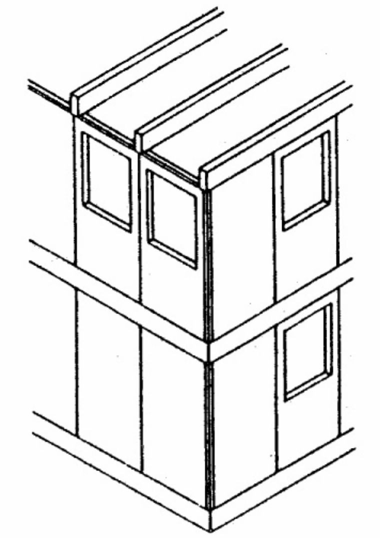


Fig 3.1.j – Panel construction - system

Fig 3.1.k – Panel Construction

3.1.2.4 Stacked plank system

This system has been rediscovered and developed in recent years. Planks are placed beside each other (on edge) and nailed together, and then used as panel elements. A wooden building element of any width can be created.
In order to reduce deformation by shrinkage and swelling it is important to use dry boards.
This construction type is simple and can be made by every manufacturer, can be prefabricated in the workshop or factory (regardless the weather) and even lower quality side planks can be used.

3.2 History of timber architecture in Japan

3.2.1 Overview

The use of timber in Japanese architecture has always been an integral part of its culture as it's not only a construction material, but also associated with nature and valued because of its colour, texture and smell.

Also, Chinese architecture has historically influenced the Japanese; another influence is the climate – since most of Japan has long, hot summers, to counteract the heat, the houses are somewhat raised for possible air circulation. Timber structures were popular choices and have traditionally been the basis for Japan's architecture as these constructions adjust well to earthquakes and work well with season changes (cool in summer, warm in winter).

As most of these constructions made by wood still exist nowadays, it shows us the quality and possibilities of constructional work with timber. But, due to devastating fires in the early twentieth century, its use has been restricted by building authorities.

For example, the earthquake in 1923 didn't destroy the timber buildings consisting of the majority of Tokyo, but a following fire that lasted forty hours did. To minimize fire risk, public buildings were supposed to be built in reinforced concrete, brick and steel constructions.

After the Second World War timber constructions were limited to a maximum of two storeys with a floor area of less than 1 000m². The first building code revision in 1950 still didn't favour timber constructions and it took until the 1980s to change that.

3.2.2 Historical development of the timber architecture in Japan

3.2.2.1 Jômon Period (14000 – 400 BC)

Around the Jômon-Period wood was the primary building material and by 300 AD Japanese architecture established a style the Shinto architecture (late third century) was based on. Straight lines of roof and eaves were the characteristics of this style, along with circular columns placed directly into the earth. The structures were the archetypes of the "Ise Grand Shrine" (first built in 692 AD).

3.2.2.2 Asuka Period (538 – 710 or 592 – 645 BC)

In this period Buddhism was introduced followed by a new style influenced by Chinese architecture – the roof lines were no longer straight but curved followed by deep overhanging eaves. Hôryu-ji Temple in Nara for example was built during this period. The layout of Hôryu-ji has been unchanged and preserved; the main hall is the oldest wooden structure in the world and the centre of the entire complex. The five storey pagoda of Hôryu-ji is 32.5m high.

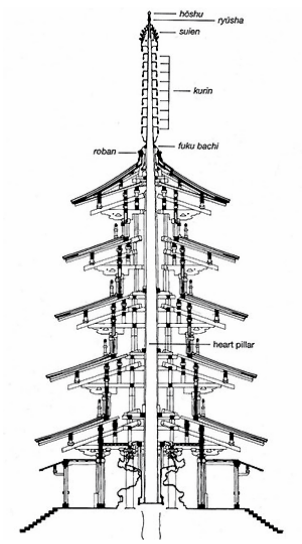


Fig 3.2.a – Section of Hôryu-ji Pagoda, Nara

Fig 3.2.b –Hôryu-ji Pagoda, Nara

3.2.2.3 Nara Period (710 – 794 AD) to Heian period (794 – 1185 AD)

During the Nara period, the Chinese capital influenced Japanese architecture. A capital city, Heijôkyô, was planned as an imitation. During the Heian period, a new type of arrangement appeared – houses had sleeping rooms in the centre with corridors connecting other apartments. This style is called "*shinden-zukuri*"; an example is the "*Tosanjo Palace*" of 1043.

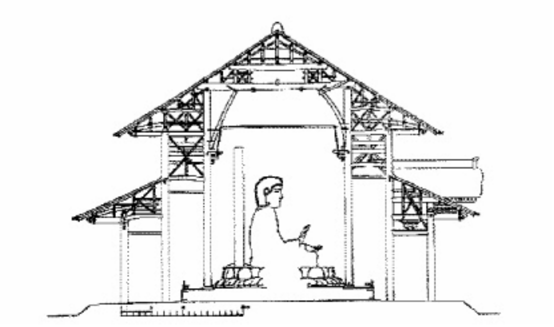


Fig 3.2.c – Section of Tôdai-ji, Nara

Fig 3.2.d –Tôdai-ji, Nara

3.2.2.4 Muromachi Period (1333 – 1568)

"Katsura Rikyû" in Kyoto is an example of a style popular during this period: simplicity with no distracting ornaments. As tea ceremonies were popular, tea cottages were built to reflect this style.

Himeji-Castle, consisting of 83 wooden buildings, combines traditional wooden architecture, stone walls and white-plastered walls; it was originally constructed during the Muromachi period but was badly destroyed due to war and was rebuilt and finished in 1618. It is representative of all the castles found in Japan.

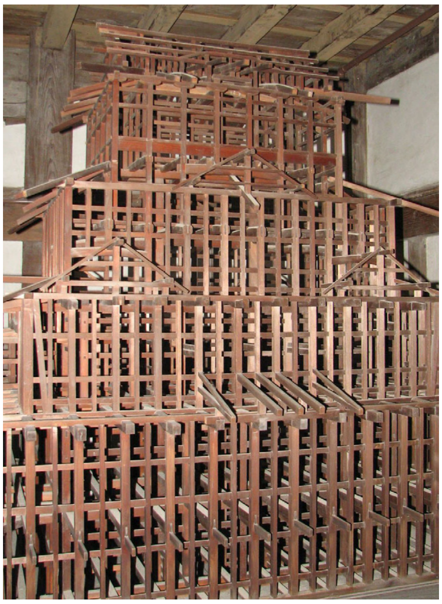


Fig 3.2.e – Himeji-jô, Himeji,

Fig 3.2.f –Structure of Himeji-jô, Himeji

3.2.2.5 Edo Period (1603 – 1868)

As Tokyo was repeatedly struck by fire, an easy to reconstruct architecture was developed – "prefabricated" lumber was stored close to the city so that immediately after a fire was extinguished, it could be sent for and houses quickly rebuilt.

3.2.2.6 Pre-war to Post-war Period (End of 1800 until today)

Because of the high density of timber buildings, fire sometimes demolished whole districts. After the big fire in 1872 a decision was made to reerect the area using brick construction. But after the earthquake in 1923, it became obvious, that brick constructions weren't earthquake-proof either, so from then on reinforced concrete became the main construction material. Due to the new materials mixed with the influences of Europe new buildings like the "Tokyo Train Station" or the "National Diet Building" were constructed.
Due to the need for reconstruction in Japan after the World War 2, new technologies were used and changed the country's architecture completely. Today, the industrial districts with their skyscrapers stand in strange contrast to the districts with housing buildings built in the sixties.

3.2.3 High-rise timber constructions - Pagodas

3.2.3.1 The structure of a pagoda

Japan's oldest pagoda was built in 706 but most of the wooden pagodas were destroyed due to fire, and only a few were destroyed because of typhoons or earthquakes.

The construction gives the pagoda its resistivity. Every storey of a pagoda is a self-contained framework with 12 columns defining the outer boundary. To reduce the depths of the storeys, the columns have to be displaced further inwards. They are carried by horizontal beams, which on their part rest on diagonal lumbers (= rofe). The load of the roofing pressing on the outer ends of the "rofe" acts as a counterbalance to the load of the columns of the next storey, pressing on the inner ends of the "rofe". The column head is the centre of the lever. The luxuriant decorated pike of the pagoda acts as a counterbalance for the top floor. The middle column – typical for the Japanese pagoda – carries the load of this pike. At the beginning these columns were constructed standing, later hanging, behaving like a pendulum. Combined with the flexible joints it absorbs the full destructive force of earthquakes.

3.2.3.2 The Yasaka-Pagoda

The Yasaka-Pagoda – also known as the Hokan-ji Temple – is one of the most impressive structures of Kyoto.
The early history of the 46m high pagoda can not be determined in detail. Having its seeds in the year 589 (under dominance of Prince Shotoku Taishi), it has been destroyed several times (due to war and fire), but has always been reconstructed - true to it's original design; in 1440 Shogun Yoshinori Ashikaga was the last to do so. The earthquake resistance comes from the construction where every fifth storey is simply supported around a continuous core. Thereby it can absorb every tremor and follow the movements of the ground.

Fig 3.2.g –Yasaka-Pagoda, Kyoto

3.2.4 A timeline of timber constructions in Japan

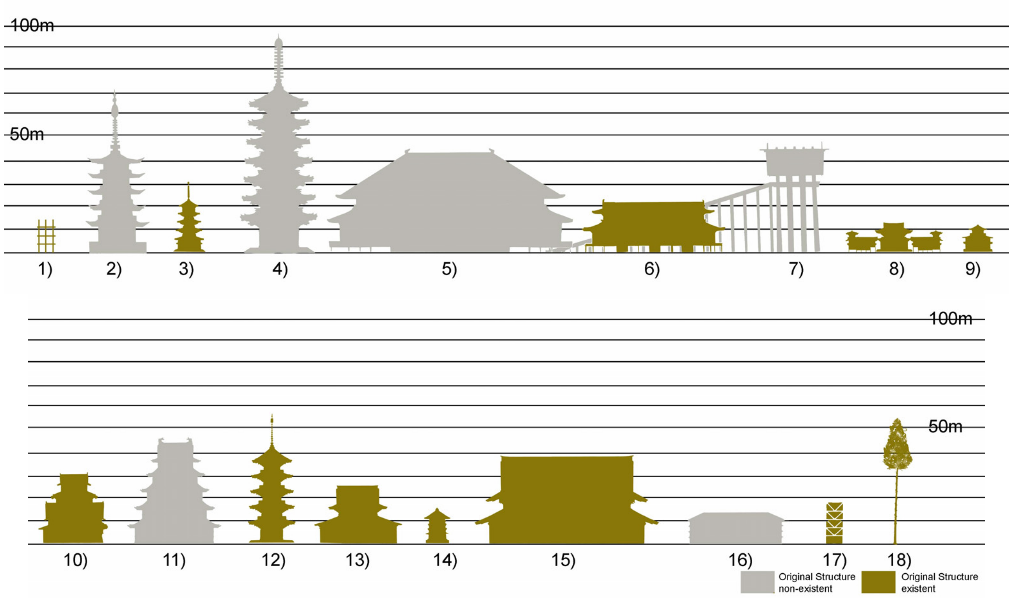


Fig 3.2.h –Timeline of timber constructions in Japan

1)	~ -2500:	三内丸山遺跡 (Sannaimaruyamaiseki); Aomori; ~10m height; ruins
2)	659:	元興寺五重塔 (Gangôjigojûnodô); Nara; ~73m height;
3)	680:	法隆寺五重塔落書 (Houryujigojûnodôrakugaki); Ikaruga, Nara; 31.5m height;
4)	752:	東大寺七重塔 (Tôdaiji); Nara; ~100m height;
5)	758:	東大寺大仏殿 (Tôdaijidaibutsuden); Nara, ~49m height;
6)	794:	平安京大極 (Heiankyô); Heian; ~22m height;
7)	900:	出雲大社 (Isumotaisha); Shimane, Izumo; ~48mheight at first; rebuild height ~24m
8)	1053:	平等院鳳凰堂 (Byôdôin Hôôdô); Kyoto, Uji; 13.6m height;
9)	1398:	鹿苑寺金閣 (Rokuonji kinkaku); Kyoto; ~13m height;
10)	1609:	姫路城 (Himejijô); Hyoogo, Himeji; ~30m height;
11)	1638:	江戸城 (Edojô); Tokyo, Chiyoda; ~51m height;
12)	1644:	東寺五重塔 (Tojigojûnodô); Kyoto; 54.8m height;
13)	1707:	善光寺本堂 (Zenkôjihondô); Nagano; ~24m height;
14)	1796:	栄螺堂 (Sazaedô); Fukushima, Aizu; ~14m height;
15)	1895:	東本願寺 (Higashihonganjimiedô); Kyoto; ~38m height;
16)	1917:	繭倉(Mayugura); Sukagawa; ~15m height (4 storeys);
17)	2005:	エムビル(M-biru); Ishikawa, Kanazawa; ~14m height;
18)		Japan’s highest tree; Japanese cedar; ~55m

Tab 3.2.a.: The “tallest” timber constructions in Japan[9]

3.2.5 The history of fire experiments within the recent years

YEAR OF EXPERIMENT	EXPERIMENT ON	LAW REVISION	FURTHER USE
1976	A 2-storey building	noncombustible construction	
1978	A small 3-storey attic townhouse	Order for simple fire resistive construction	Small 3-storey residential lofts
1987	A 3-storey building		3-storey private houses
1991	A 3-storey condominium	Simple fireproof building	3-storey condominium (other than semi-fire zone)
1996	A 3-storey downtown condominium		3-storey condominium (other than semi-fire zone)
2003	The primary structure (exterior walls, roof)	Fire resistive construction (approved by Minister)	- three-storey buildings: fire area 100m2 - four-story building - social housing, hotels, etc.
2004	The primary structure (floor, staircase)		
2008	The primary structure (between boundary wall)		

Tab 3.2.b.: 2x4 Home Builders Association[10]

[9] on base of Koshihara Laboratory, “*timberize tokyo*” exhibition 2009, translated by author
[10] cf. www.2x4assoc.or.jp - translated by author (Accessed Feb 13th, 2011)

4. FIRE SAFETY INSTRUCTIONS

4.1 Fire Safety Instructions in Europe

4.1.1 Introduction

In the 90s EUROCODES (EUROCODE 5 – deals with design, calculation and dimensioning of timber constructions.) were published as “pre-standardisation”, their usage was only given as a recommendation. In 2003, they were changed into binding standardisations.

However, as every country in Europe has it’s own standards as well as regulations and restrictions no real general instruction is available.

Following are some examples of European countries dealing with middle rise and high rise timber constructions.

4.1.2 Germany

4.1.2.1 Development

Due to the rewritten prototype building regulation (MBO 2002), it is possible (in combination with the prototype guideline for fire resistance requirements for highly fire retardant timber constructions (M-HFHHHolzR 2004)) to design timber constructions up to GK4 - up to 13m floor height of the top level and 400m² unit area. The regulations also apply for additions of storeys to existing buildings.

Load-bearing and bracing timber elements are requested to be designed highly fire retardant (F60) and to be equipped with an effective fire-resistant cladding constructed of noncombustible materials. Furthermore, the penetration of fire over the static construction has to be prevented for at least 60 minutes (Capsule criteria K).

Like in Austria, it is in the states’ discretion to apply the prototype guidelines.

4.1.2.2 Requirements

Applies only to prefabricated timber panel, timber frame and framework construction.
K60 for enclosing walls and ceilings; additional requirements for the construction of the fire security sheathing and the chosen insulations (rock wool, melting point <1000°C)

4.1.2.3 Law and/or guidelines

Guidelines for terms of fire protection of highly fire-resistant elements in timber (M-HFHHolzR) (based on model building regulation MB002)
Since July 2007, certificates legitimately back up 5-storey timber constructions.

4.1.3 Switzerland

4.1.3.1 Development

Regulations from 1993 until 2004 – only 2 ½ storey timber constructions using F30 bb (fire resistance 30mins, combustible). Since January 2005, 6-storey high timber constructions are allowed in Switzerland.

4.1.3.2 Requirements

A fire protection concept before the work begins, and guidance thru a specialist engineer are required. If the building owns a fire sprinkling system, an EI 30 casing is not necessary (=EI = non-supportive, enclosing elements).
Otherwise, the elements have to be cased on both sides. In constructions with burnable structures, the insulating layers have to be noncombustible.

4.1.3.3 Law and/or guidelines

Swiss fire protection code and fire protection guidelines VKF 2003
Since 2005:
3 storeys – REI 30
4 storeys – REI 60, insulation noncombustible
Up to 6 storeys – REI 60/EI30 (nbb), cladding noncombustible

4.1.4 Great Britain

4.1.4.1 Development

The amount of four-storey timber frame buildings increased over the last 20 years.
In 1991 the building regulations (in England and Wales) changed to allow buildings that *could* reach 8-storeys.

Building Regulation 1991:

Fire Regulation (5 storeys)

</= 11m	England/Wales 1h	Scotland 1h
11m - >/=20m	England/Wales 1h (stairs to be noncombustible)	Scotland not allowed (no timber above 5 storeys; stair shaft and protected lobbies to be of noncombustible construction; stairs to be noncombustible)

The results of the joint feasibility study (TF2000 project; start 10/1995[11]) have provided reliable guidance on the construction of buildings with 5 or more storeys ever since.
It led to the change to Scottish technical standards (6th amendment March/April 2002) and the removal of noncombustibility - requirement for separating floors between 11m and 18m.

4.1.4.2 Requirements

Current regulations for England and Wales prescribe a *minimum time that all homes must resist fire* in order for occupants to escape.
Timber frame can currently go up to 18-20 metres within the current regulations.

4.1.4.3 Law and/or guidelines

The Building Regulations 2000, fire safety, 2007 edition

4.1.5 Finland, Norway, Sweden, Denmark

4.1.5.1 Development

A result of a Nordic project to supply documentation and information on the safe use of timber in buildings, a design guide for light timber frame structures was published in 1999.
An extended version including solid timber structures was published in November 2002. As a further result, the Nordic building codes have gradually changed and now allow for an increased use of timber structures in multi-storey buildings.

[11] see http://projects.bre.co.uk/tf2000/index.html (Accessed: Feb 13th, 2011) for further details about the TF 2000 Project.

The move to performance based regulations makes it possible to modify the extremely restrictive view on the fire behaviour of timber that still exists in many countries, mainly because of prescriptive fire codes.

New fire design possibilities for timber buildings have been developed for
- Load-bearing structures
- Separating structures
- Detailing in structures
- Wooden facades
- Active fire protection by e.g. residential sprinklers
- Risk assessment

Number of stories in timber allowed in Nordic building codes[12]:

COUNTRY	up to 1993	1994	1997	1999	2004	2007
Sweden	2	∞	∞	∞	∞	∞
Norway	3	3	∞	∞	∞	∞
Finland	2	2	4*	4*	4*	∞
Denmark	1-2	1-2	1-2	4	∞	∞

* - Sprinklers required

4.1.5.2 Requirements

Detailing:
… in design is essential for the fire safety of timber buildings and especially for timber frame structures.

Development so far:
- fire stops within timber structures
- ventilation opening and eaves
- attic separation

Wooden facades:
… are not generally allowed in the Nordic building codes, but requested by architects and builders.

Development so far:
- partial wood
- fire rated windows or devices closing at fire
- cantilevers over windows
- small or no windows
- fire retardant wood
- residential sprinklers

Wooden facades can e.g. be used in sprinkled buildings, which is logical since the risk for flames out of a window from a fully developed fire is eliminated.

4.1.5.3 Law and/or guidelines

Fire testing methods and calculation rules are being harmonized within the EU and its Construction Product Directives. For surface linings new Euro classes will replace previous national classification systems that form obstacles to trade. For structural elements new design methods for fire resistance of timber structures are given in Eurocode 5 Part 2.

[12] cf. http://www.vtt.fi/inf/julkaisut/muut/2009/SP_Report_2008_29%5B1%5D.pdf - Birgit Östmann, SP Trätek Stockholm, 2005 (Accessed: Feb 13th, 2011)

4.1.6 Italy

4.1.6.1 Development

DM 16/05/1987 n 246 – “Code for buildings in residential areas - Fire-regulations”
This Code’s content described the criteria for materials and structures for constructions according to fire regulations, not higher than 12m eaves height. It applied for existent buildings as well as for new constructions.

For constructions higher than 24m (eaves height), the code DM 16/05/1982 n 94 applied. In this technical regulation for residential buildings, the buildings are classified into A, B, C, D and E – according to the height of fire, which is an indication of minimum planning requirements[13]:

- The need for possible combinations of fire fighter’s fire ladders
- The maximum areas of subdivision (max 8 000 m)
- The minimum resistance to fire frame and separating (R min / REI 60)
- The type and number of stairwells and at least one lift shaft

CLASS	Height	Max. area of the compartment	Max. area of competence of each scale on each floor	Type of staircase	Characteristic REI for staircases, elevators, …
A	< 12 – 24m	8000	500	No prescription	60 (**)
			500	Protected if they are not complying with the requirements of 2.2.1	60
			550	No evidence of smoke inside	60
B	24 – 32m	6000	500	No prescription	60 (**)
			500	Protected if they are not complying with the requirements of 2.2.1	60
			550	No evidence of smoke inside	60
			600	Smoke-proof	60
C	32 – 54m	5000	500	No evidence of smoke inside	90
D	54 – 80m	4000	500	Smoke-proof with a filter inside the ventilation stack section with no less than 0.36m²	90
E	> 80m	2000	350 (*)	Smoke-proof with a filter inside the ventilation stack section with not less than 0.36m²	120

(*) With a minimum of 2 staircases for each building
(**) Only for devising elements between compartments

4.1.6.2 Requirements

Examples of buildings with more than 5 storeys do exist, but it depends on the zone they are situated in. Buildings constructed in (earthquake) zone 1 are only to be built 2 storeys high. The attic above the second floor are not be inhabited. Within the other zones the buildings are limited according to the seismic classifications of the site and the plasticity of their construction. Other materials (reinforced concrete …) are limited according to their resistance and plasticity.

4.1.6.3 Law and/or guidelines

Norme tecniche per le costruzioni, D.M. 14 January 2008

[13] see: http://www.leoingegneria.com/Leggi/DM246-87.pdf - translated by author (Accessed Feb 13th, 2011)

4.2 Fire Safety Instructions in Austria
Demands according to OIB Guideline 2 (OIB-Richtlinie 2)

4.2.1 Introduction

Since 2002, by developing the OIB Guidelines (*Österreichisches Institut für Bautechnik – Austrian Institute for structural engineering*), a harmonization of the structural prescriptions within Austria was under progress but although the guidelines have been completed, it is in the states' discretion to apply them.

The biggest innovations according to the Austrian timber industry included in these guidelines are:

- 4 storey timber constructions possible in all states of Austria
- 2 storey timber constructions can be built on top of 4 storeys steel/concrete/… constructions
- townhouses can be constructed right along the site boundary
- exemptions due to fire prevention concepts are included in the guideline

The general requirements about fire protection are handled in Guideline 2, which is divided into:

Guideline 2.1 – fire protection for company buildings
Guideline 2.2 – fire protection for garages, covered parking spaces and parking levels

4.2.2 Requirements

4.2.2.1 … Concerning the fire behaviour of building materials

Essential properties for evaluating building materials according to their fire behaviour are:

- Inflammability
- Combustibility
- Expansion of flames
- Expansion of fumes.

Because all these properties depend on countless factors standardized examinations are used to compare the fire behaviour of every single building material.

The classification is stated in:

Fire behaviour:	A1, A2, B, C, D, E, F
Expansion of fume:	S1, S2, S3
Drip-off:	d0, d1, d2

Further on, for buildings from GK2, references to *Ö-NORM B3806 [6]* should be made.

4.2.2.2 … Concerning the fire resistance of the structural components

The requirements for fire resistance of components are being placed with the REI classification of the ÖNORM EN 12501-2 [7].

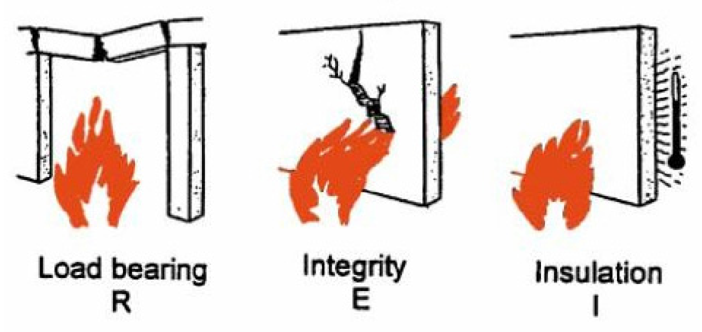


Fig 4.2.a – Explanation for the performance criteria

Abbreviation	Meaning	Area of application
R	carrying capacity	description of fire resistance ability
E	room proximity	
I	Insulation	
I_2	Insulation	fire protection doors
30, 60, 90	duration of fire resistances [min]	all components
S, S_m	limit of smoke permeability	smoke protection doors, ventilation systems
C	category for self-closing properties	smoke protection doors, fire protection closures

Tab 4.2.a.: An extract for classifications[14]

It has to be considered that building materials classified A2 have to be used for parts designed as fire resistant for 90 minutes.

Classification	GK1	GK2	GK3	GK4	GK5
1 Load bearing elements (except ceilings and fire compartment walls)					
1.1 top floor	none	R 30	R 30	R 30	R 60
1.2 other floors above ground level	R 30	R 30	R 60	R 60	R 90
1.3 floors below ground level	R 60	R 60	R 90	R 90	R 90
2 Partitions					
2.1 top floor	-	EI 30	EI 30	EI 60	EI 60
2.2 other floors above ground level	-	EI 30	EI 60	EI 60	EI 90
2.3 floors below ground level	-	EI 60	EI 90	EI 90	EI 90
2.4 between flats/operation units in townhouses	-	EI 60	-	EI 60	-
3 Fire compartment-forming walls and ceilings					
3.1 … along the site boundary	REI 60 EI 60	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90
3.2 others	-	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90	REI 90 EI 90
4 Ceilings and roof pitches (less than 60°sloped)					
4.1 top floor ceilings	none	R 30	R 30	R 60	R 60
4.2 top floor partition ceilings	none	REI 30	REI 30	REI 60	REI 60
4.3 other floors' partition ceilings	none	REI 30	REI 60	REI 60	REI 90
4.4 ceilings within flats/operation units above ground level	R 30	R 30	R 30	R 30	R 90
4.5 ceilings of rooms below ground level	R 60	REI 60	REI 90	REI 90	REI 90
5 Balcony slab	none	none	none	R30 or minA2	R30 + minA2

Tab 4.2.b.: General requirements for building materials[13]

4.2.3 Fire prevention concepts

In general, it is possible to differ from the quoted requirements, if proof can be given that the following objectives can be achieved:

- Endangering of life and health of persons due to fire can be prevented
- Spread of fire can be restrained

[14] Abridgement of ÖNORM EN 12501-2 [7], demands according to OIB 2; Source: Zuschnitt; „*Sonderthemen im Bereich Holz, Holzwerkstoff und Holzbau*"; September 2008

The following special buildings absolutely require a fire prevention concept:

- Gathering sites (more than 1 000 people); Hospitals; Retirement and nursing homes; Prisons; Other buildings, if because of their purpose or construction the guidelines cannot be used

When creating a fire prevention concept, the OIB-Manual "deviations from fire protection and fire prevention concepts" is to be taken into account.

4.2.4 Creation of fire compartments

To constrict the spread of fire and smoke within buildings, fire compartments with an area of 1.200m² for residential use and 1.600m² for business use with a longitudinal extent of a maximum of 60m are specified.
In addition, fire compartments are not allowed to exceed more than four storeys above ground.
New for Austria is the obligated installation of smoke alarms in lounges of flats as well as in hallways used as emergency escape routes for lounges.

The fire compartment forming ceiling either has to be extended with a 0.8m horizontal overhanging element (constructed using the same fire resistance classification);
Or an overlapping ceiling stripe of an outer wall (min. 1.2m height; fire resistance classification EI 90) has to be constructed.
For buildings within the classification GK5 at least materials classified as A2 have to be used.

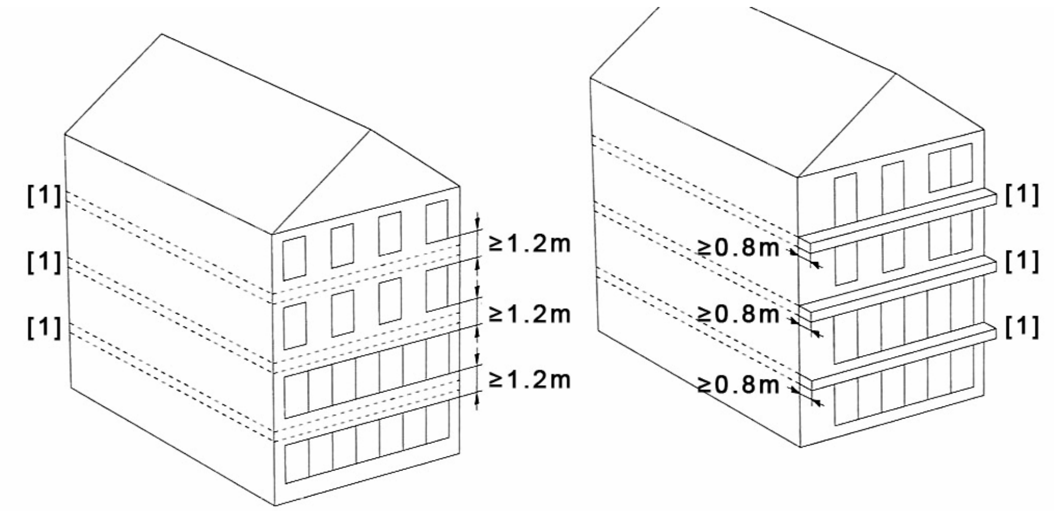


Fig. 4.2.b - [1] - fire compartment forming ceiling

Doors, gates, windows and other openings in outer walls have to be designed in a distance of 0.5m to connecting fire compartment forming walls, unless the horizontal spread of fire can be prevented with other equivalent actions.

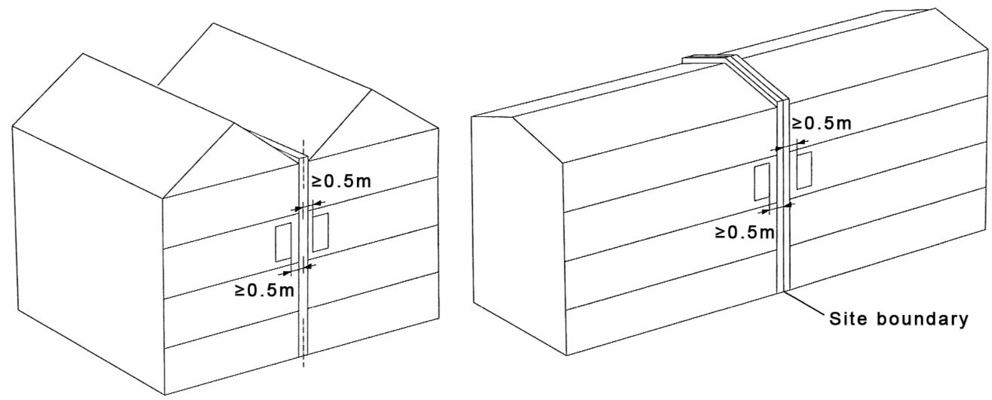


Fig. 4.2.c – Distances of openings to fire compartment forming walls

4.2.5 Regulations for category 5 (GK5)

4.2.5.1 Definition: Buildings of category 5 (GK5)

Buildings with an escaping level less than 22m, but not definable as GK1, 2, 3 or 4, as well as objects with below ground levels only.
Buildings with only one escape route supplied with stair cases without an air lock are required to be supplied with a mechanical ventilation system or an automatic fire alarm system.

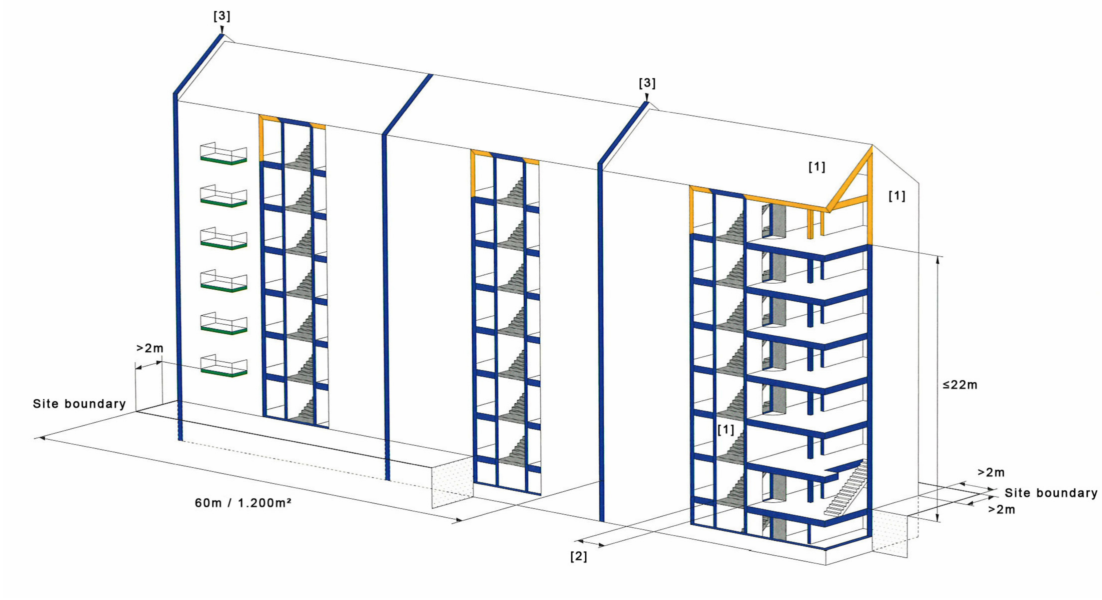


Fig 4.2.d – Definitions for GK5-buildings

[1] – Concerning the requirements for fire behaviour of building materials, ÖNORM B 3806 has to be considered.
[2] – Concerning the passage width of hallways, stairs and doors along escaping routes the requirements of guideline 4 have to be considered.
[3] – Fire compartment forming walls are to be extended 15cm above the roof.

Buildings with a maximum of 6 storeys the upmost two storeys can be constructed in timber, fire resistant for 60 minutes.

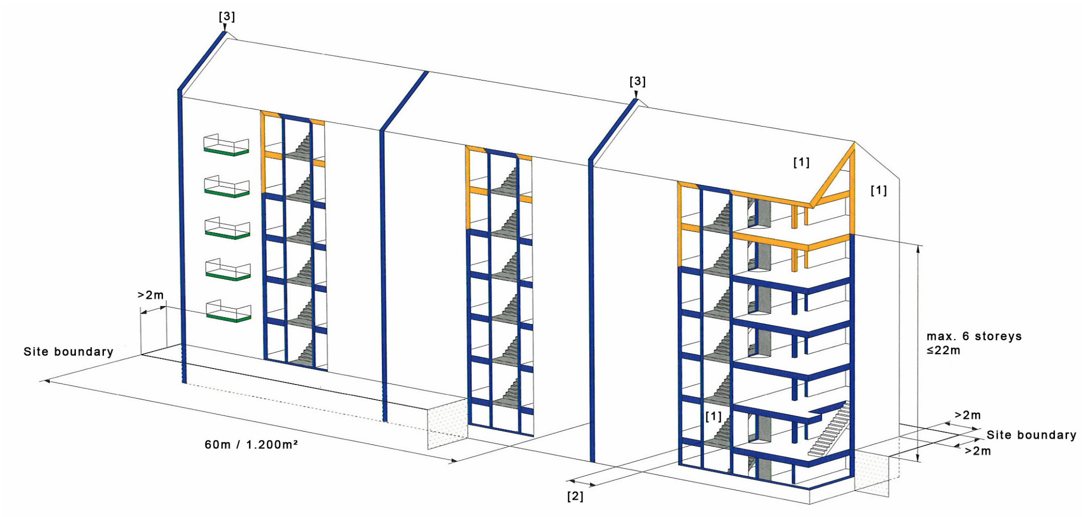


Fig 4.2.e – Definitions for GK5-buildings

[1] – Concerning the requirements for fire behaviour of building materials, ÖNORM B 3806 has to be considered.
[2] – Concerning the passage width of hallways, stairs and doors along escape routes, the requirements of guideline 4 have to be considered.
[3] – Fire compartment forming walls are to be extended 15cm above the roof.

4.3 Fire Safety Instructions in Japan

4.3.1 Introduction

1974	Industrial method globalization - first timber construction
1982	Three storied hut constructions are possible (It is treated by ministerial ordinance as a simple, fireproof structure.)
1987	Three storied residential timber constructions are possible
1992	Three storied condominium timber construction with fire-prevention in quasi-fire zones are possible. (Construction as a simple, fireproof building)
1997	Three storied condominium timber construction in quasi-fire zones are possible.
1997	Four storied timber constructions are possible – (Depending on the performance regulations of the technological standard.)
2004	Residential timber constructions are possible - with fire protection system
2005	Fire-block wall A wooden fire-resistive construction and the industry's first outside wet wall.

Tab 4.3.a.: Brief history of timber constructions in Japan[15]

In the year 2000 the architectural standard law was revised and limited fireproof timber buildings became possible.

Every region used to have it's own specification and limits for timber buildings due to fire-resistive performances.

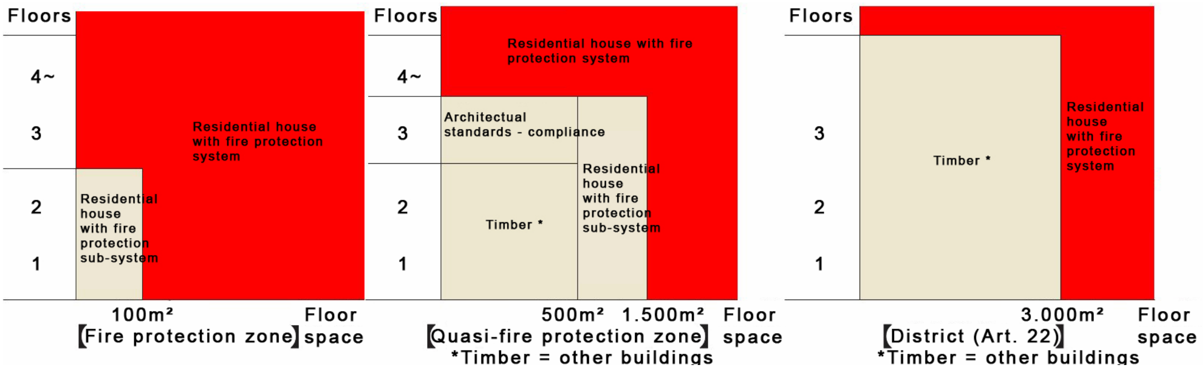


Fig 4.3.a – The red area shows the range of buildings not constructed in timber[16]

In urban areas, three storied buildings could not be constructed using timber. Within fire protection zones, exceeding 100m², in quasi-fire protection zones 1 500m² and zones based on law article 22 exceeding 3 000m², timber constructions could not be built.

Furthermore, kindergarten, day-care centres, theatres, movie theatres and other public buildings weren't able to be constructed with timber.

4.3.2 Structural limitations

4.3.2.1 Categorisation

To prevent a building from collapsing due to a fire, there are different kinds of categorisations regulated in the building codes.

[15] cf. www.mitsuihome.co.jp/technology/mokuzou - translated by author (Accessed Feb 13th, 2011)
[16] on base of Koshihara Laboratory handout for the "*timberize tokyo*" exhibition 2009, translated by author

(A) - Regional partition and structural limitation for fire prevention

A regional partition exists to prevent the danger of a fire in the urban area - "fire protection zones" and "quasi-fire protection zones" are specified.
In the building code, the number of stories and the scale corresponding to these regional partitions are provided, and the structure of the building is limited.

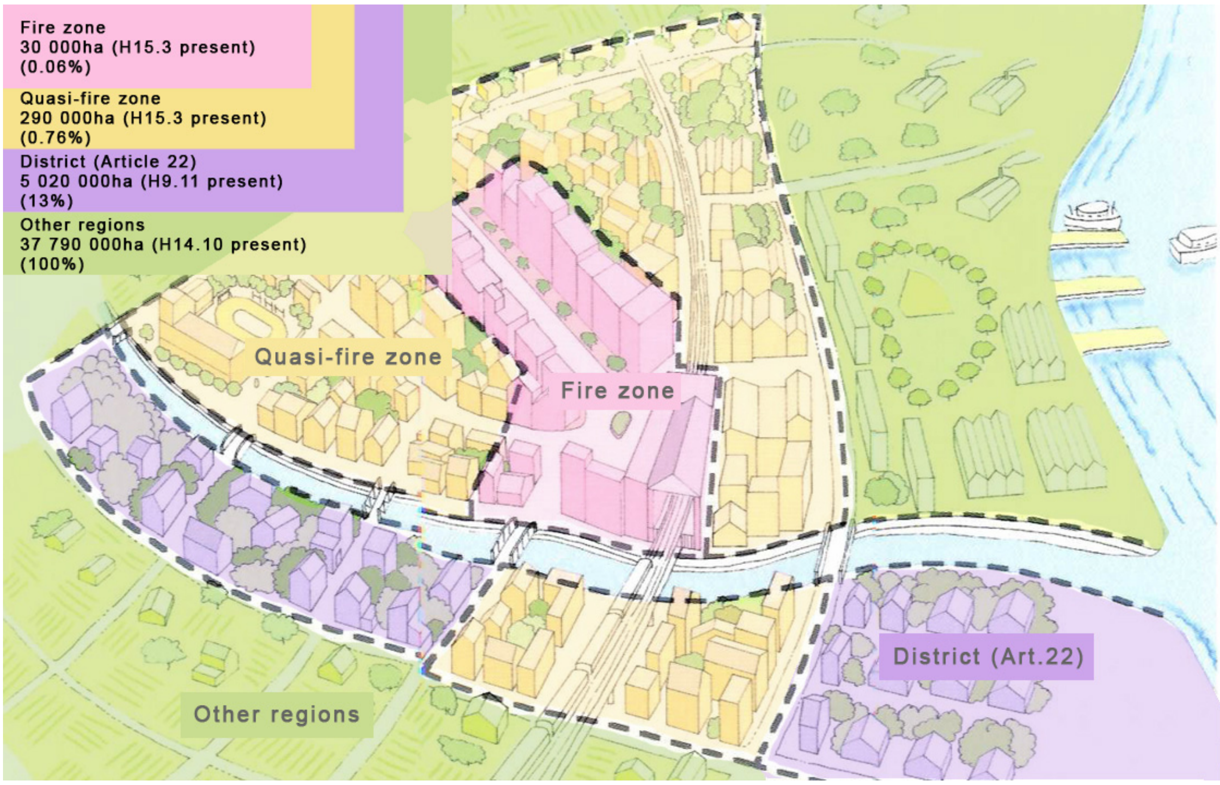


Fig 4.3.b – Regional partition for fire prevention

Fire zone	- Concentrated in urban areas, urban and commercial centre of the city along highways; business districts
Quasi-fire zone	- Commercial and business district and residential areas near the fire zone
District (Article 22)	- Non-fire zone and semi-urban areas

(B) - Structural limitation of large scale buildings

If the building's height is 13m or less and the eaves heights are 9m or less and the total area is 3 000m2 or less, the fire-resisting structure is not limited.
However, if the building exceeds the 13m height and the principal structural part is not to be a fire-resisting construction, a timber construction is possible as long as it fulfils the standards for fire prevention.

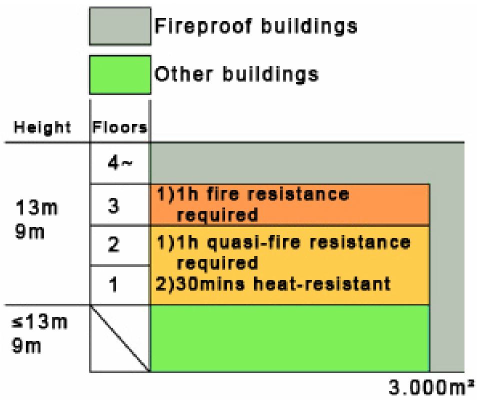


Fig 4.3.c – Height-limitations

(C) - Structural limitation by usage of buildings

When unspecified (a special building, restricted by purpose of building structures), a fire protection system or sub-system has to be provided.

4.3.3 Timber constructions after the revision of the building code in 2000

There are three strategies to use timber as a construction material:

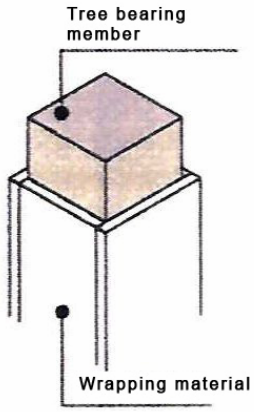
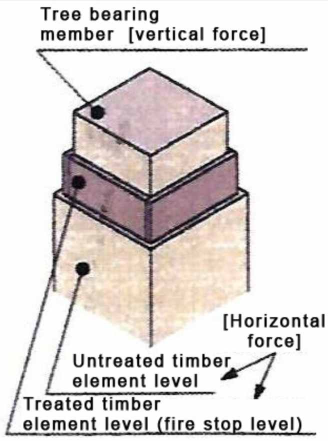
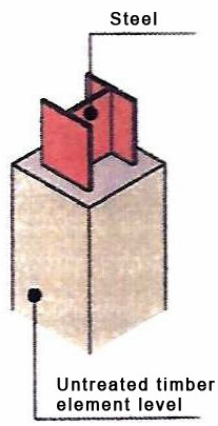
	Type 1 General coating type (Hidden timber)	Type 2 Layers with treated timber (Fire-stopping elements)	Type 3 Steel covered with timber (Hybrid elements)
Outline			
Structure	Timber only	Timber only	Steel + timber structure
Features	Carbide coating to prevent fire and burn the tree	The combustion of the outer-most layer stops when arriving at the treated timber layer.	The combustion of the outer-most layer stops when arriving at the steel element.

Fig 4.3.d – Types of construction[17]

Type 1 - General coating type (Hidden timber)

Hereby the timber construction is covered with a plasterboard coating. Though, this construction covers any wood showing on the surface.

Type 2 – Layers with treated timber elements to be more fire-resistant (Fire-stopping timber elements)

After the impact of heat ends, combustion is stopped at a “burning stopping” layer. As for this layer, wood, etc… treated to be non-flammable is used.

Type 3 - Iron frame internals covered with timber (Hybrid elements)

To secure performance as a fire-resisting construction, an iron frame construction with a wooden coating using laminated lumber is devised. With this strategy, because of the internal iron, the combustion of the cover will stop after the heating ends. It’s a fireproof construction but though the structure is made of iron, a lot of timber is still used.
Because it is now possible to realize high performance in structural as well as fire safety, the mixture of timber and other materials will show new possibilities for future construction techniques.

4.3.4 Limitations for timber constructions (exterior material)

4.3.4.1 Precautionary measures

Not only the fire within a building is the biggest danger, because it could spread to a surrounding building if it is not extinguished in time and might cause a much bigger catastrophe than “just” burning down. In order to prevent such a situation, there is an obligation to take precautionary measures with fire protection systems, not only on the interior of the house, but also with the exterior of the house, including the roof.

[17] on base of Koshihara Laboratory handout for the “*timberize tokyo*” exhibition 2009, translated by author

4.3.4.3 Parts likely to catch fire

On the first floor, within a distance of 3m and on the second floor, within a distance of 5m or less from the borderline or the front road centre line – different segments of the house are at greater risk of catching fire because of a burning building's flying sparks.

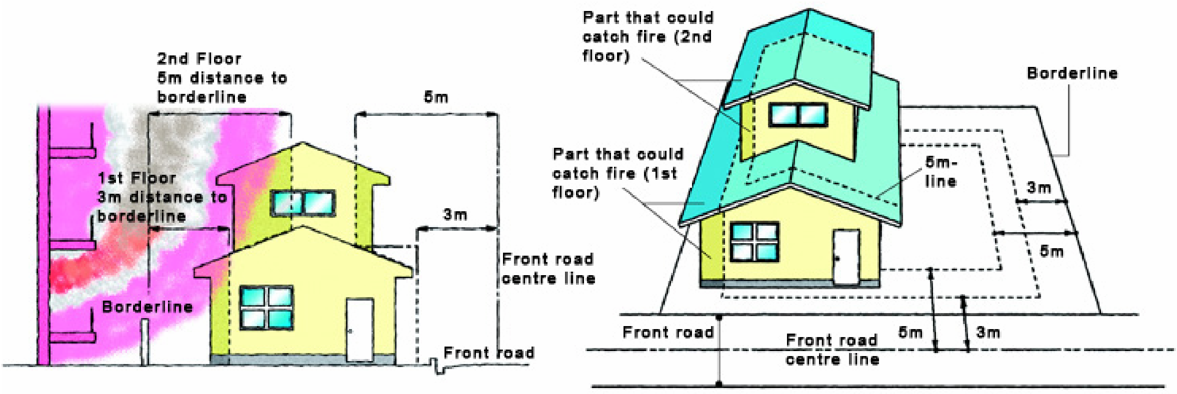


Fig 4.3.e – Parts likely to catch fire

4.3.4.4 Slow burning constructions and semi-slow burning constructions

Not only the fire protection structures and the network of iron coated with mortar achieves the required level of protection in the eaves or walls to suppress fire spreading to the surrounding buildings, but paint and plaster as an outer wall design also provide the structure with protective layers.

The performance needed by the slow burning construction etc… has been clarified since an architectural, standard law revision in June, 2000, and therefore the use of wood has increased.

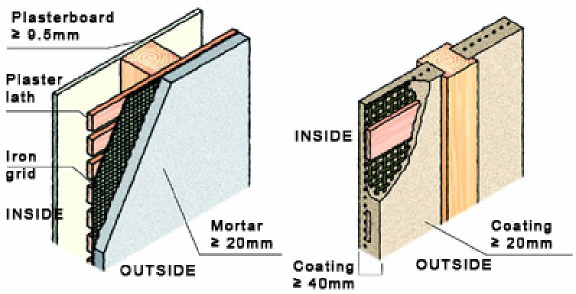


Fig 4.3.f – Structural fire design example

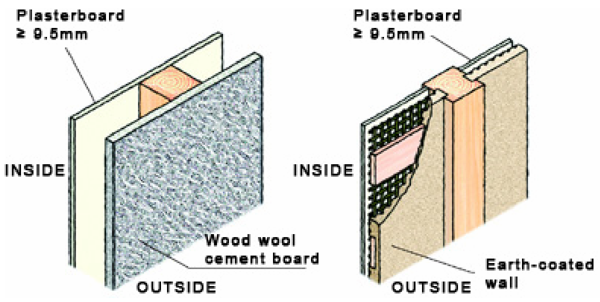


Fig 4.3.g – Semi-fireproof construction specifications

Fig. 3.3.h shows exterior wall detail. The insertion of aluminium foil between two reinforced gypsum boards with the thicknesses of 15mm and 21mm on the indoor-side show a required performance with the heat shield effect.

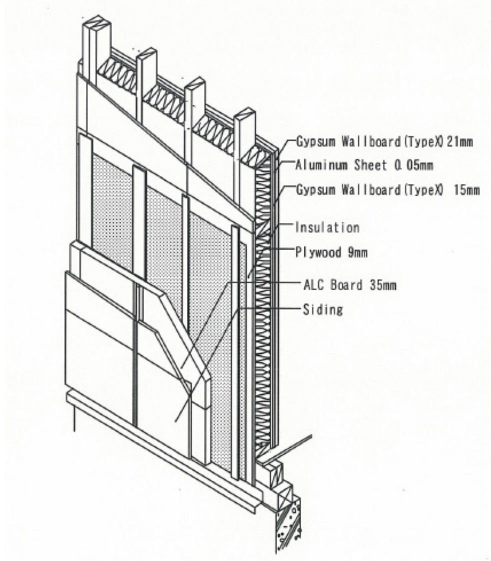


Fig 4.3.h – One-hour fire-resistive structure of exterior wall

5. MIDDLE and HIGH-RISE TIMBER BUILDINGS TODAY

5.1 Projects in Europe

5.1.1 Introduction

Due to it's good calculable properties, timber matured to make high-tech material and has conquered new areas of application. It's no longer primarily a classic handicraft material but is also a modern substance for industrial fabrication.
The new possibilities, innovative, precise and keen constructions and techniques combine high-tech with ecology and sustainability.
The European states are slowly rethinking and revising their building codes in favour of middle-rise timber constructions. Here is a selection of recent works among middle-rise buildings.

5.1.2 Austria

5.1.2.1 "Haus am Mühlweg", Vienna

Architect:	Dietrich + Untertrifaller Architects ZT
Project Initiator:	Bauträger Austria Immobilien (BAI)
Engineering consultant:	KLH Massivholz GmbH
Construction:	Core: reinforced concrete Structure: timber
Type of use:	Residential building
Storeys/ Height:	4 Floors + loft
Time for completion:	Start of research 2004 Start of construction October 2005 Completion June 2007
Costs:	~ 11 Mio €

Fig 5.1.2.a – Haus am Mühlweg, Wien

5.1.2.1.1 Constructional Facts

It is a mixed timber construction were massive KLH-boards were used as a supporting, insulating and moisture absorbing material. This and the core made of reinforced concrete forms the supporting structure of the buildings. In relation to the effective area about 0.45m³ timber per square metre is utilized and therefore a huge amount of CO_2 is absorbed and stored for a long time.

Material and fabrication:
Characteristic values for KLH (Kreuzlagenholz – *cross laminated timber*) wall and slab constructions were calculated using a testing program. Basically KLH massive timber panels fulfil all the requirements on buildings according to Vienna's building regulations.
Under controlled conditions inside an air-conditioned factory hall the wall elements were prefabricated. This offers a high standard of quality when processed. Because of the factory-made installation of the windows, high passive house standard (U-Value 0.80W/m²K) can be achieved. Only the floor structure (after the fitting of installations) was made on site.
Because of quite big elements (no joints in longitudinal direction) a very short time of construction was achieved. One block with 18 accommodations units was erected rainproof within one week. Noise of the construction site and more were reduced to a minimum.

Façade:
The facade was produced in a factory, element by element. The final rendering was added after installation, offering good and cost saving heat insulation.

Energy and Economy:
A high insulated passive house standard with controlled ventilation.
- 3 – pane heat insulated windows with insulated frame
- Every house is equipped with a 60m² solar system (by Energiecomfort with solar power collectors = a total of 240m²)

5.1.2.1.2 Plans, Details

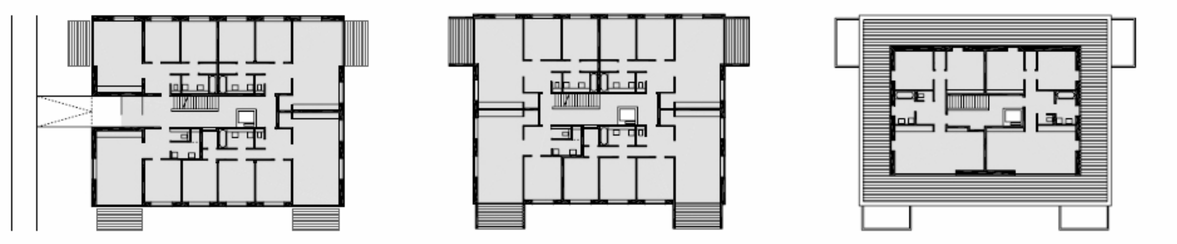


Fig 5.1.2.b – Floor plans

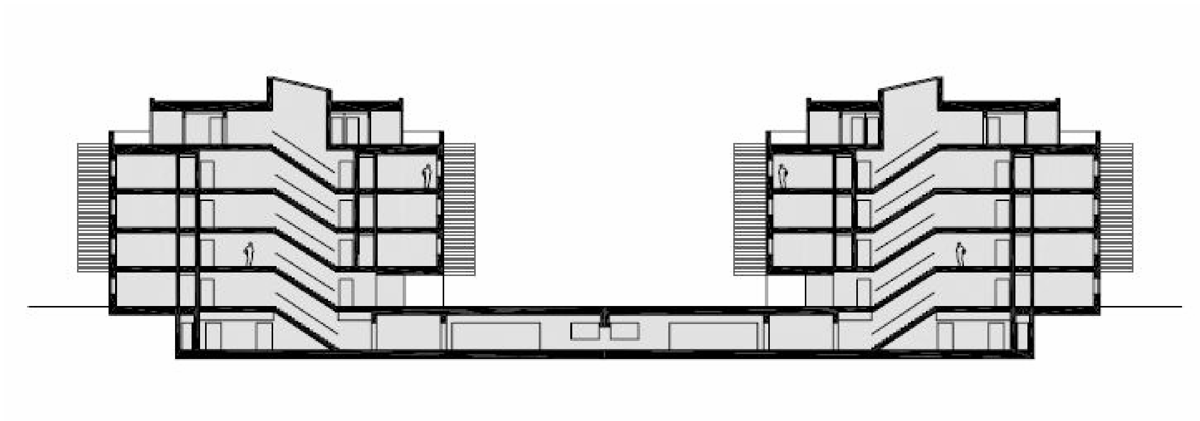


Fig 5.1.2.c – Section

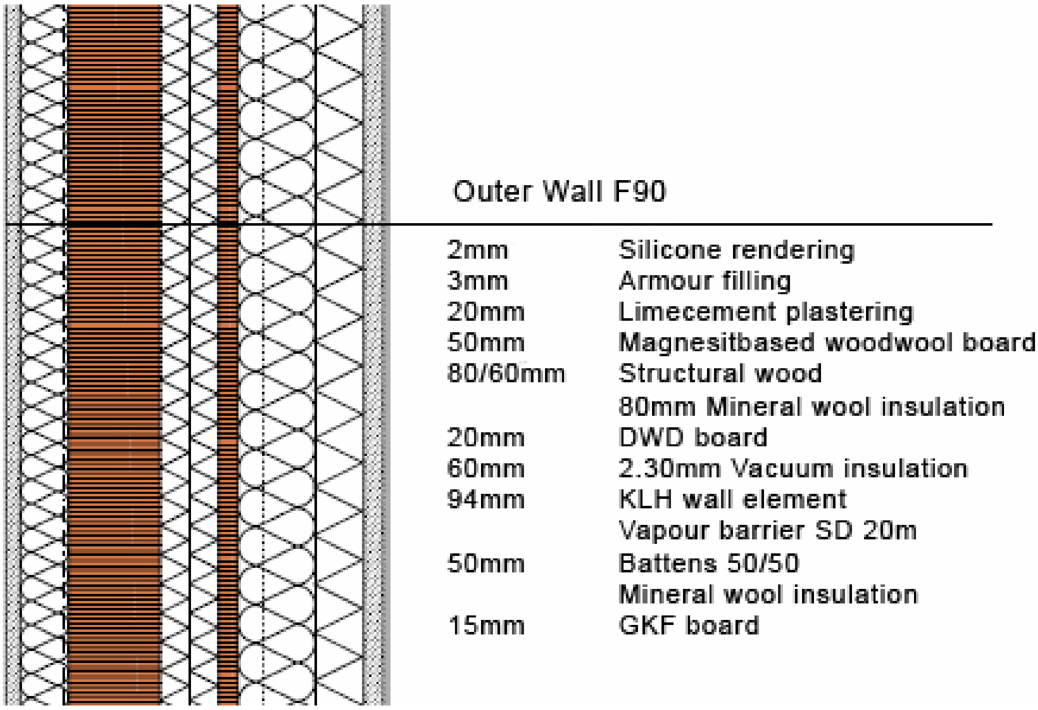


Fig 5.1.2.c – Detail: Façade; Dimensions in [mm]

5.1.3 Germany

5.1.3.1 "E3", Berlin

Fig 5.1.3.a – E3, Berlin

Architect:	Kaden + Klingbeil
Construction:	S*tructure*: timber post and beam *Ceilings*: timber concrete composite slab
Type of use:	Residential building; Ground floor business area
Storeys/ Height:	6 Floors / 23m
Time for completion:	10 months construction period (06/2007 – 03/2008)
Costs:	n/a (private investors)

5.1.3.1.1 Constructional Facts

The static structure with non-supporting internal walls allows individual floor plans, greater possible transparency of the façade and thereby a benefit of passive solar energy.
The main structure is a timber frame construction, with a built framework after 8 weeks. Wind bracing is used to stabilize the building. However, supporting parts are designed in massive gluelam and timber concrete composite slabs. The construction of the timber-concrete composite slab resting on the headers and accordingly the beam is a novelty – overall height could be saved and the heights of the lintels minimized. There is a future in composite structure (timber and concrete) - talking about this project, a high span length of the inserted ceiling was achieved. There are 82 joints throughout the building that connect the massive columns with two horizontal beams by using a steely fitting – 5min to assembly one of those static elements.
The two internal utility shafts are designed in concrete; access is made via a separate open staircase, also designed in reinforced concrete. Individual apartment units are accessible via "bridges" (thereby avoidance of a closed site gap) and according to the fire regulations this also works as a fire escape route.
A detail regarding energy: The primary energy input for the whole shell construction lays around 30% of the energy input for a traditional massive construction plus the thermo technical properties of timber combined with the outer insulation ensure a requirement of energy way below 40kWh/m² (a dense building shell reduces the loss of warmth)

Walls:	cross laminated solid timber walls, casing with gypsum plaster slabs; compound system for heat insulation (rock wool)
Ceilings:	timber concrete composite slab, 16cm timber, 10cm concrete topping, floating screed
Staircase:	reinforced concrete construction (fire resistance 90min), elevator with one-sided panorama-glazing, stair tops and bridges made with reinforced concrete
Facades:	mineral exterior plaster, wooden windows (partly room-high), wooden sun protection
Energy:	controlled ventilation, heating/hot water via teleheating-supply (hot water mainly via solar energy)

5.1.3.1.2 Plans, Details

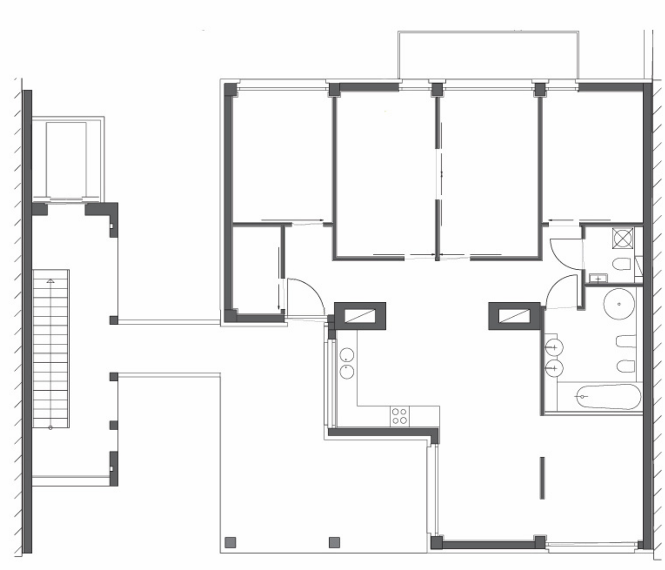


Fig 5.1.3.b – Ground Floor

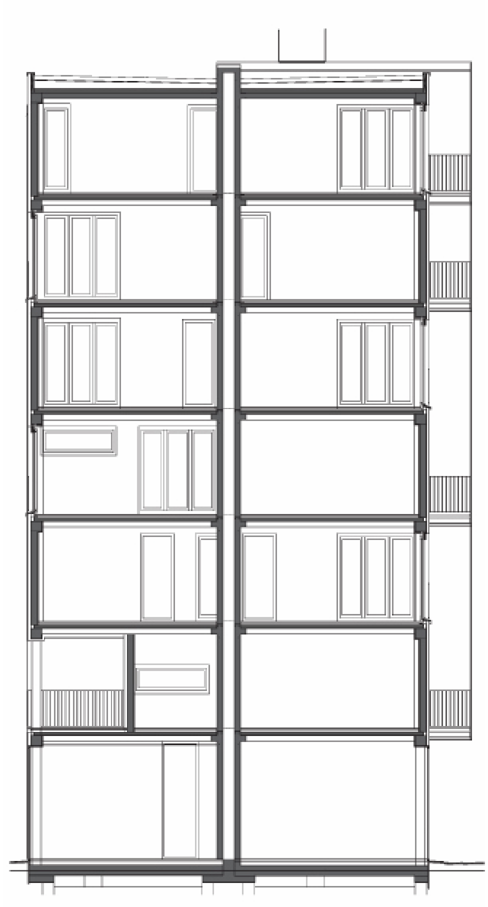


Fig 5.1.3.c – Section

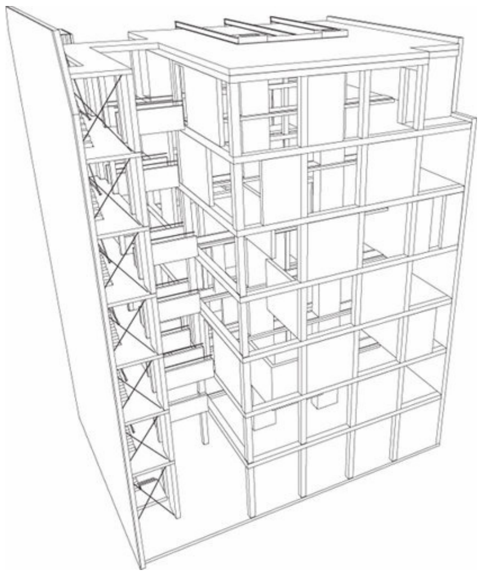


Fig 5.1.3.d – Structural System

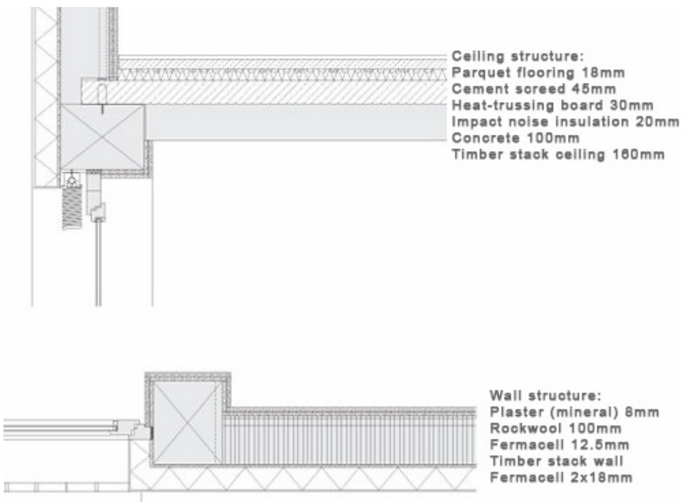


Fig 5.1.3.e – Details; Dimensions in [mm]

5.1.3.2 *"Wohnen an der Barnimkante" (Living on the „Barnimkante"), Berlin*

Architect:	Susanne Scharabi
Project Initiator:	UBB Umbaubüro GmbH & Co. KG
Engineering consultant:	TSB Ingenieurgesellschaft mbH
Construction:	Structure: mixed (steel, concrete) Façade: curtain type timber facade
Type of use:	Residential building Ground floor business area
Storeys/ Height:	7 Floors
Time for completion:	Start March 2008 – completion July 2009
Costs:	~3 Mio €


Fig 5.1.3.f – Barnimkante, Berlin

5.1.3.2.1 Constructional Facts

The static system is a hybrid construction, designed with structural steel and reinforced concrete. The façade is designed with timber frame element panels; larch was used for the façade facing the courtyard.

These larch panels delayed the building licence because Berlin's building law doesn't allow the use of wooden panels for constructions of class 5 (< 22m). This construction was only possible because of the fire protection concept that assured the resistance to fire – horizontal Aluminium-plates prevent a spread of fire from floor to floor.
The floor plans are highly variable due to the column-free construction. Even width and location of the windows was individually adjusted.
In spite of their large width spans, the ceilings could be executed using prefabricated reinforced concrete elements with a rather low thickness of 18cm. The columns and beams were mainly executed using section steel with fire protection cladding.
The energy concept is based on a highly insulated building shell to minimize the necessity of heating. Because of the timber frame construction, a high degree of heat insulation could be achieved despite the lack of thicker walls. Furthermore, all windows are triple glazed and the controllable ventilation system saves heating energy because of the minimized loss of ventilation. Using a heat exchanger, thermal energy is detracted off the discharged air and fed to the supply air for rewarming. The degree of waste heat recovery is about 95%.
To supply the building with heat and warm water, a central gas heating source with 60KW heating energy is adequate.

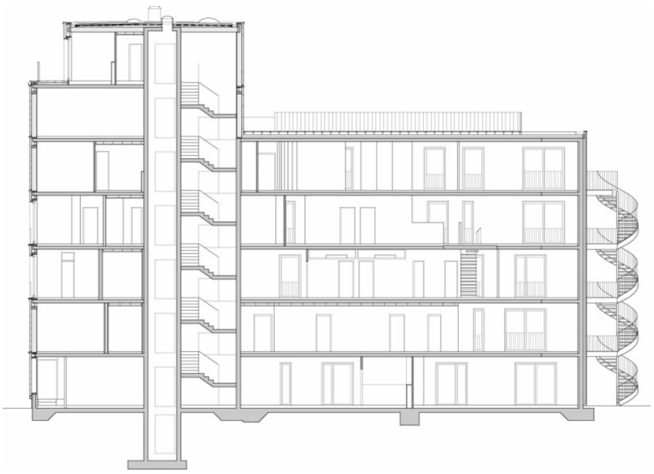


Fig 5.1.3.g – Section

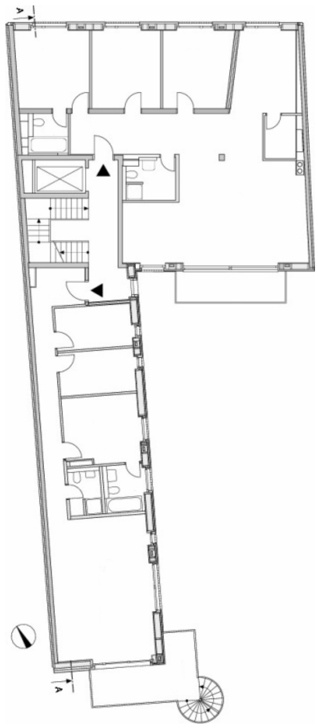


Fig 5.1.3.h – Standard floor plan

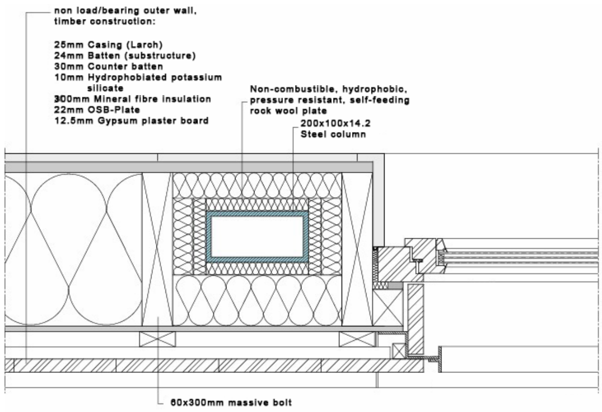


Fig 5.1.3.h – Detail outer wall; Dimensions in [mm]

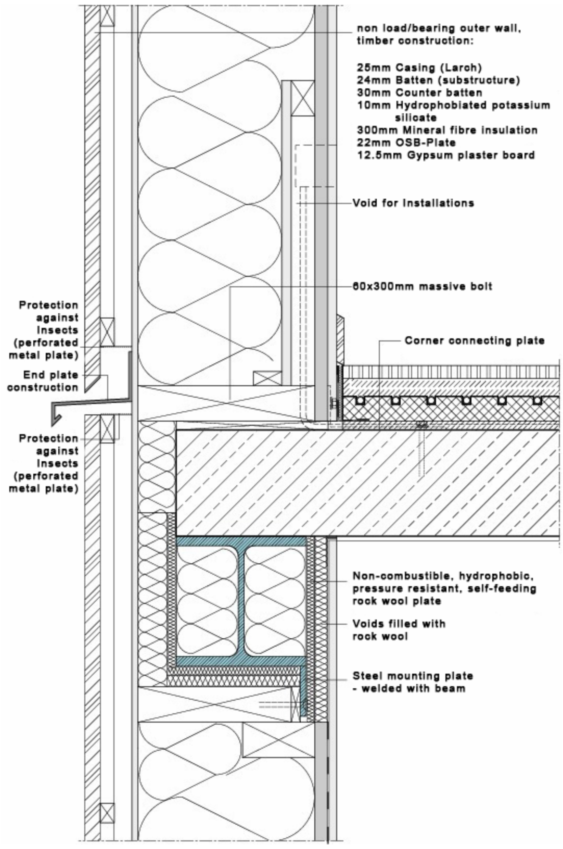


Fig 5.1.3.i – Detail outer wall; Dimensions in [mm]

5.1.4 Switzerland

5.1.4.1 "MFH Holzhausen" (Multi-family house Holzhausen), Steinhausen ZG

Architect:	Scheitlin Syfrig + Partner
General contractor:	Renggli AG, Sursee
Engineering consultant:	Makiol + Wiederkehr, Beinwil am See
Construction:	First floor + core: concrete Rest: timber only
Type of use:	Residential building Ground floor business area
Storeys/ Height:	6 Floors
Time for completion:	Finished summer 2006 (10 months construction period)
Costs:	~ 7 Mio CHF (~ 4.4 Mio € in 2006)

Fig 5.1.4.a – MFH Holzhausen, Switzerland

5.1.4.1.1 Constructional Facts

Constructing the staircase using non combustible material (reinforced concrete) was part of the fire prevention concept, but the 1st floor up to the attic was built using prefabricated timber elements.
Because of an insulation of 240mm and controlled ventilation, 7 700l of heating oil is saved every year.

The building has an asymmetric form, so individual elements are exposed to enormous forces. Therefore, heavily stressed walls are carried out with a massive multilayer plate (200mm) with enclosed steel elements that are partially welded to the concrete floor. With special steel elements the timber construction was fixed to the massive built staircase.
In total, 155m³ of gluelam, 350m³ insulation materials, 20 250m² façade panels and 22.3 tonnes elements of steel were used.
The problem of noise insulation was solved by constructing a flexible, suspended ceiling using gypsum plaster board and loading the floor with a concrete plate (which offers better noise control at a deep frequency level). Because of unconnected ceiling elements, resting on separate shear walls and due to GYS-Pre-wall installation byways of sound transmissions are suppressed while at the same time optimal fire protection is achieved.

Requirements for protection against earthquakes are code regulated. The calculations follow the local requirements regarding the bedrock and are verbalized without referring to a specific material.

5.1.4.1.2 Plans, Details

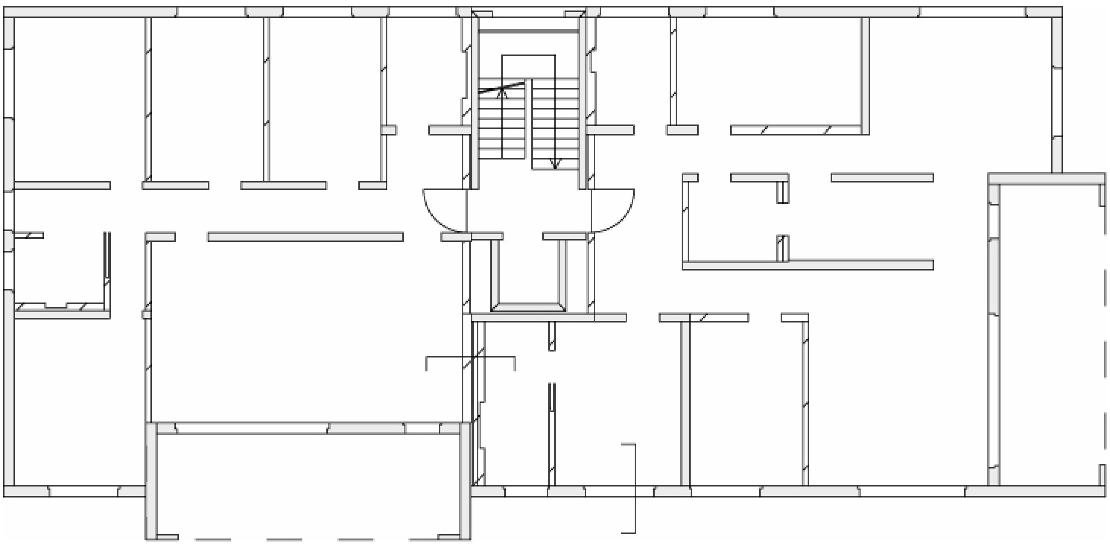


Fig 5.1.4.b – Standard floor plan

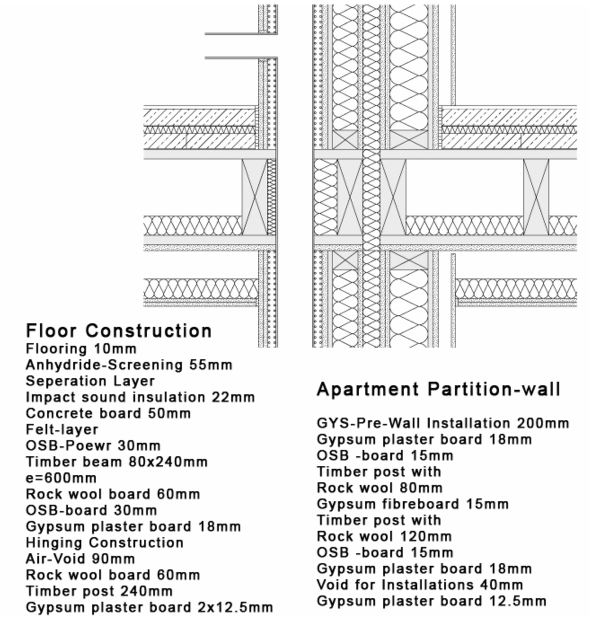


Fig 5.1.4.c – Apartment Partition wall detail; Dimensions in [mm]

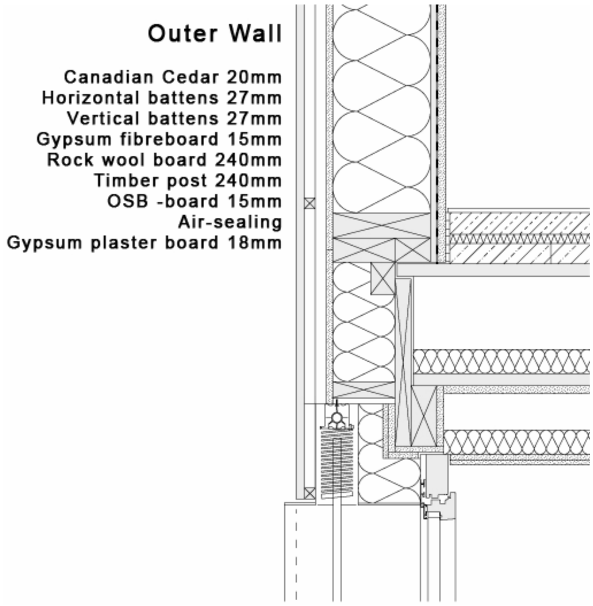


Fig 5.1.4.d – Outer wall detail; Dimensions in [mm]

5.1.5 Great Britain

5.1.5.1 "24 Murray Grove", London

Architect:	Waugh Thistleton
Project Initiator:	Telford Homes
Engineering consultant:	Megan Yates; Michael Popper & Associates; Nick Walker
Construction:	Structure: timber only
Type of use:	Residential building
Storeys/ Height:	9 Floors
Time for completion:	Start March 2008 Completion September 2008
Costs:	~ 3 Mio GBP (= 3.7 Mio € in 2008)

Fig 5.1.5.a – Murray Grove, London

5.1.5.1.1 Constructional Facts

Cross laminated solid timber was used for load bearing walls, floor slabs and even stair and lift cores; only the 1st floor was designed with reinforced concrete.
Each of the panels were prefabricated (even cut-outs for doors and windows), an immense saving of time could be achieved by immediate positioning of the panels once they were on the site – the structure was built in 9 weeks due to "platform construction" (it took 3 days for one level).
Joints are secured with screws and angle plates.

Material:
Structural system pioneered by KLH Massivholz GmbH of Austria. The panels were formed by gluing together timber strips into a solid mass element with minimal movement characteristics; each panel is prefabricated (including cut-outs for windows and doors). Even the staircase and elevator structures are designed in timber. All supporting elements are 90min fire resistant, part of them even 120min.

Façade:
The exterior cladding is made up of over 5 000 individual panels across the building, with a size of 1200 x 230mm, that was manufactured by Eternit and made up of 70% waste timber.

Sustainability[18]:
If the building was a concrete structure:
It would contain approximately 950 m³ of concrete (=285 tonnes of cement would produce 67 500kg of carbon).
If the building was a reinforced concrete structure:
It would require about 120 tonnes of steel (= would have generated about 57 250kg of carbon)
As a timber structure:
901 m³ of timber was used within the building – the fabric will store over 186 000kg of carbon.

[18] cf. http://www.forest.fi/smyforest/foresteng.nsf/0/b3bfa6f9b0e11584c225758500472e15?OpenDocument - estimations were made by Waugh Thistleton Architects

5.1.5.1.2 Plans, Details

Fig 5.1.5.b – Third floor plan

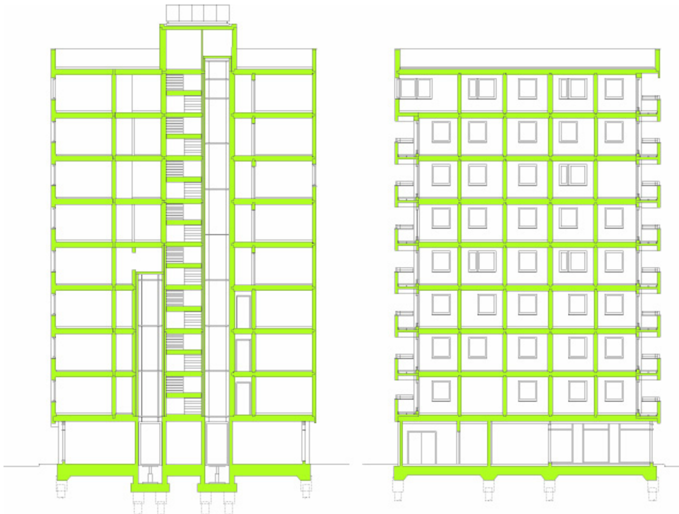


Fig 5.1.5.c – Sections

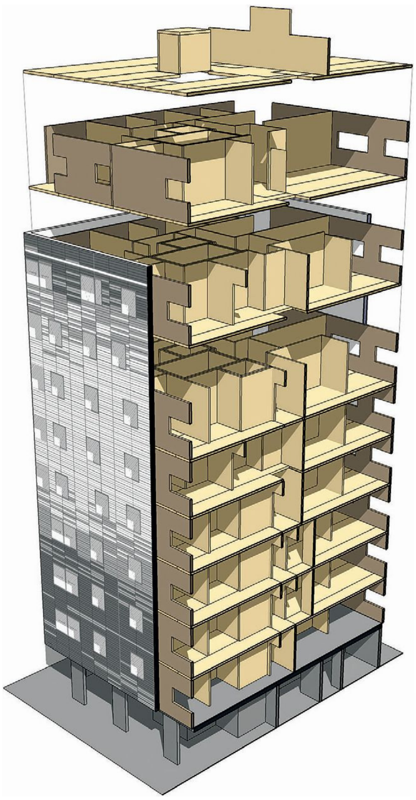


Fig 5.1.5.d – Isometric sectional view

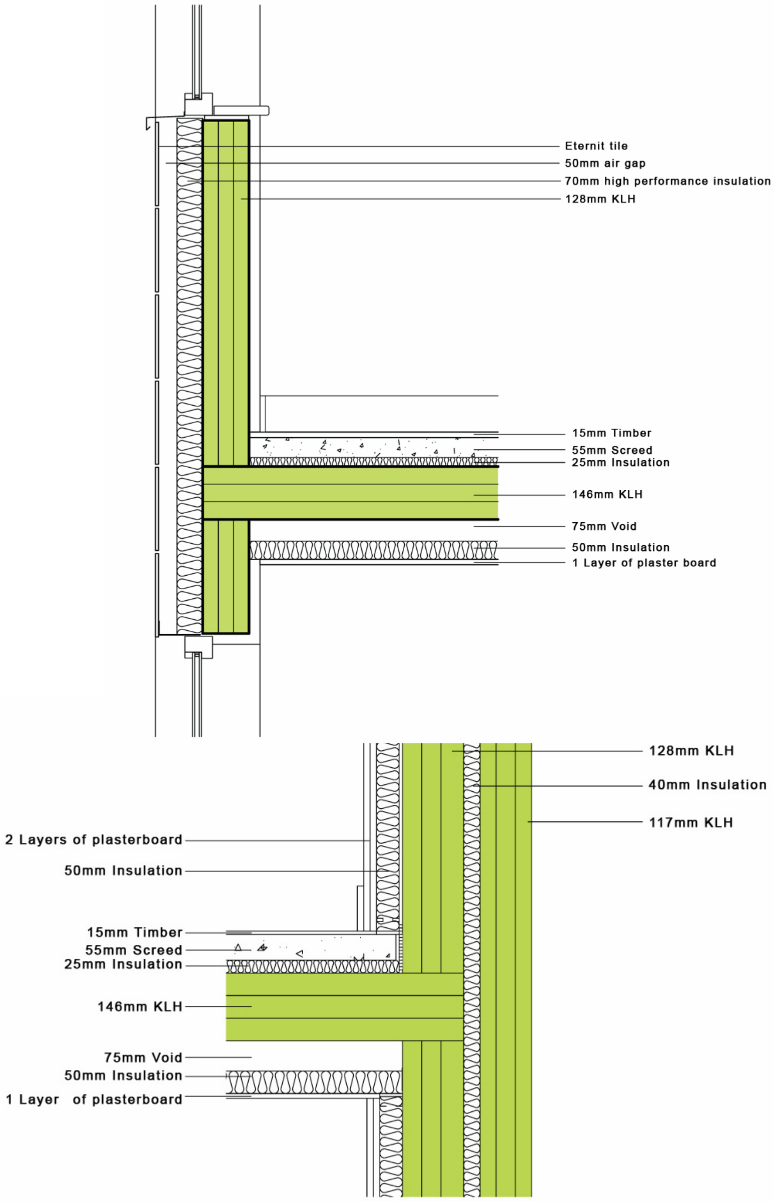


Fig 5.1.5.e + 5.1.5.f – Details

5.1.6 Sweden

5.1.6.1 "Välle Broar - Limnologen", Växjö

Architect:	Div.
Project Initiator:	Hans Andrèn
Engineering consultant:	n.n.
Construction:	timber only
Type of use:	apartment buildings
Storeys/ Height:	7-8 Floors
Time for completion:	Start 2006; Project VB is still under construction (est. ~10 – 15 yrs.)
Costs:	~ 800 000 – 2 000 000 Mio €/year

Fig 5.1.6.a – Limnologen, Växjö, Sweden

5.1.6.1.1 Constructional Facts

"Välle broar" is a project estimated to run for 10-15 years. In Växjö, Sweden, around 15ha area is earmarked for timber buildings: around 1 500 apartments and 50 000m² business area.
One block of the area is called "Limnologen", four eight-storied timber constructions with a total of 134 apartments located just north of the University campus in Växjö.

Floor:
The upper part is made out of three layers of massive timber. The middle part is rotated 90 degrees; an insulation layer is positioned between the beams. Underneath these layers wooden T-beams made out of glue laminated timber are positioned to stiffen the structure of the floor in its longitudinal direction. The floor structures are fabricated with 1.2m width and various lengths.

Apartment separating walls:
Studs with a centre distance of 600mm compose a vertical bearing frame the separating wall is a part of. A board is connected to the studs on top of which battens are fastened with a centre distance of 450mm. The outer parts are two gypsum boards. Between the beams, both studs and battens, there is wood fibre insulation. The wall is composed of two of those layers separated by a 20mm air gap. This air gap prevents mechanical vibrations from transferring directly between the walls.

Ceiling:
Made of massive wood studs and battens which are orthogonal to each other. Two 13mm gypsum boards are fastened on the battens. The studs and battens make the structure stiffer in both directions. Between the studs, some wood fibre insulation is placed.

5.1.6.1.2 Plans, Details

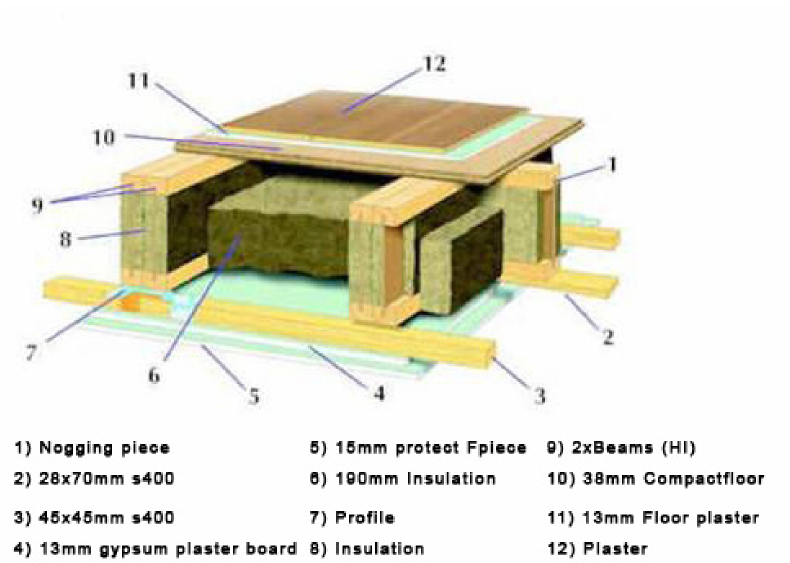


Fig 5.1.6.b – Detail: Floor

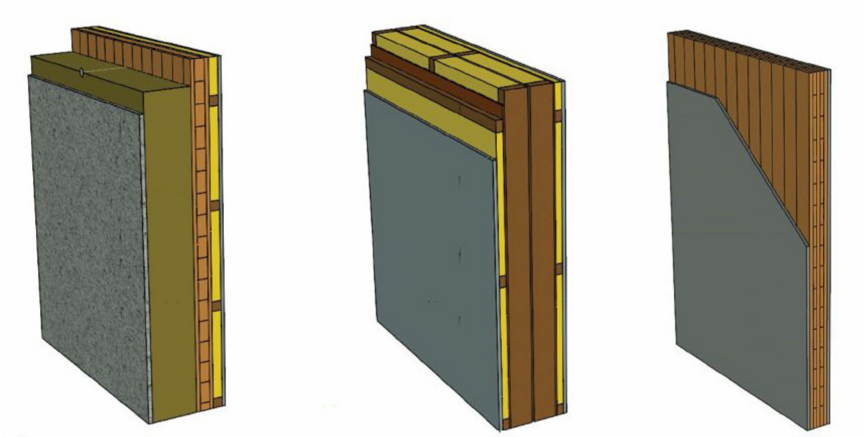


Fig 5.1.6.c – Wall details (from left to right): outer wall with plastered façade; separation wall (cavity wall), inner wall

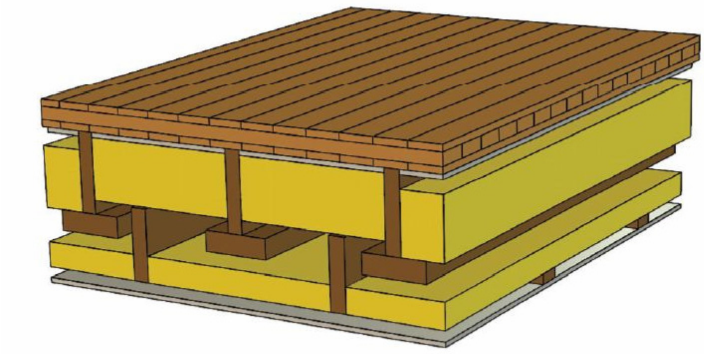


Fig 5.1.6.d – Ceiling construction

5.1.7 Finland

5.1.7.1 "FMO Tapiola", Tapiola, Espoo

Architect:	Helin & Co Architects, Pekka Helin
Project developer:	FINNFOREST
Structural designer:	WSP SuunnitteluKortes Oy, Jukka Ala-Ojala
Construction:	Timber and steel bracing
Type of use:	Office building
Storeys/ Height:	5 Floors /
Time for completion:	June 2004 – September 5th 2005 (15 months)
Costs:	~ 26 Mio €

Fig 5.1.7.a – FMO Tapiola, Tapiola, Espoo

5.1.7.1.1 Constructional Facts

Frame:
The structure is based on a modular system with a total of more than 500 supporting structures, Kerto columns and beams. Apart from the exits and lift wells the entire frame consists of Kerto LVL (= laminated veneer lumber). The wooden frame and the facades are designed in prefabricated wooden parts. Bracing is made using eight bracing steel wire nets, concrete staircases and concrete lift wells.

Façade:
There are three types of wood used for the façade: The cladding consists of split gluelam plank, the sun-deflecting façade slats are made of Finnforest ThermoWood and the façade panels are made of Finnforest ColorWood.

5.1.7.1.2 Plans, Details

Fig 5.1.7.b – Floor plan

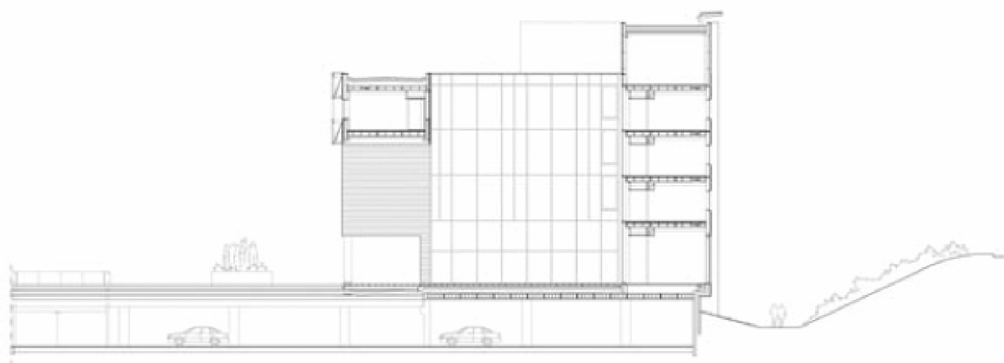


Fig 5.1.7.c – Elevation

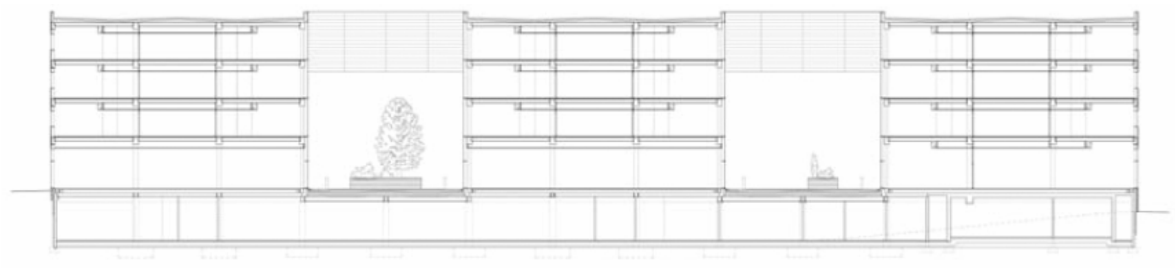


Fig 5.1.7.d – Elevation

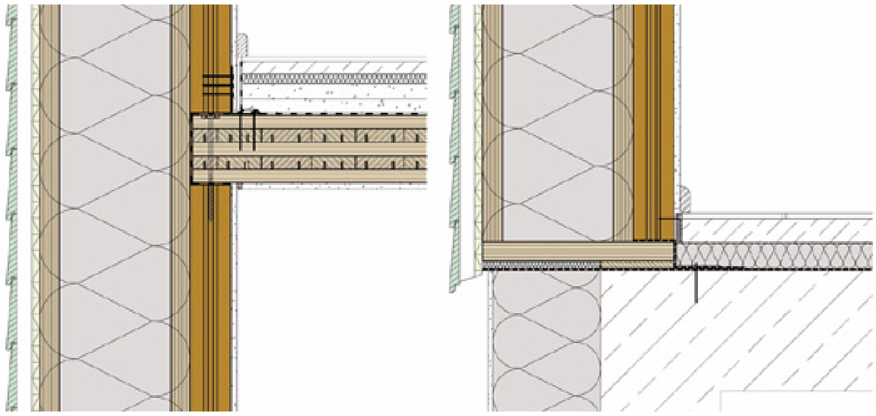


Fig 5.1.7.e – Outer wall/floor detail

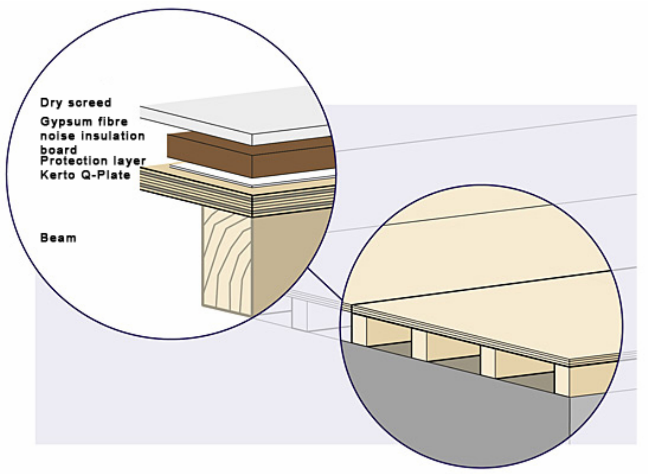


Fig 5.1.7.f – Ceiling detail

5.2 Projects in Japan

5.2.1 The recent years

After the revision of Japan's architectural standard law, *Japan 2x4 Home Builders Association* started the development of fire-resistant timber constructions (2x4 constructions).

The cumulative number of timber buildings constructed in Japan reached 658 as of November 30th, 2007. This can be reconstructed due to the request that a copy of approval certificate upon every application of building construction had to be submitted to the *Japan 2x4 Home Builders Association*.

Tokyo…………………………………………………………..	……..…505
Kanagawa…………………………………………………..	………..…78
Aichi…………………………………………………………	…..………12
Chiba………………………………………………………..	………..…10
Saitama……………………………………………………..	………...…7
Osaka, Hyogo………………………………………………	………...…6
Hokkaido, Okayama……………………………………….	………...…5
Ishikawa…………………………………………………….	………...…3
Ibaragi, Gunma, Yamanashi, Niigata, Shiga, Nara, Wakayama, Hiroshima, Shimane, Oita, Nagasaki………..	………...…1

Tokyo as the leading prefecture listed 505 buildings, followed by Kanagawa (78), Aichi (12) and Chiba (10).

Tab 5.2.a.: Issued numbers of approval certificates by prefecture[19]

Nationwide, the fire protection zone covers 82.2% of total, but still 541 buildings have been erected in this zone. The residential use occupies 96.0%, but public facilities (i.e. commercial buildings …) have gradually increased, according to the register.

ZONE CATEGORY	Fire protection zone – 505 Quasi-fire protection zone – 90 Others – 27
BUILDING USE	Residential house – 413 Apartment house – 172 Combined house (for residential and other uses) – 47 Social welfare facility – 8 Commercial facility – 2 Hotel – 1 Others – 15
NUMBER OF STORIES	Single-storied house – 5 Two-storied – 113 Three-storied – 515 Four-storied – 24 Five-storied – 1
FLOORAGE	100m² or less – 152 100-200m² – 363 200-300m² – 84 300-500m² – 34 500-1 500m² – 17 1 500 or larger – 8

Tab 5.2.b.: Listing according to zone, the use of the buildings, number of stories and the floor area[18]

The key to using timber as a construction material is not whether the material is flammable, but about designing it to be safe during a fire.

Following are introductions of the two largest timber construction companies in Japan, *2x2 Home Builders Association* and *Shelter Co., Ltd. (KES System)*.

[19] Based on the 2009 research "*Fire-resistive Buildings of Wood Frame Construction in Japan*" by Junichi Izumi, Chief Manager, Technology Development Group, Technology Administration Headquarters Mitsui Home, Co., Ltd. Tokyo – Japan

5.2.2 2x4 Home Builders Association

5.2.2.1 The Association

Established in 1976, "*2x4 Home Builders Association*" is the incorporated organization of wood frame building contractors, building materials suppliers and architect's offices.

5.2.2.2 A "Monocoque" system

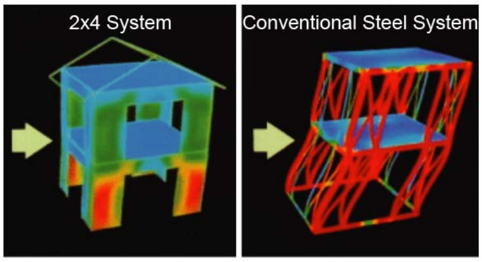


Fig 5.2.2.a – Structural systems

In the 2x4 System, the plywood for structural use absorbs the force of shaking while a conventional steel system concentrates on areas such as pillars and joints.

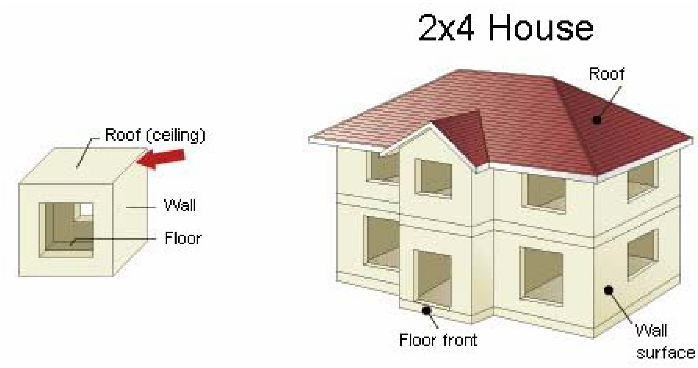


Fig 5.2.2.b – 2x4 House: A Monocoque system

The 2x4 System is a "*Monocoque*" structure (a single-piece construction) – floors, walls and the roof build a 6-face unit that can catch the shaking of earthquakes and disperse its power. Because the seismic force doesn't concentrate on one part only there is no collapse damage and the system delivers outstanding strength against earthquakes.

The structure was originally developed for aircrafts where a strong resistivity is requested. It is an extremely strong structure also adopted for space shuttles, the Shinkansen and even Formula One racing cars.

The system combining the framework and the plywood with nails has a damping characteristic (left).
With a base isolation device, it's even more secure as it prevents the seismic forces to harm the building (right).

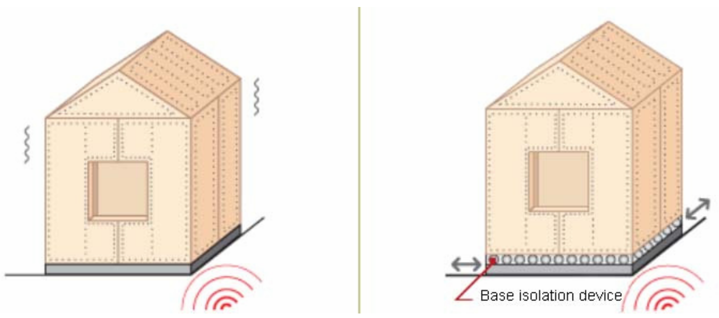


Fig 5.2.2.c – Earthquake: stable construction and plus isolation

5.2.2.2 Firestop method

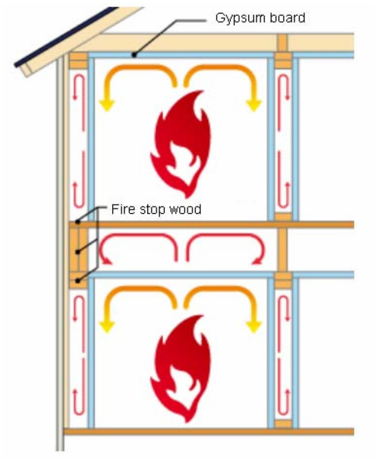


Fig 5.2.2.d – Firestop system

For the use of wood (which can become the pathway for spreading fire), the 2x4 system cuts off the flow of air and prevents the fire from spreading to upper floors. Furthermore, floor joists and the frame work material are joined at fixed intervals creating several fire areas; therefore, the progression of fire spreading is further delayed.

Insulation can be embedded into the walls and floors, delaying the catch of fire of the wood and gypsum board. This structure's fire resistance is even higher.

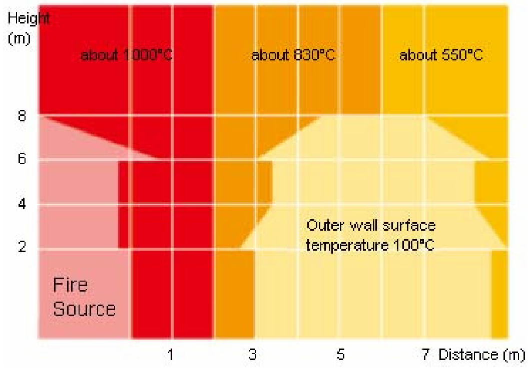


Fig 5.2.2.e – A house on fire and it's neighbours

The 2x4 house prevents catching fire despite the surface temperature of the outside wall (according to research it is not until 800°C or more outside temperature before a neighbouring house catches fire).

5.2.2.3 Moisture

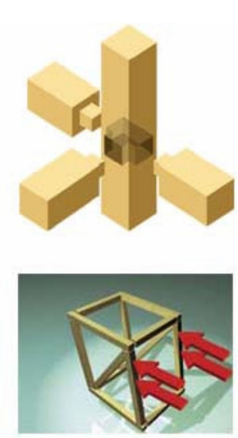
Condensation water caused by sudden changes in temperature tends to occur in the interior walls and roofs in particular, and causes wood to rot and breed of mould.
Because the boards of the wood frame house walls are filled with insulation, indoor and outdoor temperature differences are gradually relaxed and the structure becomes less likely to cause condensation.

However, wind and rain affect the timber buildings as well as severe summer and winter temperatures and nature itself. It is important to maintain the building, just like a human body.

5.2.3 KES System (Shelter Co., Ltd.)

5.2.3.1 KES System vs. traditional methods

By using a unique design of metal plates to reinforce timber joints the KES System achieves a great strength when using timber as a construction material and simplifies the designing of projects.



Traditional Japanese timber joints, such as “tsugite” and “shiguchi” (left) are made without using bolts or plates; but because this method involves cutting away parts of the structural section, the strength of the wood is reduced. A shortcoming of these traditional structures is that the post and beam frame are structurally disadvantaged due to the joints having to resist most forces.

By using metal plates (KES System; right), integrated into the beams and columns, there is no need to cut away large parts of the structural sections that leads to more rigid frames. Therefore walls and floors resist forces as load bearing mass.

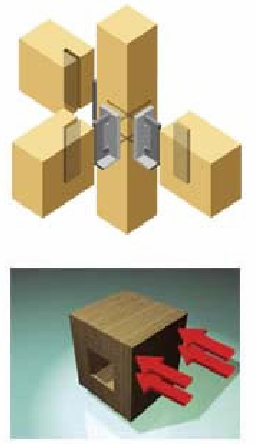


Fig 5.2.3.a – Traditional structure

Fig 5.2.3.b – KES System

Unlike the conventional method of constructing Japanese houses, where the columns are tied to a sill that is laid onto concrete footings, the KES structural system ties the timber columns directly to concrete footings, similar to the construction method of historic temples and shrines.

The following chart compares the KES Jointing system with a conventional timber-framed structure.

	KES 140	KES 120	jointing pipe system for timber frame	Conventional timber jointing metal plate
Metal joint for foot of columns on the ground floor	B Connector 4.1 times stronger than a conventional hold-down hook P=10.402t	SB Connector 2.5 times stronger than a conventional hold-down hook P=6.127t	P=1.329t	Hold-down hook P=2.500t
Metal joint for foot of columns on the first floor	M Connector 1.4 times stronger than a conventional fixing plate. P=10.534t	SW Connector 6.5 times stronger than a conventional fixing plate. P=4.896t	P=1.329t	Fixing plate P=0.750t
Metal joint for receiving beams	JM Connector 3.9 times stronger than a conventional beam bolt P=10.198t	SJ Connector 3.1 times stronger than a conventional beam bolt P=8.230t	P=7.420t	Beam bolt P=2.592t

Fig 5.2.3.c – Comparison of KES Joints and conventional joints

5.2.3.2 Laboratory test

The picture shows testing KES Systems shear walls (left) compared with a conventional Japanese timber construction (cross-based; right).
The criteria were based on JISA1414.

Two KES Systems were used for the test:

- KES System 140
- KES System 120

Fig 5.2.3.d – Laboratory test

- *KES System 140* (140mm square laminated timber column, 140x240mm laminated timber beam, JM connectors at top of the columns, SB Connectors at bottom of the columns, 11.1mm OSB board for the shear wall.
- *KES System 120* (120mm square laminated timber column, 120x240mm laminated timber beam, SJ connectors at top of the columns, SB Connectors at bottom of the columns, 9.5mm OSB board for the shear wall.
- *Conventional Japanese timber structure (standard specification)* (120mm square column, 120x240mm beam, cross bracing with BP-2 plates.

When bearing a load of up to 1.06 ton force, the conventional structure's sill of the wall became broken. In contrast the KES System 120 was able to bear a load of up to 2.2 tons force and the System 140 even up to 3.5 tons force. Both systems' shear walls retained their structural integrity.

<u>*5.2.3.3 Future of KES Systems*</u>

The future of KES Systems aims to use timber not only for small scale constructions like residence buildings but also for large scale public buildings.

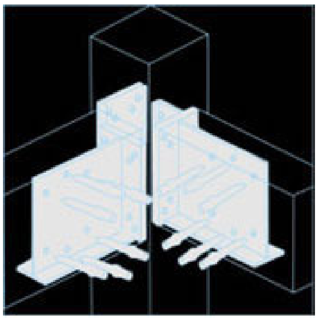


Fig 5.2.3.e – KES One

KES ONE

For the construction of rigid frame structures, enabling large spans for a variety of building types.

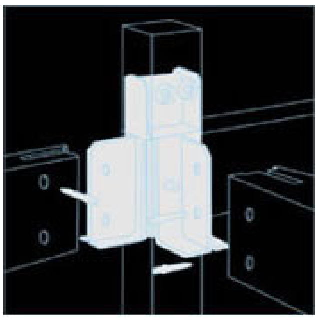


Fig 5.2.3.f – KES 140

KES 140

An earthquake resistant structure using 140mm square columns and original metal plates.

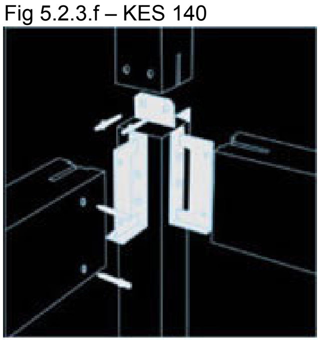


Fig 5.2.3.g – KES 120

KES 120

An earthquake resistant structure using 120mm square columns and original metal plates.

5.2.4 M-Building (エムビル)

5.2.4.1 Introduction

The "*M-Building*", located in Kanazawa, is Japan's first hybrid timber middle rise building. The used construction type is hybrid, a combination of a steel frame covered with timber.

5.2.4.2 Data

Location:	Kanazawa, Ishikawa Prefecture (石川県金沢市広岡一丁目 1112 番)
Architectural design:	-architect office- Stray^{t} Sheep
Structural design:	Kirino Structural Engineering Office Associates; Nick Walker
Constructor:	Tamura Associates
Construction type:	First floor: RC 2nd ~ 5th floors: hybrid (timber/steel)
Type of use:	School
Storeys / Height:	5 Floors / 14.24m
Area:	116.07m² site area/ 74.96m² building area
Time for completion:	March – August 2005
Costs:	730 000 €

Fig 5.2.4.a – M-Building, Kanazawa

5.2.4.3 Constructional Facts

The 1st floor is approved for being two hours fire resistant (as it is RC structure: first floor slab and its walls, and the second floor slab; slab span is 6.2m.); the 2nd~5th floor is approved for being one hour fire resistant.

Column – 1 hour fire resistance = 1 hour no damage
Beam – 1 hour fire resistance = 1 hour no damage
Floor – 1 hour fire resistance = 1 hour no damage, 1 hour heat shielding
Roof – 30 min fire resistance = 30 min no damage, 30min flame barrier
Non-bearing wall – 1 hour fire resistance = 1 hour heat shielding, 1 hour fire barrier
Stairs (inside) – 30 min fire resistance, 30 min no damage

The wooden hybrid structure adopted for 「エムビル」is constructed with a space of 2.5mm between the iron frame and the laminated lumber that acts as a thermal barrier.

When conducting a heating test, it is necessary for the steel frame's maximum temperature to be below 350°C. Due to the hybrid structure the fire-resistive performance was achieved by using the „stopping-layer". In the heating test, the maximum temperature of the iron frame beam was suppressed to 120°C.

An added advantage for the site of the building is, fire fighters can arrive within 5 minutes after the outbreak has been alerted.

Floor, roof and stairs:
- The floors are constructed with 120 mm reinforced concrete slabs (joined with screws and steel plates).
- The stairs are made of steel frames.

Walls:
- Because of the use of braces the *lateral* walls are non-load-bearing.
- The load-bearing *longitudinal* walls are made of nailed plywood, 24mm thick, and at intervals of 150-250mm screwed on each side of a frame. It bears horizontal force during a longitudinal earthquake. The horizontal shear force is transmitted from the plywood to the horizontal frame as well as to the downstairs bearing wall by using anchor bolts embedded in the concrete slab.

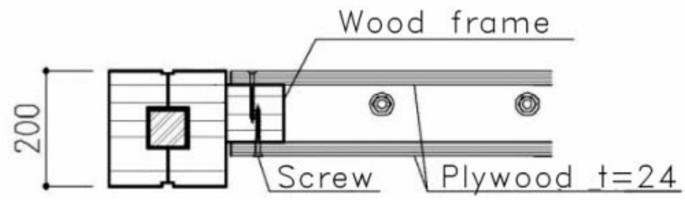


Fig 5.2.4.b – Joint of load-bearing plywood wall and column
Dimensions in [mm]

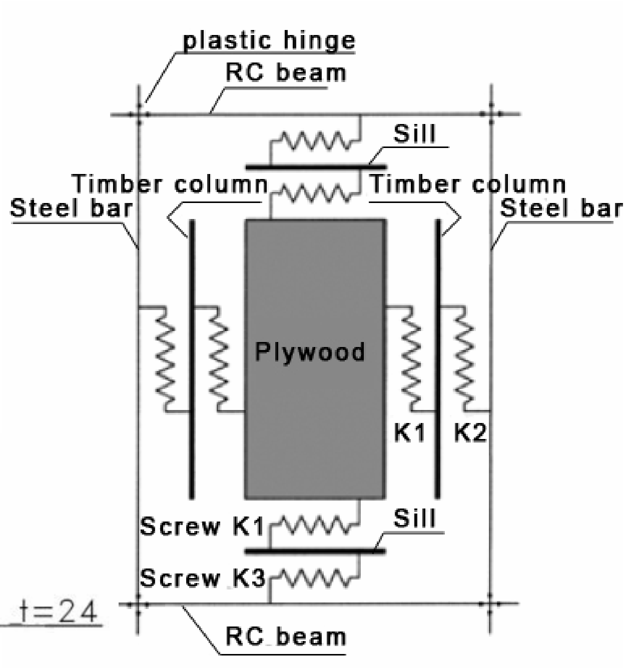


Fig 5.2.4.c – Model of load-bearing plywood wall

Columns, beams, braces:
Has a one hour fire resistance due to fire resistance test confirmed; they reveal a wooden structure, constructed using steel covered with laminated timber (larch or Douglas fir):

- **Column:** 200x200mm using larch E105-F300 with steel bars – 65x65mm using SS400.

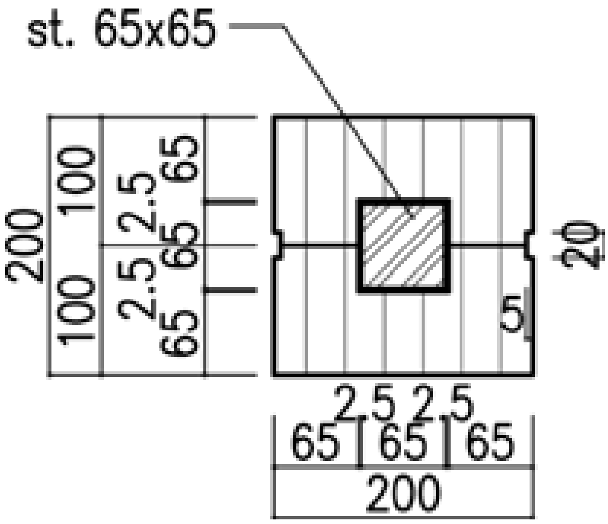


Fig 5.2.4.d – Cross section column; Dimensions in [mm]

The columns transmit vertical load to the steel frames through a gusset plate. The timber layer is not loaded due to the 2.5mm layer of void; it supports axial force and resists buckling during a longitudinal earthquake. During a lateral earthquake the column produces a reaction force of braces.

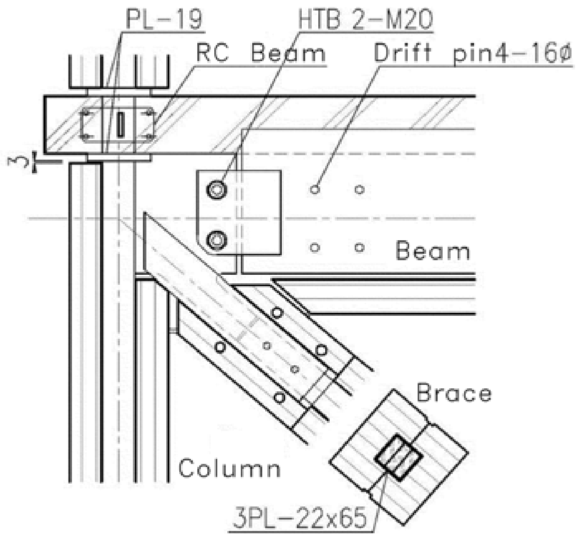


Fig 5.2.4.e – Column, brace and beam – joint detail lateral; Dimensions in [mm]

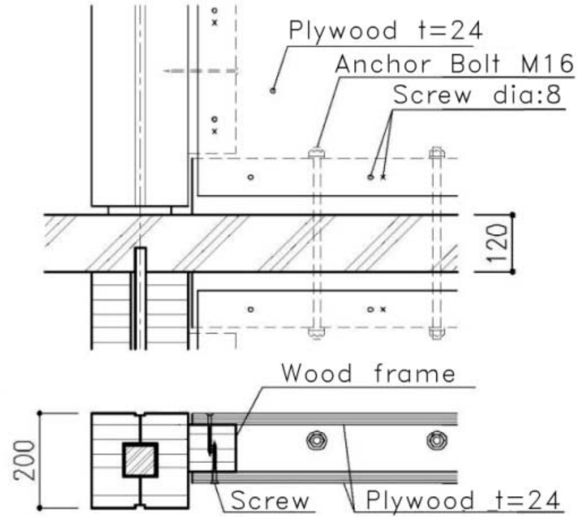


Fig 5.2.4.f – Column – joint detail longitudinal Dimensions in [mm]

- **Beam**: 200x330mm with steel plates – PL 22x300mm using SS400.

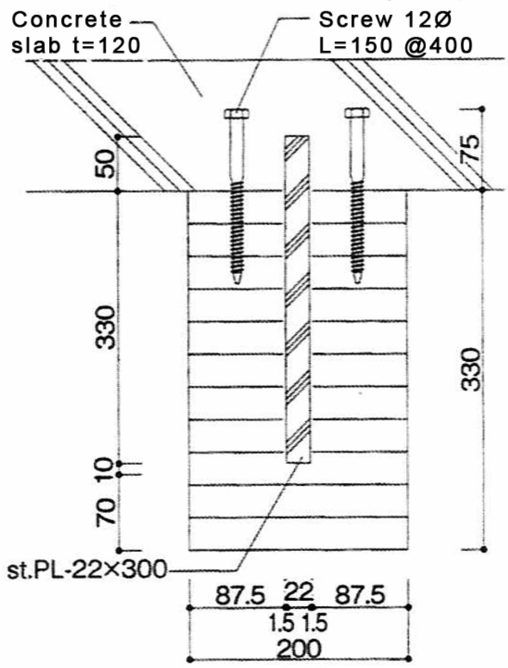


Fig 5.2.4.g – Cross section beam; Dimensions in [mm]

To transmit the load from the timber to the steel frame they are joined at the beam edge using drift pins. A lateral timber based hybrid beam bears axial force and produces a reaction force of braces during an earthquake. The gusset plate from the steel frame of the column and the steel frame of the beam are joined with high tension bolts for the beam column connection.

- **Braces:** 200x200mm using larch E105-F300 with steel bars – 2xPL-22~25x65mm with PL-22~16x65 in between, using SS400 (it has the same cross section as a column as this is a necessity for being fire-resistant).

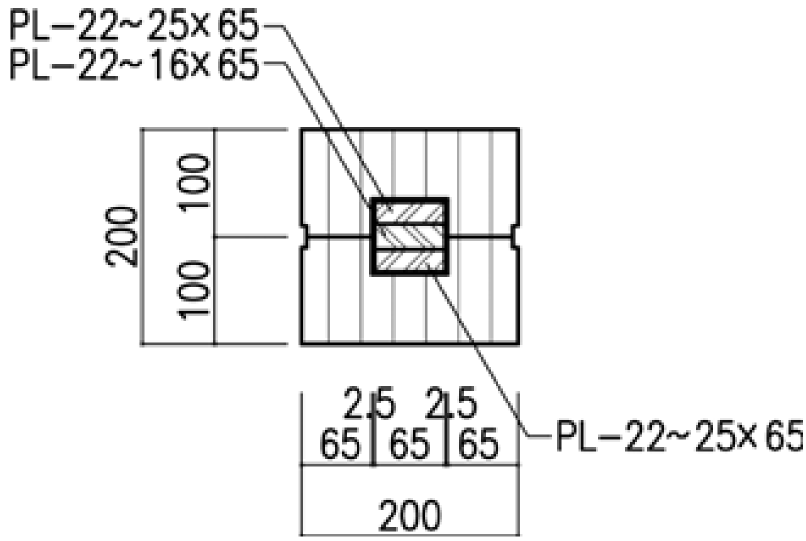
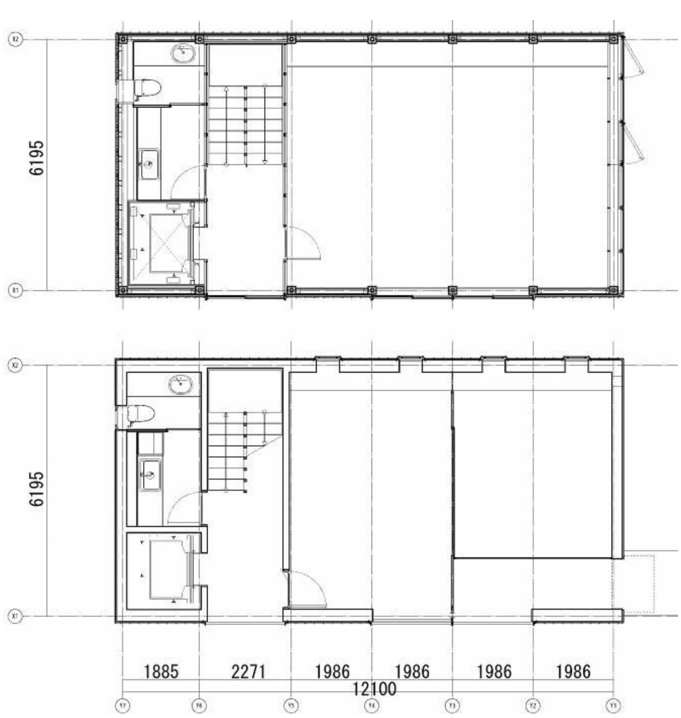


Fig 5.2.4.h – Cross section of a brace; Dimensions in [mm]

The brace bears axial force during a lateral earthquake.

5.2.4.4 Plans, Details



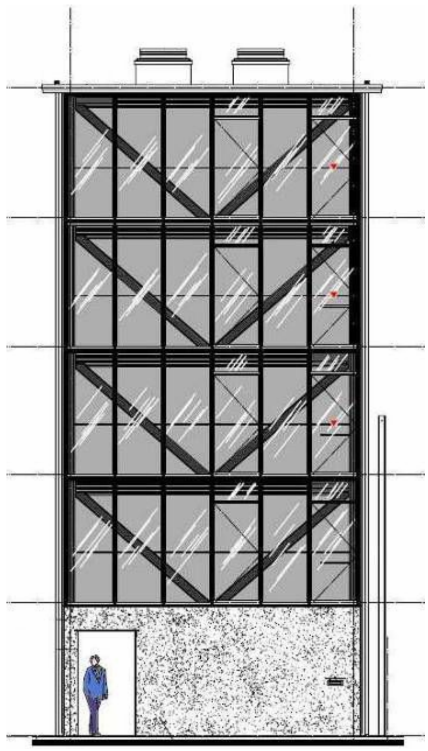


Fig 5.2.4.i – Floor plan; Dimensions in [mm]

Fig. 5.2.4.j – Elevation

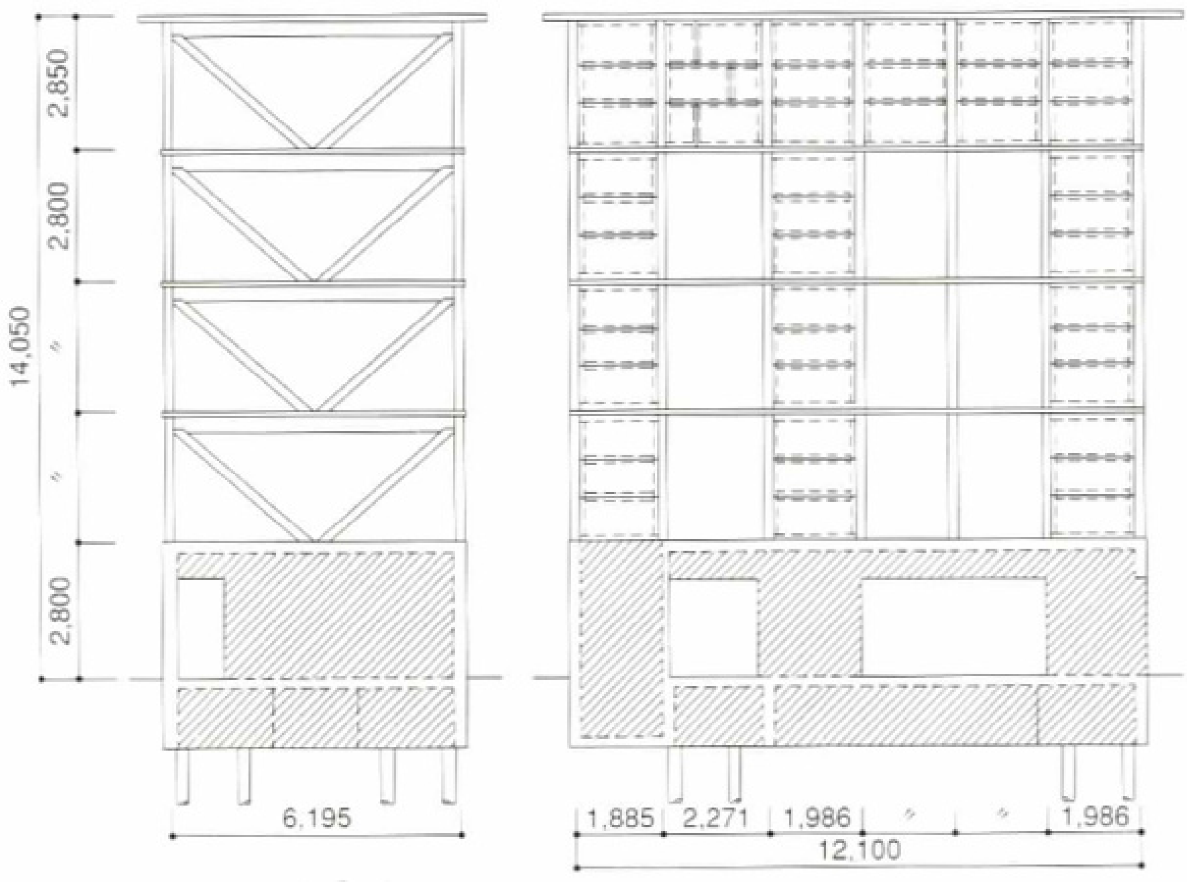


Fig 5.2.4.k – Section longitudinal and lateral; Dimensions in [mm]

5.2.5 Mokuzai Kaikan (木材会館)

5.2.5.1 Introduction

The Mokuzai Kaikan houses the Association of Wood Wholesalers in Tokyo. It's design is a model to promote the possibilities and the potential of wood as a construction material, especially because of the legal restrictions that limit its use.

5.2.5.2 Data

Location:	Shinkiba, Tokyo (〒136-0082 東京都江東区新木場 1-18-8)
Architectural design:	Nikken Sekkei Ltd Nikken Space Design Ltd., Japan
Structural design:	Nikken Sekkei Ltd
Constructor:	Taisei Architecture Associates
Construction type:	SRC and timber
Type of use:	Office, Hall
Storeys / Height:	7 Floors / 35.73m
Area:	1 652.90m² site area/1 011.26m² building area
Time for completion:	Nov. 2007 – July 2009
Costs:	n/a €

Fig 5.2.5.a – Mokuzai Kaikan

5.2.5.3 Constructional Facts

The first floors contain the entrance, a gallery, and office halls (tenant's office, conference room, etc…), the 3rd ~ 6th floors offer free working space with a timber constructed hall on the top floor.

Main structure:

The main structural support is done by using Steel Reinforced Concrete, which absorbs the tear and tensile strength. Cast in cedar frames it gives the concrete a wooden texture. 105mmx105mm blocks of Japanese Cypress (which is a standard size distributed by the timber markets of Japan) were stacked and integrated into all parts of the building.

To establish one combined panel, a traditional Japanese technique (*"tsugite technique"*) was modified to adjoin the wooden beams along their length. To maintain load transfer, oak wooden plugs were inserted between the Cypress and were unified by bolts, and secret steel bolts complete the vertical connection to create a smooth surface on the composite structural panels.
The steel frame structure is covered with wood, to emphasize the theme "wood". The main forces (such as seismic lateral force) are born by the load bearing wall of the east side, and both North's and South's thin columns primarily bear the vertical load.
The exterior is provided with a reinforced concrete slab to prevent the spread of flames in case of a fire, which was confirmed as being safe.

Moreover, by providing an adequate ceiling height to allow smoke, in case of a fire, to accumulate, the fire safety issues were defined as being fulfilled. As a result, using "combustibles" such as wood within the work space was used freely as an interior material.
In order not to change the floor heights, the air conditioning is oriented on the outer west side of the building.

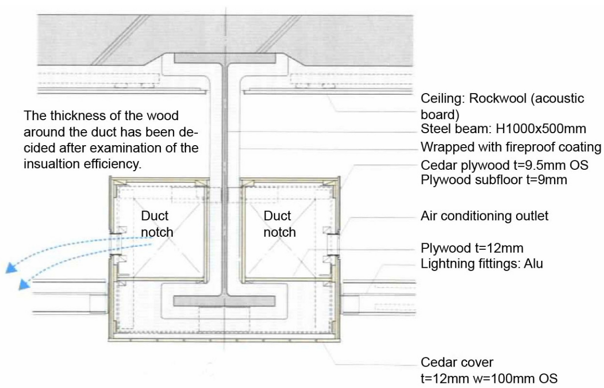


Fig 5.2.5.b – Wooden duct

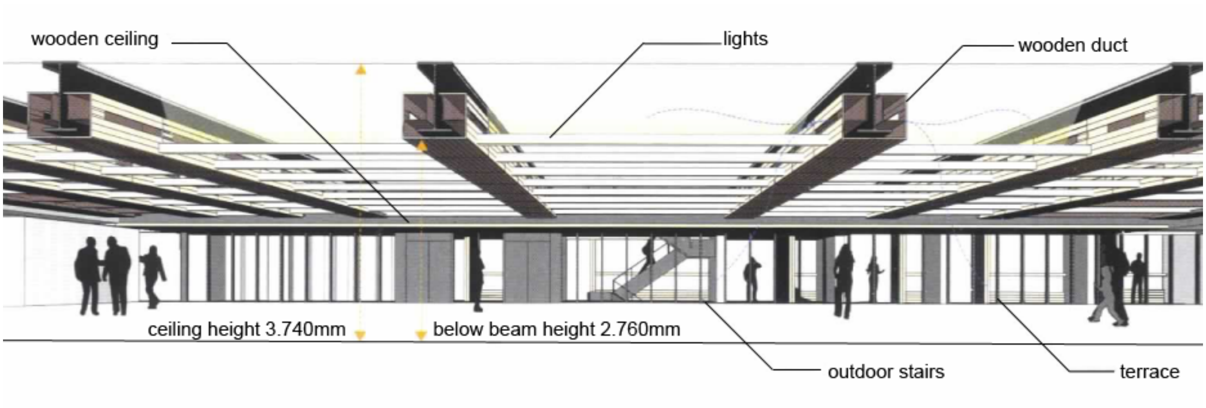


Fig 5.2.5.c – Detail of floor height; Dimensions in [mm]

Sun-protection:

Because of the climatic condition of Japan - to protect the employees from direct sunlight and moreover to suppress the negative environmental impact on the south and the west side, the terraces act as blinds and ensure privacy and provide shade within the working space.

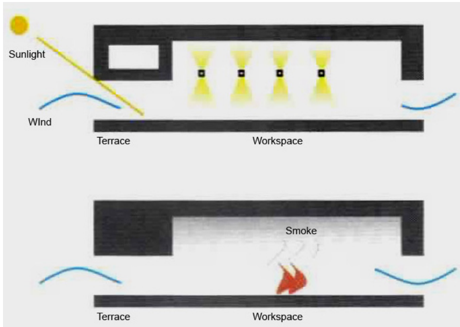


Fig 5.2.5.d – Scheme of sunlight influence and wind circulation

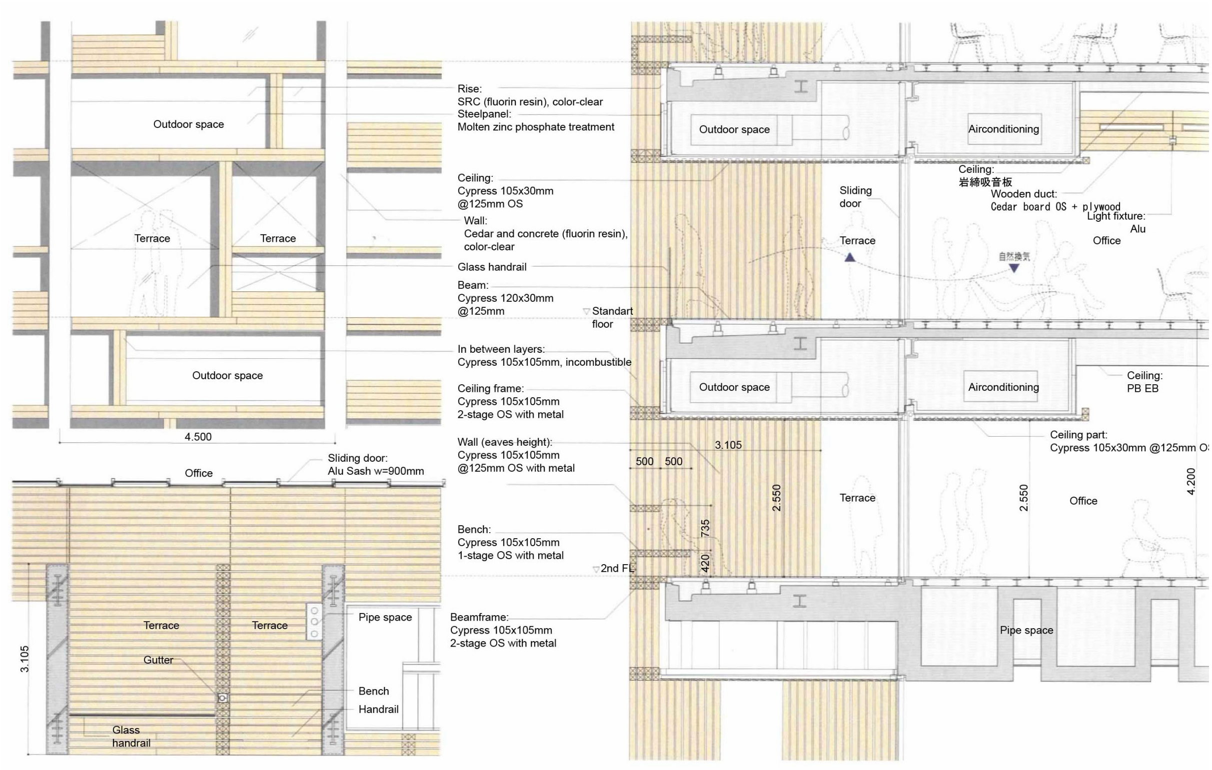


Fig 5.2.5.e – Detailed section of offices and terraces; Dimensions in [mm]

The wooden hall, top floor:

The latest digital detail technology – the computer controlled NC ("Numerical Control Machining") – allowed a high accuracy in wood handling and mass production: 115mm beams were processed to form a structure spanning 25m for the hall on the top floor. For this structure, the span was achieved without using laminated lumber (gluelam), but Japanese cypress, presenting a new age of technology. The wooden beams were divided into three parts at the parts, with a small juncture in regard to restriction of transport, and were joined on site.
The roof surface, in order to be protected from fire, wind and rain, is covered with aluminium panels.

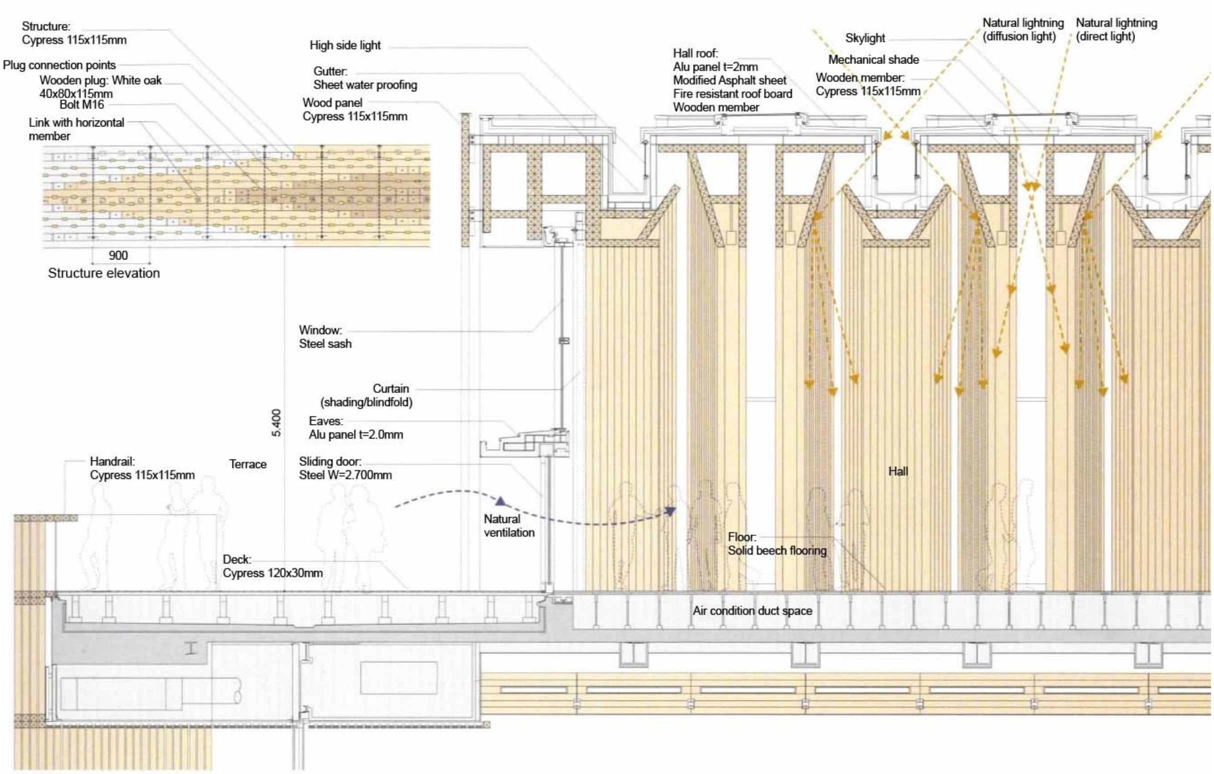


Fig 5.2.5.f – Detail of the hall and terrace; Dimensions in [mm]

The used wood:

Within this amount a great variety of different types of wood was used, chosen for every type of characteristics:
The floorings are made of *oak* and *beech*, windows and doors of "*tamo*" (*Japanese ash*); internal walls are of *wild cherry* and *walnut*; the *washitsu* (Japanese room) and parts of the office are made of *Japanese cedar*; "*kashi*" (evergreen oak; from Tono/Gifu) was used for the structural parts (exterior); plus, for the water tank *cypress* was used.

More than 1 000m³ of wood was used for this project, which means that more than 600 tonnes of CO_2 are stored right in the middle of a metropolis. Still, after completion, it was necessary to carefully observe the process of the building concerning the vertical deformation and dry shrinkage of the wooden beams, because of the Japanese climate, especially the humidity.

5.2.5.4 Plans

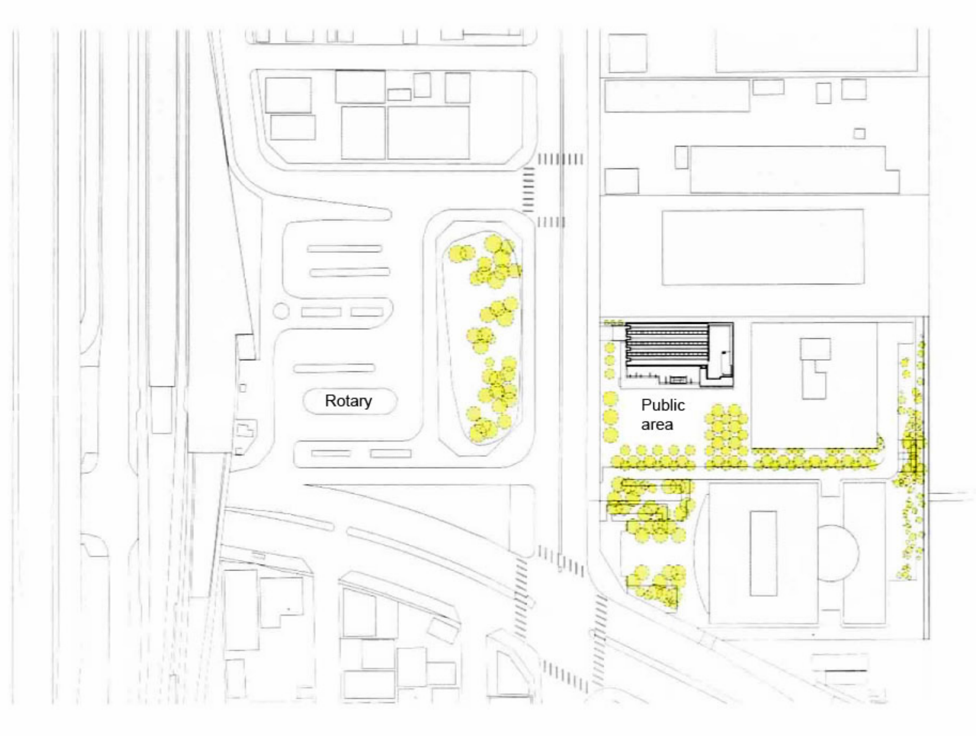
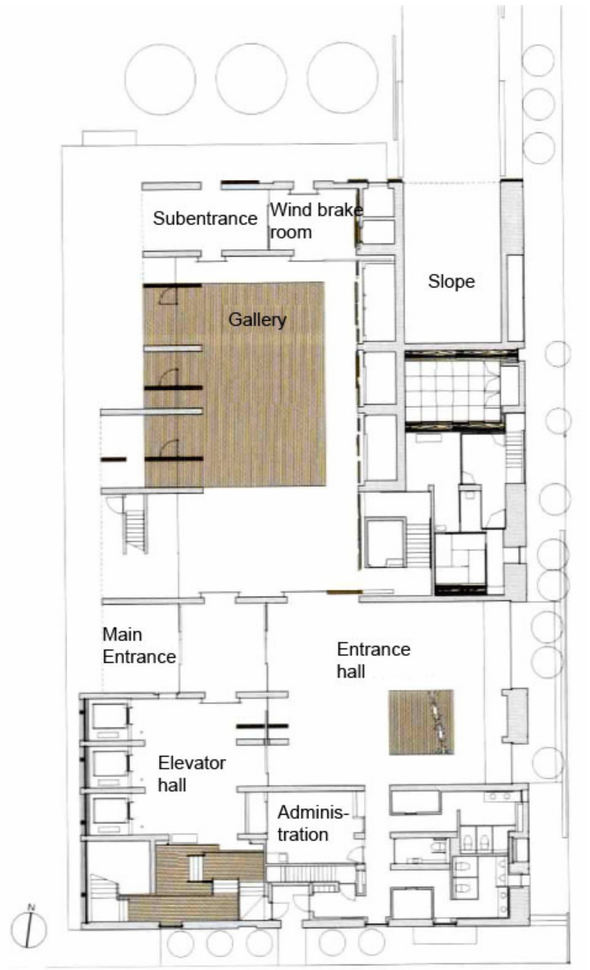


Fig 5.2.5.g – Site map



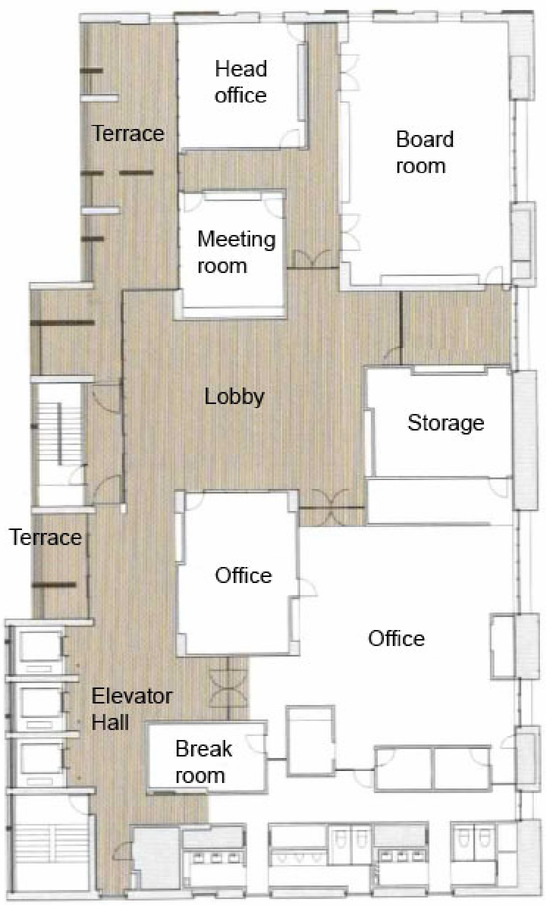


Fig 5.2.5.h – Ground Floor

Fig 5.2.5.i – 2nd Floor

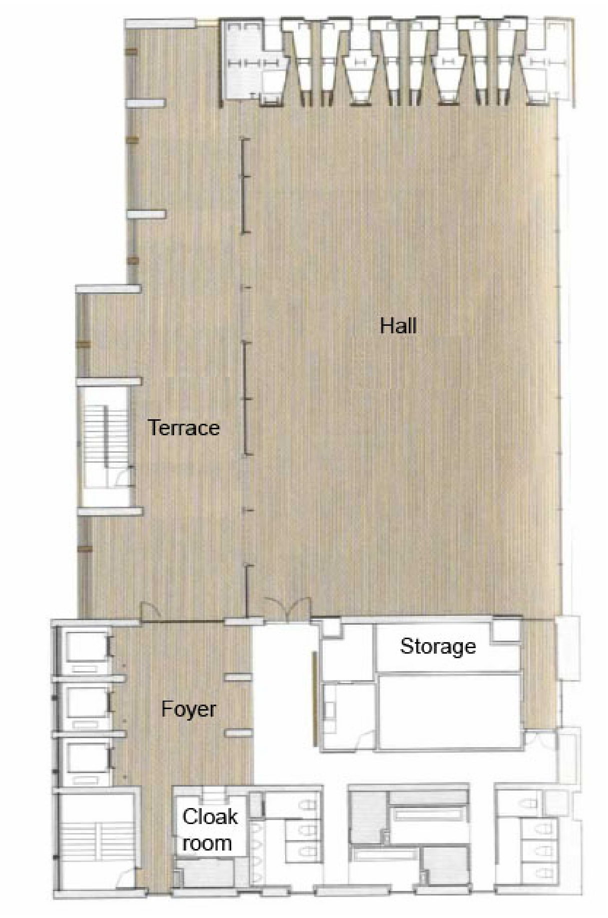


Fig 5.2.5.j – 7[th] Floor

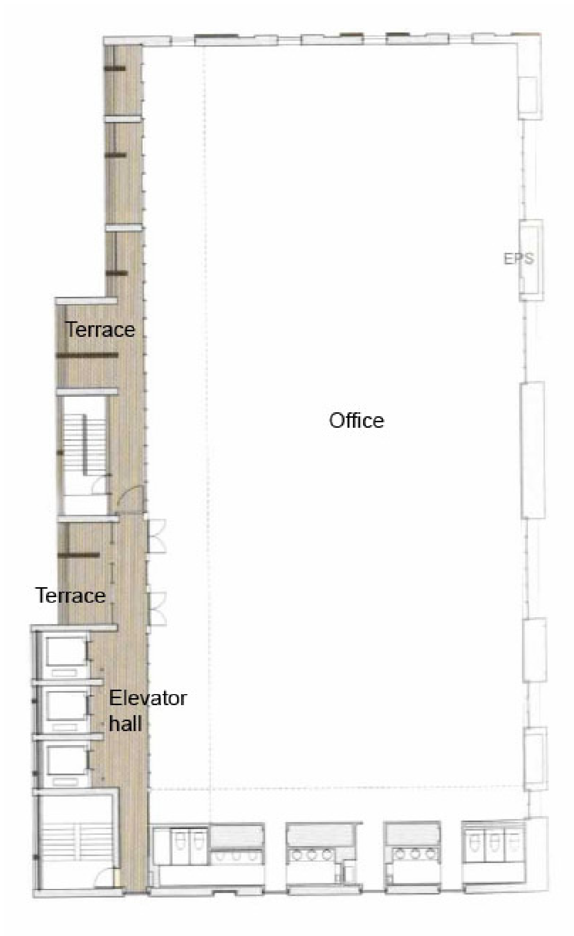


Fig 5.2.5.k – Standard Floor

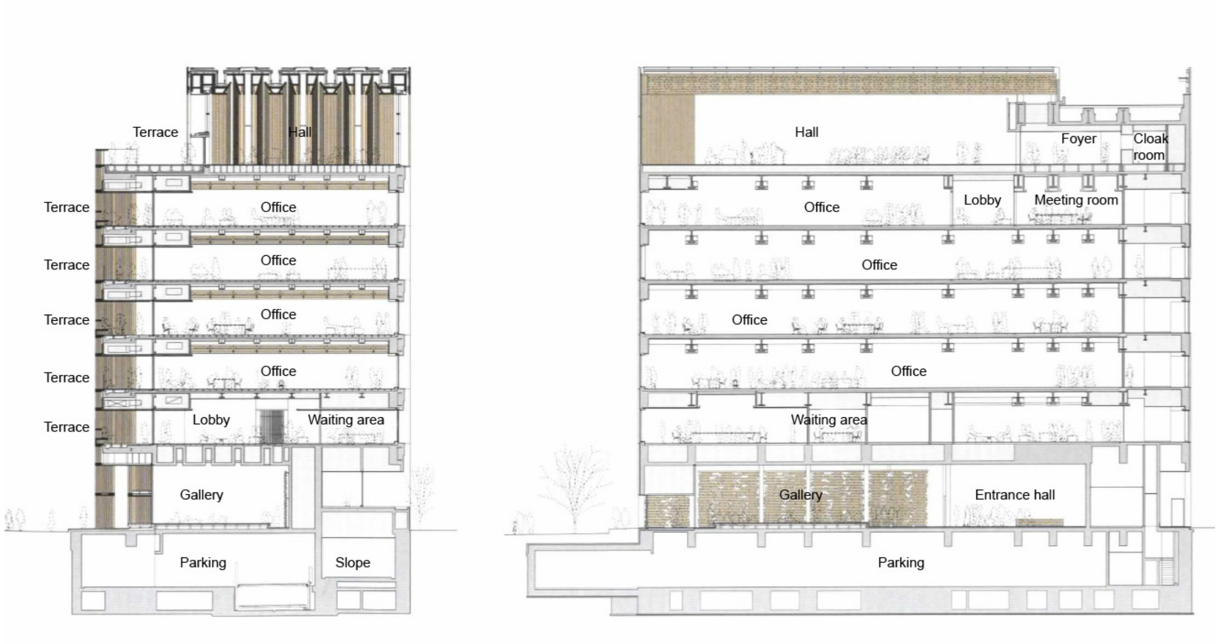


Fig 5.2.5.l – Sections

5.2.6 GC Osaka Office Building (ジーシー大阪営業所ビル)

5.2.6.1 Introduction

Located in an urban area in Osaka with a narrow front side and with great depth, the building houses a dental equipment corporation.

5.2.6.2 Data

Location:	Chûô District, Osaka (大阪市中央区南新町 2-3-17)
Architectural design:	Shigeru Ban Architects Marunouchi Architects
Structural design:	Van Structural Design Marunouchi Architects
Constructor:	Kajima Corporation
Construction type:	Above ground: hybrid (timber/steel) Underground: SRC
Type of use:	Office
Storeys/ Height:	6 + 1 Floors
Area:	602m² site area/ 348.76m² building area
Time for completion:	July 1999 - June 2000
Costs:	n/a €

Fig 5.2.6.a – GC Osaka Office Building, Osaka

5.2.6.3 Constructional Facts

Structural system:
For the structure of the building, one-storey-high *Vierendeel trusses* with a span of 22m are located on the second, fourth and sixth floor. Because of the columns, the smaller rooms are located on these floors.

On the first, third and fifth floor, because of their flexibility due to the column-free zone, the larger rooms, such as the showroom, meeting room, etc. are located.

Joists and thin beams are fitted across a pitch of about a 1m span, supporting the floor between the crossbeams of the Vierendeel trusses on both sides of the building.

The façade is a glass curtain wall, allowing the system of the building to be seen from the street.

Fire safety:
By covering the steel structure with wood, it was used as a “fire barrier” design and acts as a finish, which also allows minimized costs and resources.

In order to meet the fire-safety requirements where 23mm timber must be 30min fire-proof and 45mm one hour, 50mm (2x25mm particle boards) timber covering the steel frame was used.

5.2.6.4 Plans, Details

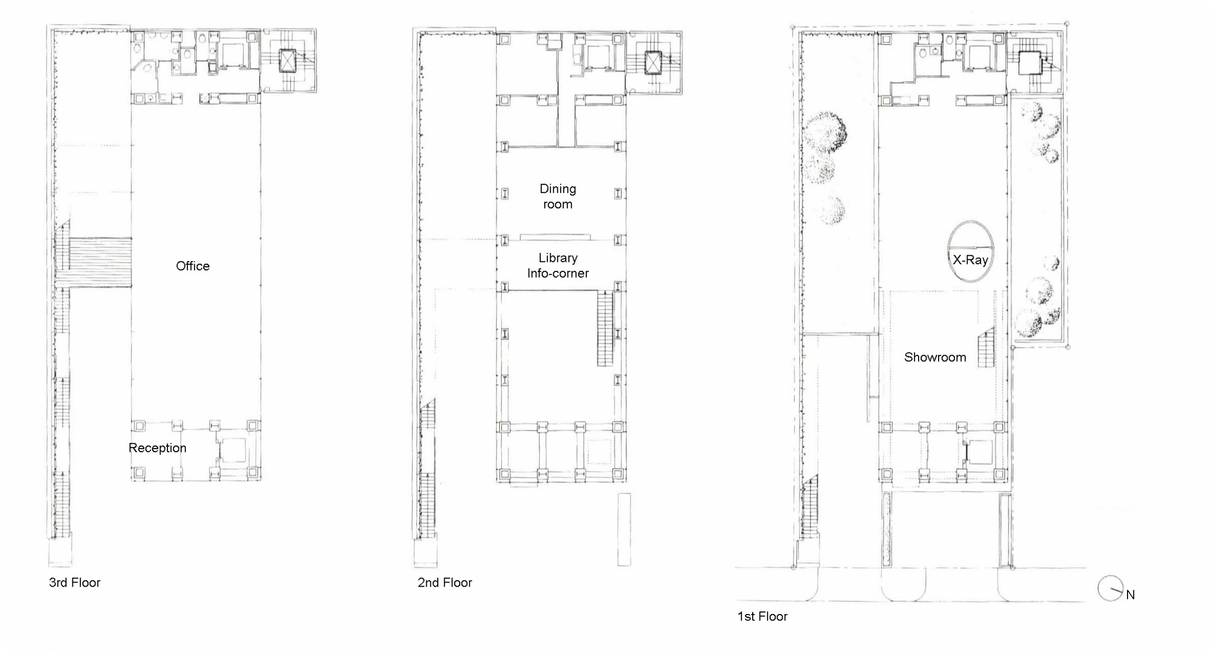
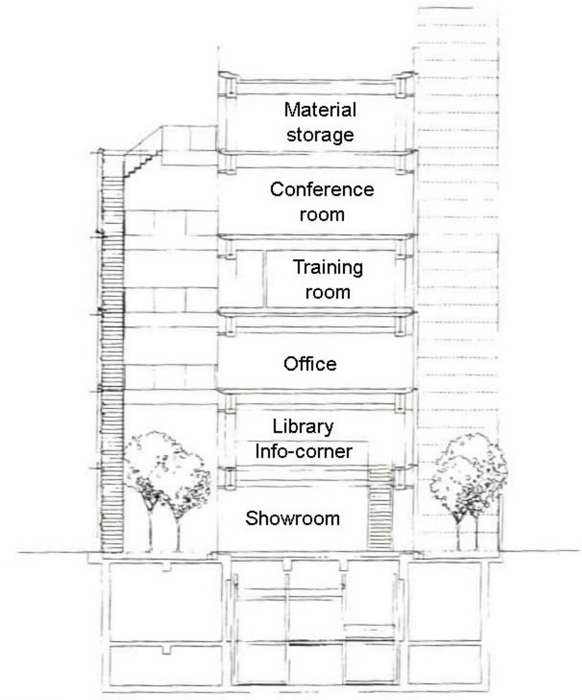


Fig 5.2.6.b – Floor plan



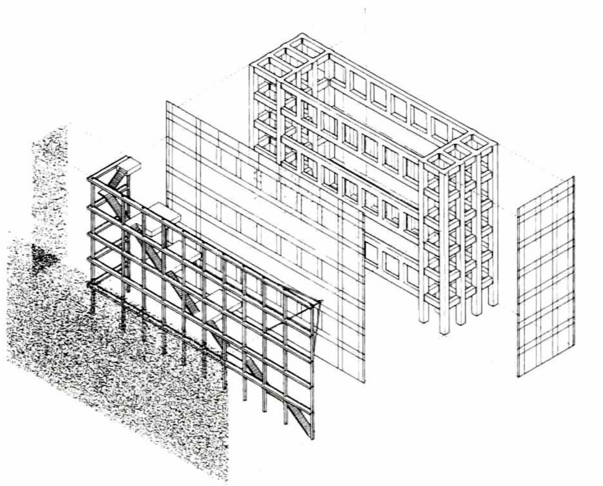


Fig 5.2.6.c – Section

Fig 5.2.6.d – Axonometry

5.2.7 Marumi Building (丸美産業本社社屋)

5.2.7.1 Introduction

After being 60 years in business with lumber (construction – supplies and fixtures), the decision was made to rebuild the headquarters of Marumi Sangyo Co., Ltd., with a new design by Shin Takamatsu. The wish was to express their passion about wood.

5.2.7.2 Data

Location:	Aichi, Nagoya (名古屋市瑞 穂区瑞穂通 3 丁目 21)
Architectural design:	Shin Takamatsu Architect & Associates Co., Ltd
Constructor:	Kajima Corporation Central Branch Meiko Construction Co., Ltd. Inc.
Construction type:	First floor: SRC 2nd ~ 5th floors: hybrid (timber/steel)
Type of use:	Office
Storeys/ Height:	5 Floors
Area:	1 110.47m² site area/ 879.66m² building area
Time for completion:	May 2007 – July 2008
Costs:	n/a €

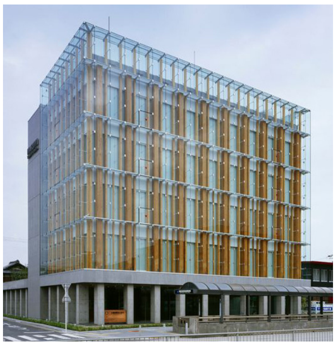


Fig 5.2.7.a – Marumi Building, Nagoya

5.2.7.3 Constructional Facts

Main structure:
It was chosen to be a timber hybrid structure, combining wood and steel in an attempt to fulfil the required fire regulations. Gluelam made of larch was used for the columns. The L-type core bears the seismic forces.

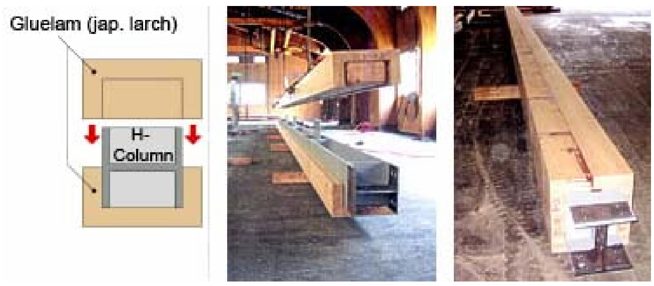


Fig 5.2.7.b – Hybrid construction explanation

Façade:
The façade is a double skin glass from the second floor to the top, which not only acts as an insulation shielding against radiation of the sun, but also improves sound insulation. The inner glass is made of fire-resistive glass. Its columns are H-type steel columns covered with Japanese Larch, with 1hr fire resistance and bearing long-term axial force. To protect the wood from rain, it was covered with a waterproof layer.

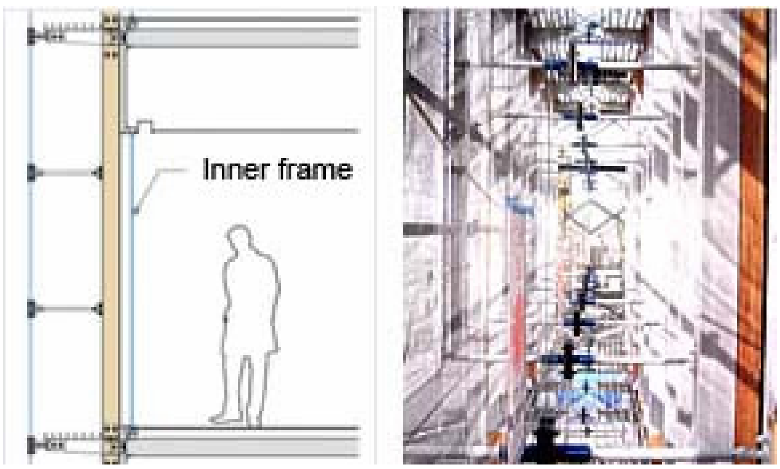


Fig 5.2.7.c – Detail: Façade

5.2.7.4 Plans, Details

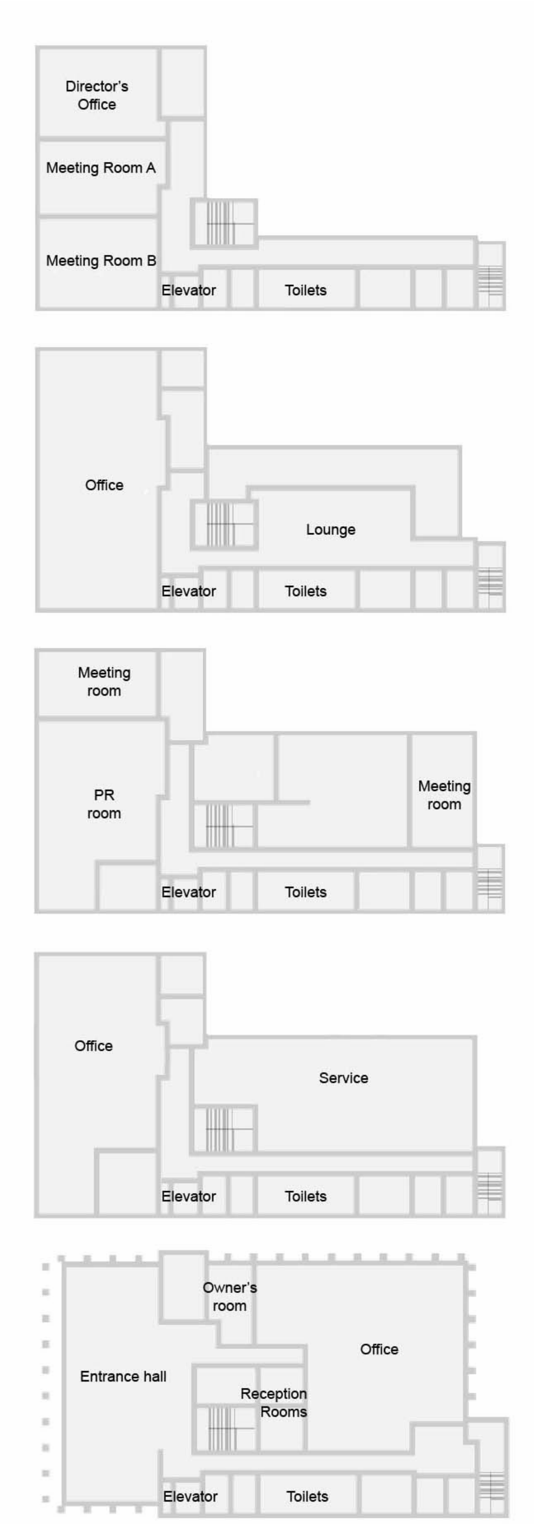


Fig 5.2.7.e – Floor plans

Fig 5.2.7.d – Rendering of the façade

5.2.8 Funen Moku Building (八丁堀中條不燃木材ビル)

5.2.8.1 Introduction

On a site of 4m width and 35m length this hybrid building was nationwide the first attempt using a steel frame body structure, cladded with a noncombustible timber façade.

5.2.8.2 Data

Fig 5.2.8.a – Funen Moku Building, Tokyo

Location:	Chûô District, Tokyo (東京都中央区八丁堀 4-5-12)
Architectural design:	Ishii Kazuhiro Arch. Res. Inst.
Structural design:	KKE Atsushi Akira Sasaki
Constructor:	Rinkai Nissan Construction Co., Ltd.
Construction type:	Body: steel frame Façade: timber
Type of use:	Office and Apartments
Storeys/ Height:	9 Floors / 24.40m
Area:	124.34m² site area/ 88.70m² building area
Time for completion:	Completed in 2006
Costs:	160 €/m²

5.2.8.3 Constructional Facts

The main structure has a steel frame with a noncombustible timber façade; this, because the timber has been impregnated for three hours with boric acid.

What makes the project interesting is that the stairway is confined by a thin room and showing a noncombustible façade made of wood.

The building looks like a tower, due to it's aspect ratio (4m width : 24.4m height). Flexural rigidity cannot be guaranteed sufficiently and horizontal deformation is quite large, causing the problem of a torque occurring in the posts.

Therefore, in order to ensure rigidity, the main structure is a steel based frame construction and a buckling restrained braces - braced side shaft core.
In addition, the stairwell is buckling restrained – braced to control the deformation and twist. Due to these braces a high aseismic capacity is secured.

With a ratio of *width : height = 1 : 6* and *width : depth = 1 : 5*, the design was very limited and strict. To secure a maximum of total floor area, desig started with organising the iron frame. The idea to use timber for this project was always in mind, but it had to be not too costly for the client.
A thin steel frame and a simple and clear structure made it possible to design a usable building on a small site; the colour of the façade on the front and back, as well as the interior design for the 6th and 7th floor had to be approved by the client.
With a low unit price (18 000 円 (~ 160 €)/m² in reference to this project) the façade as well as the 6th and 7th floor were able to be constructed using noncombustible timber.

The roof terrace, also made by noncombustible timber, is covered with a 3.2m extended façade, Therefore it remains unseen from the surrounding buildings of the same height.

5.2.8.4 Plans, Details

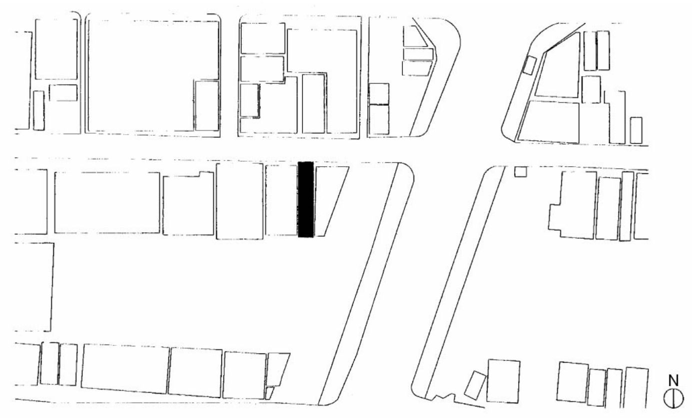


Fig 5.2.8.b – Site plan

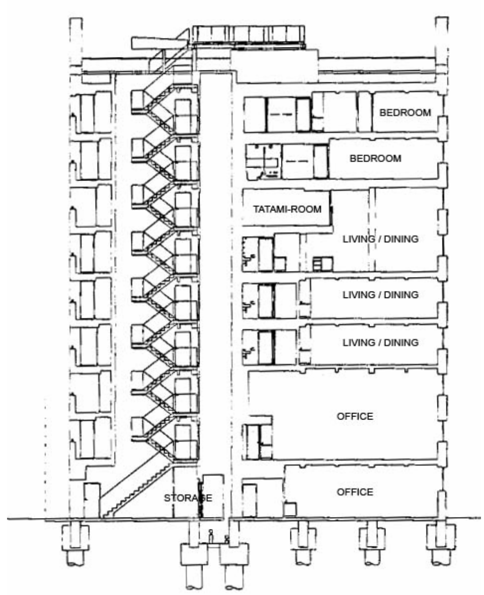


Fig 5.2.8.c – Section

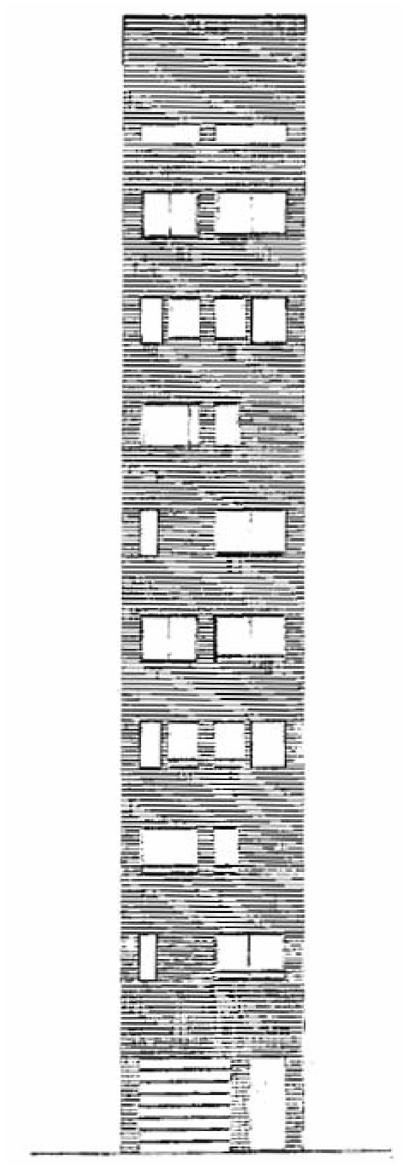


Fig 5.2.8.d – Elevation

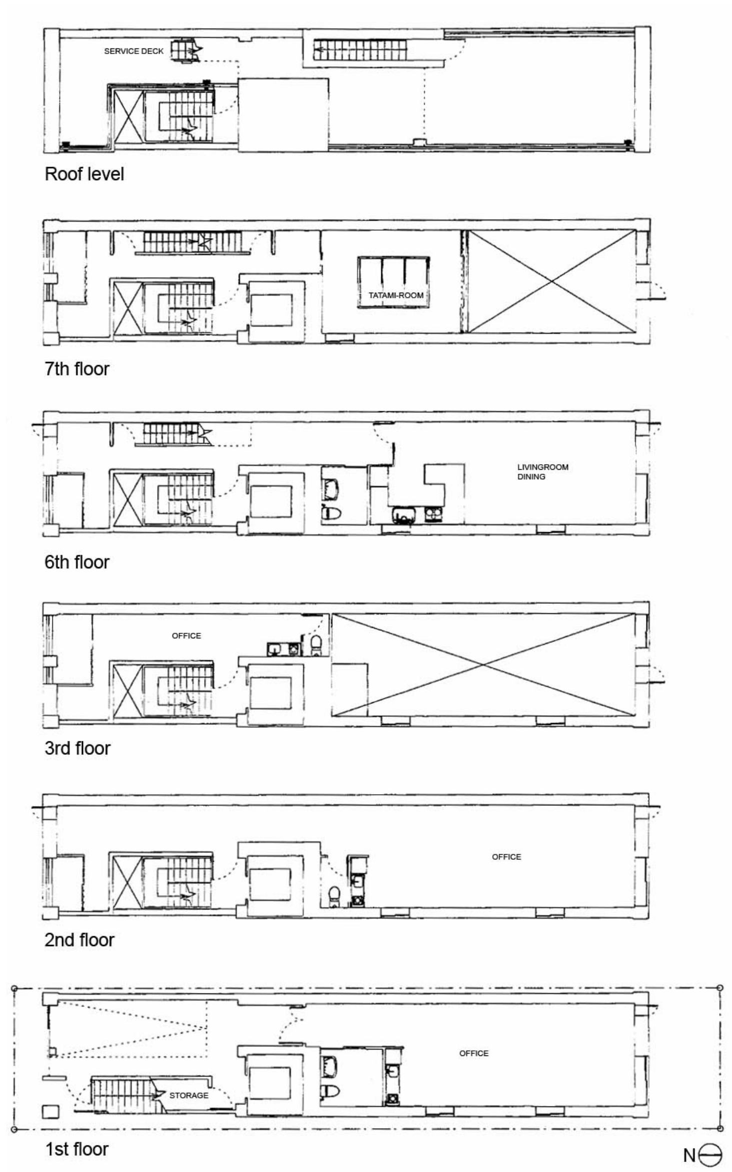


Fig 5.2.8.e – Floor plans

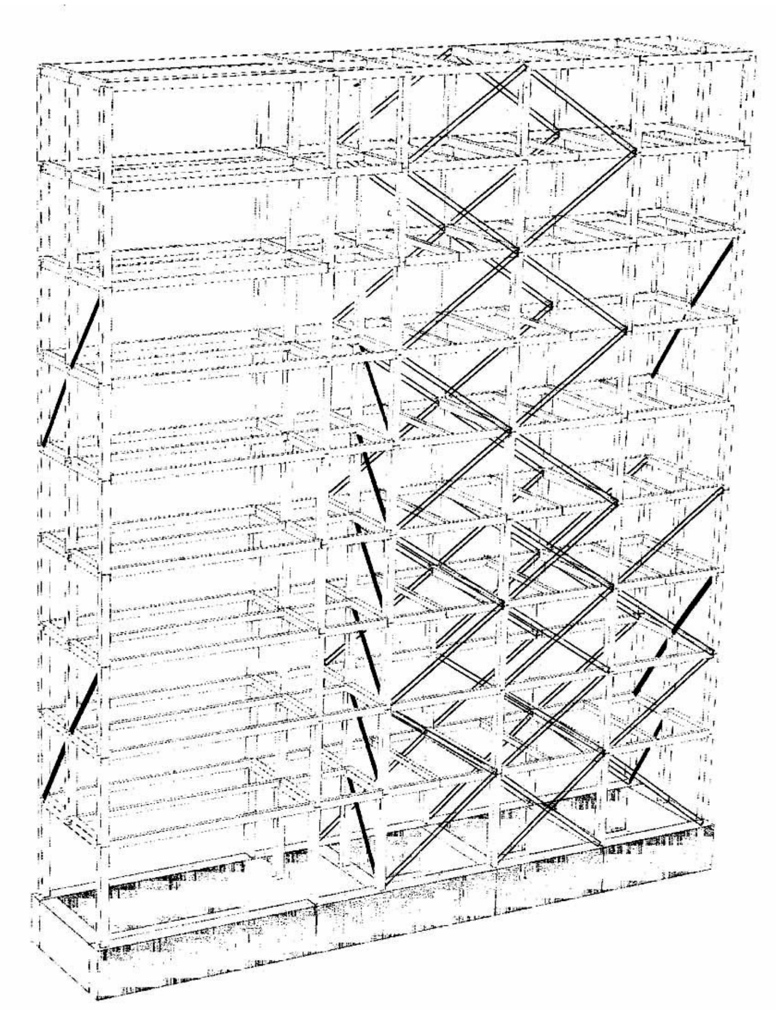


Fig 5.2.8.f – Axonometry and bracing system

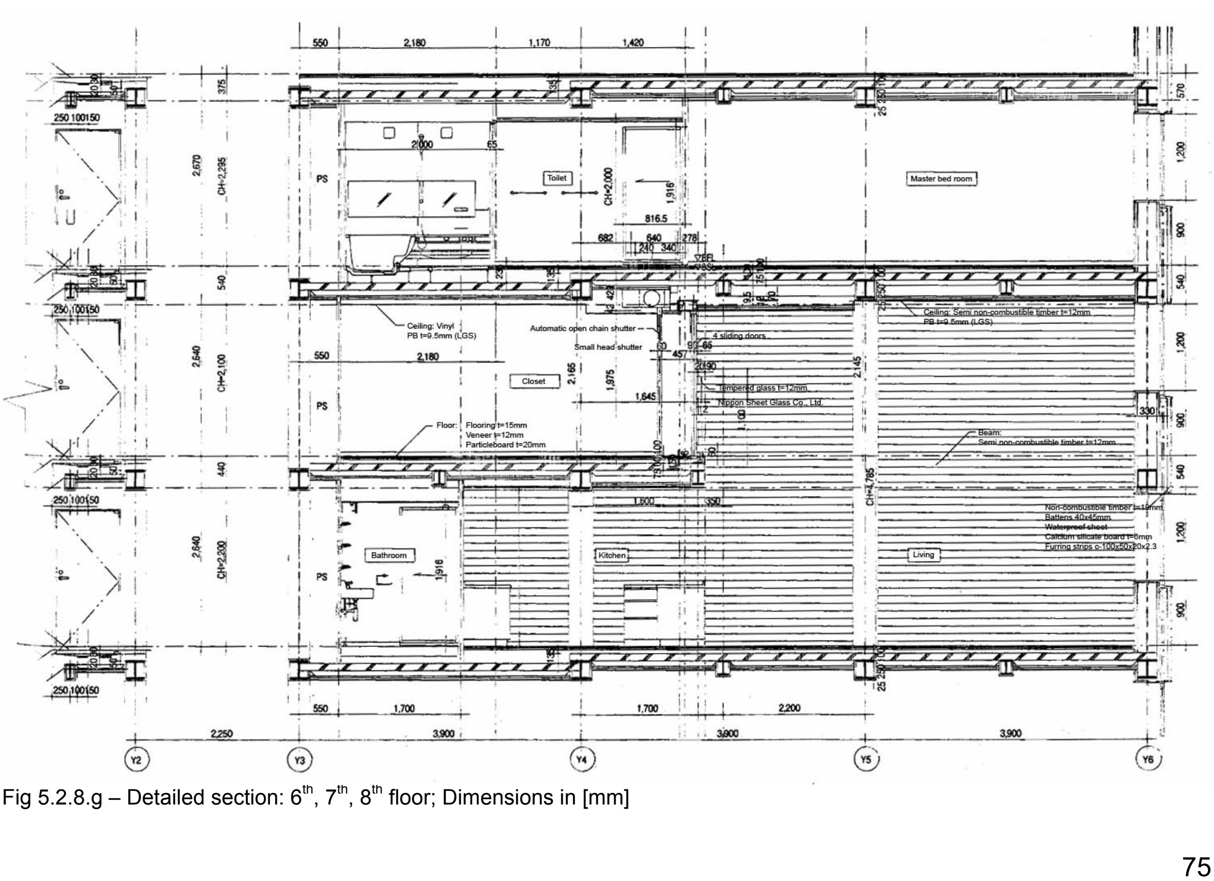


Fig 5.2.8.g – Detailed section: 6th, 7th, 8th floor; Dimensions in [mm]

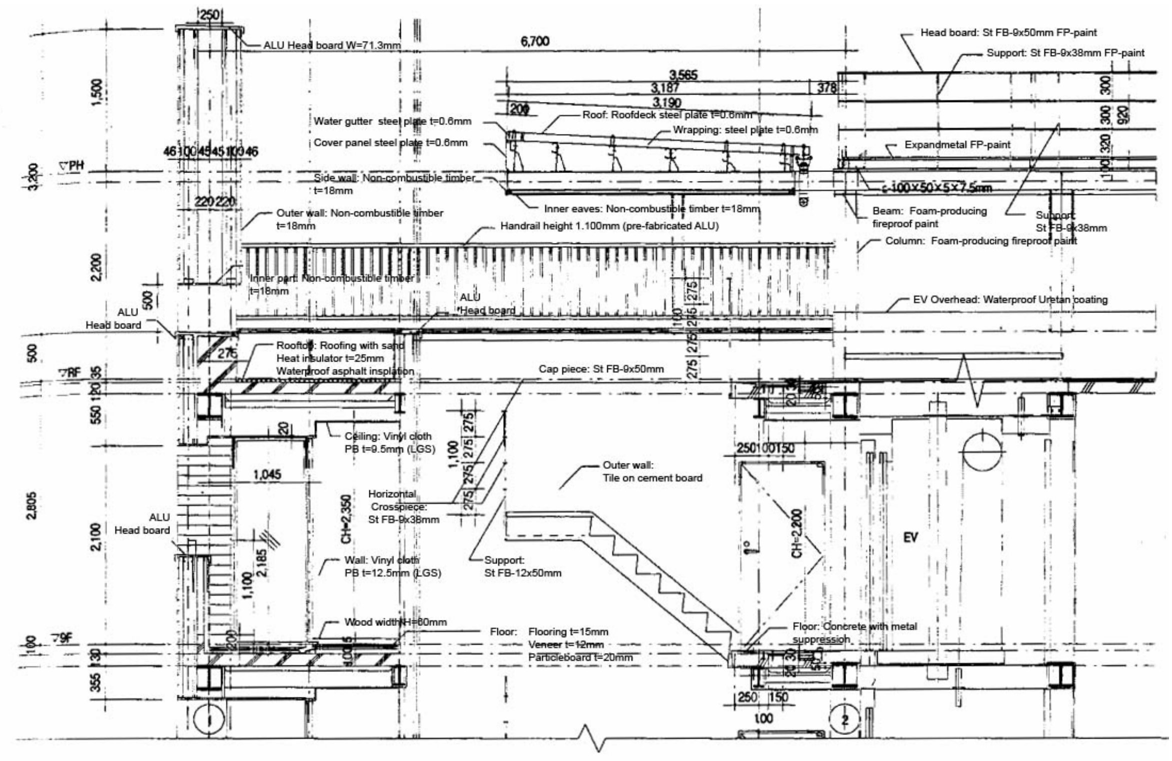


Fig 5.2.8.h – Detailed section: 9th floor – roof; Dimensions in [mm]

6. THE FUTURE OF MIDDLE- and HIGH-RISE TIMBER BUILDINGS

6.1 Projects in Europe

6.1.1 Introduction

Wood meets all the technical and constructional demands of a modern construction material. Light weight and yet highly resilient, good thermal properties and the possibility of dry construction – the demand for timber constructions increased strikingly over the past few years. Different stiles and forms, facades, a comfortable indoor climate, warm surfaces and a good acoustic promote wood as being an essential material.

The enormous development in the field of construction and energy efficiency has to be used and increased. But although they are manifold, as colleges, universities and the industry are constantly working on finding new constructional and technical solutions, market development is still progressing slowly. Single projects appearing in different European countries constantly draw attention to the use of timber construction in middle-rise buildings and show that the prejudices against wood as a constructional material are not justifiable.

Due to the building law revisions in most of the European countries architects and engineers are becoming more adventurous. Here are examples for the future of high-rise timber constructions in Europe.

6.1.2 Austria

6.1.2.1 Research project 8+, Austria (no precise site yet)

Architect: DI Michael Schluder
Construction: *Underground levels + ground level*: RC
1^{st} ~ n^{th} *floor*: timber only
Engineering consultant: DDI Wolfgang Winter (statics)
DI Frank Peter (fire safety)
Type of use: Business/office…
Storeys/ Height: ~20 Floors / ~80m
Time for completion: Under development since February 2008
Costs: n/a

Fig 6.1.2.a – Rendering - 8+

6.1.2.1.1 Introduction

In 2008, the Austrian promotion association for research (FFG) financed a project “8+”, to research middle- and high-rise timber constructions (>/= 8 stories high) – the report ended with a concept for a high-rise design with 20 storeys.
The aim was to offer areas used for business and offices with approximately 700 – 1 000m² floor space per storey and a maximum of flexibility for the floor plans with an economic static system even with as few columns as possible.

A CO_2 balance showed that after 25 years - due to absorption in the building - a reduction of 1785 tonnes CO_2 could be achieved.

The study includes 20 standard floors calculated by using the Euro-Code. The basic economical factor for constructing the project is the building shell.

Four different construction types were examined and compared with one another. All types met the requirements. In all of these types, the joints are the static and economic dominating part of the system.

6.1.2.1.2 Detailed description

Measures:
Length ~ 45m
Width: ~18m
Height up to ~ 75m / up to 20 levels above ground

Statics:
The façade and the ceiling support the stiffness of the building, so that stair cases, elevators and supply shafts can be arranged freely.

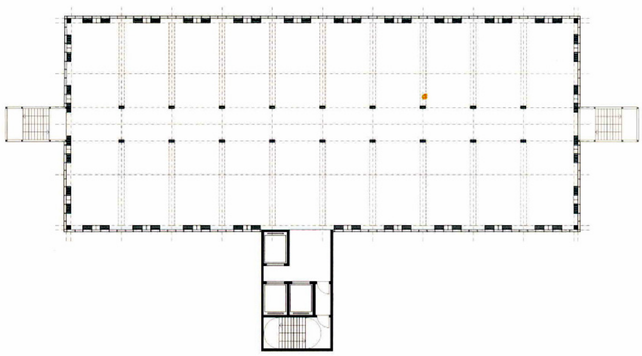


Fig 6.1.2.b – Suggestion for floor plan

Ceilings:
Besides the static requirements there are also physical building and fire protection requirements to consider - In high-rise buildings, a fire resistivity of REI 90 is required for the ceilings.
The necessary noise insulation can easily be achieved even when using common timber ceiling systems.

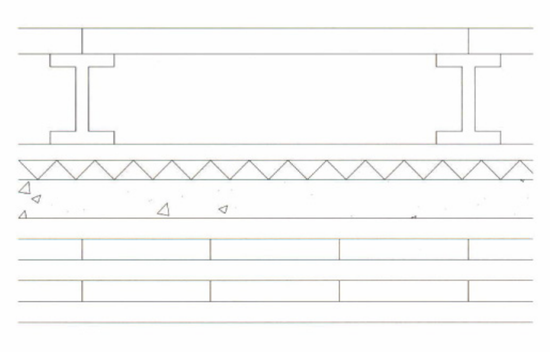


Fig 6.1.2.c –Ceiling construction

The ceiling's dead load is very low (~250kg/m²) which lowers the construction's total load in comparison to a solid structure. The currently chosen ceiling construction is a laminated timber construction with a dry screed.

200mm double floor Nortec
25mm Rigidur cement screed
29mm Floorrock HP30-1
50mm split fill 4/8
162mm laminated timber

Façade:
The construction occupies most of the façade area and therefore reduces the costs for the façade itself.

Fire prevention:
The way of construction allows damaged elements easily to be changed.
Details are still under construction – fire resistance of columns and ceiling construction is being tested.
For the structure, ceilings and walls, a fire resistivity according to ONR 22000 has to be proven, and a fire sprinkling system is necessary to prevent the spread of fire.
The building service supply shafts are constructed in reinforced concrete and are situated on the outer side of the building's façades.

6.1.3 Norway

6.1.3.1 Barentshaus, Kirkenes

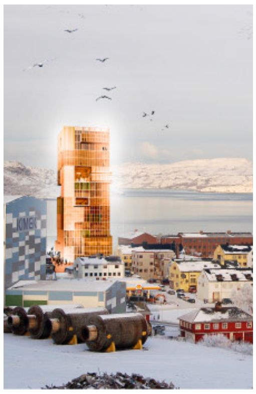


Fig 6.1.3.a – Barentshaus

Architect:	Reiulf Ramstad RRA
Construction:	Using gluelam and massive fir wood segments
Project Initiator:	Barents registry, development agency
Engineering consultant:	n/a
Type of use:	n/a
Storeys/ Height:	~17 Floors / ~55m
Time for completion:	Under development; scheduled to start 2012
Costs:	~ 60 Mio €

6.1.3.1.1 Introduction

The base structure of the high-rise building is a timber construction kit that hasn't been developed yet. A combination of gluelam elements and massive fir wood segments shall provide the approximately 55m high tower stability.
The construction services engineered the building to save more energy than it's users consume. This will be possible not only because of the use of recycled building materials, but also the used water will be used as a source of heating and the window panes will collect solar energy.

As the project is still under development and no investor yet has been found, further information is unavailable.

6.2 Projects in Japan

6.2.1 Introduction

The revision of the architectural standard law in 2000 widened the possibilities for a new territory, but it took until 2005 (after finishing the first five-storey timber construction, the M-Building in Kanazawa), to finally draw attention to timber as a main construction material for middle-rise buildings.

By proving possible solutions to fulfil the requirements for fire safety *and* promote timber as the new old building material, this project has given the Japanese a basis for their hope for further future projects.

6.2.2 Timberize Tokyo

Dedicated architects sharing the same passion – wood and architecture – combined their knowledge and decided to show Japan what wood is really able to do. With the name "*Timberize Tokyo*" they successfully promoted their ideas for the future of middle-rise timber constructions.

The team members are, under coordination of Prof. Dr. KOSHIHARA Mikio (Professor of the University of Tokyo, Institute for Industrial Design):

Designer:

KOSUGI Eijiro, UTSUMI Aya / KUS
YAGI Atsushi /Atsushi Yagi Architect & Associates
KUHARA Hiroshi / KUHARA Architects
FUSE Yasuyuki / Fuse Yasuyuki Architects Office
KASHIMOTO Kohei / Team_KK
YAMADA Toshihiro / HUG

Structural Engineers:

KIRINO Yasunori / Kirino Structural Engineering Office
KATO Masahiro / MID
SATO Takahiro / SD-Lab.

timberize tokyo

By courtesy of Dr. Koshihara, their concepts and ideas on how to utilize timber are illustrated in the following subsections. All these projects are "located" on *Omotesandô*, a lively and highly frequented avenue in the Minato and Shibuya wards, sometimes also referred to as "Tokyo's Champs Èlysèes".

6.2.2.1 „30"

Architectural design: YAMADA Toshihiro / HUG
Construction type: Timber only
Type of use: Office
Height: 7 storeys

Introduction, structure, fire safety:
The main structural system, a frame construction along direction "X" and a "load bearing wall" structure absorbing horizontal forces along "Y", with columns every 6m, ensures the functionality of space and offers an efficient timber frame structure.

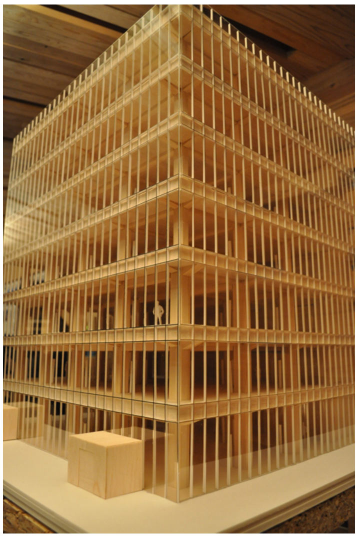


Fig 6.2.2.1.a – Model "30"

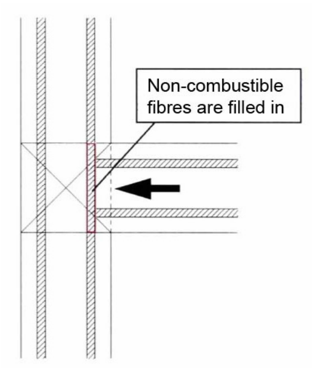


Fig 6.2.2.1.b – Joint filling

Because the fire stopping layer ends at the joints of pillars and beams (of the wooden frame constructions), the change of x- and y-axis became reasonable to prevent anisotropy.

The spreading of fire is prevented due to the thickness of the floor construction (which has to be at least 90cm), as well as adding a noncombustible filling to the joints.

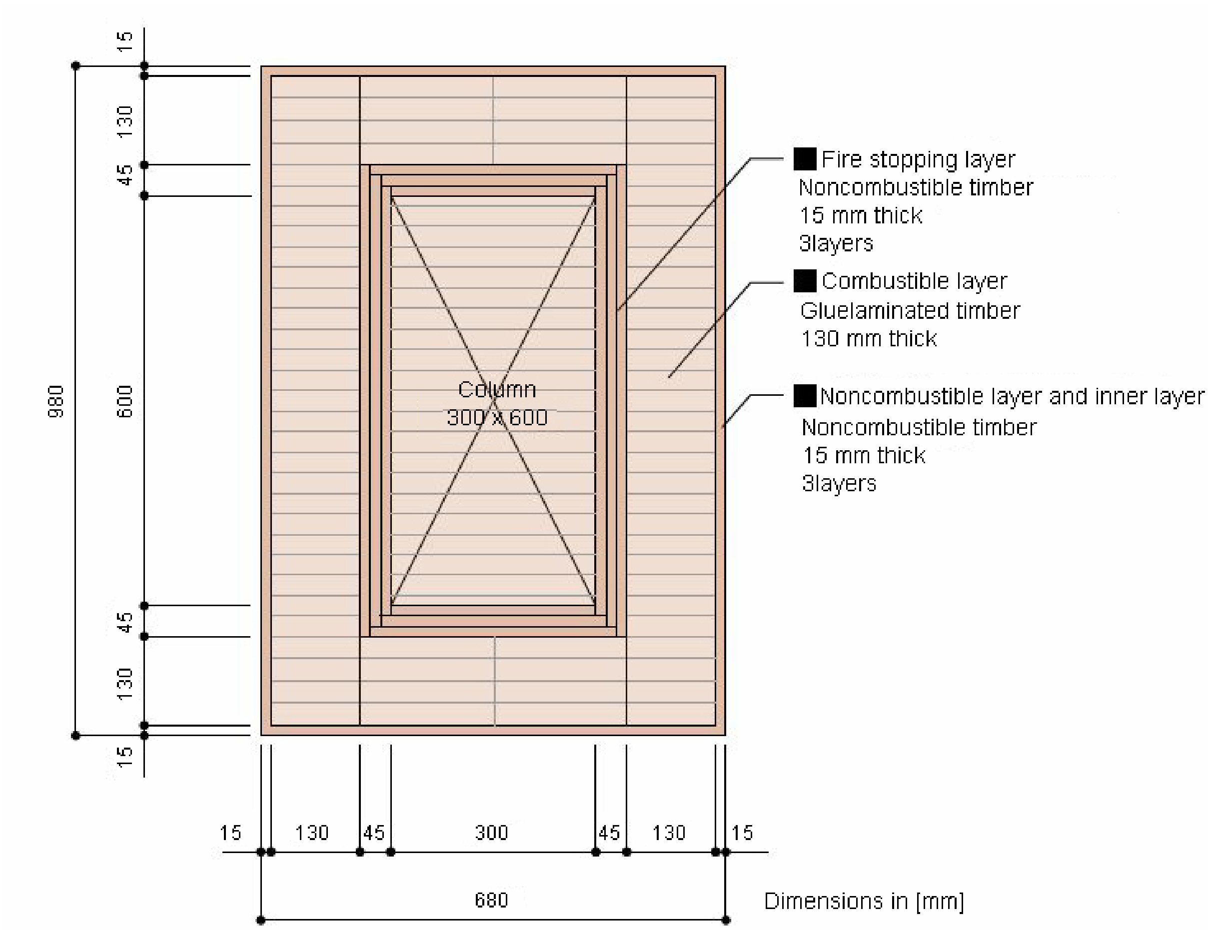


Fig 6.2.2.1.c – Column – 2hrs fire resistance

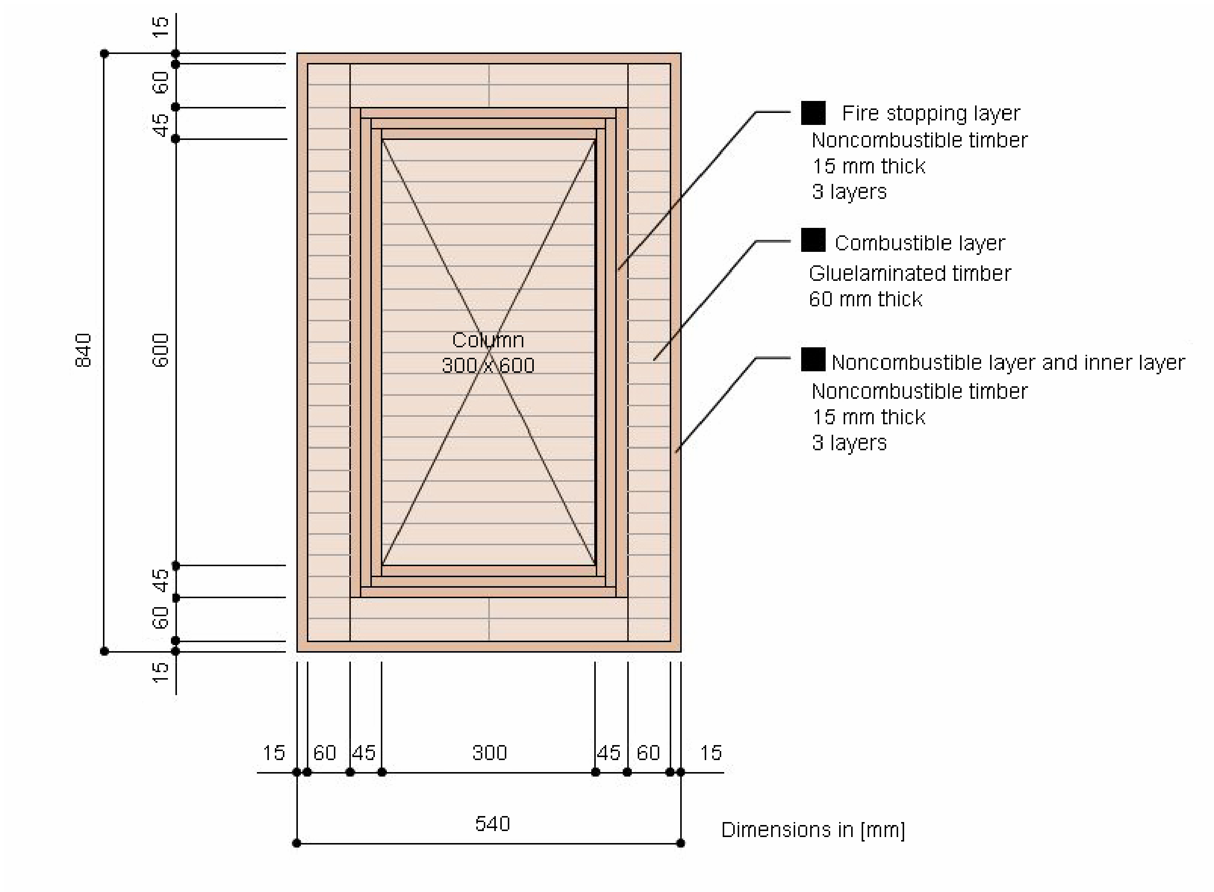


Fig 6.2.2.1.d – Column – 1hr fire resistance

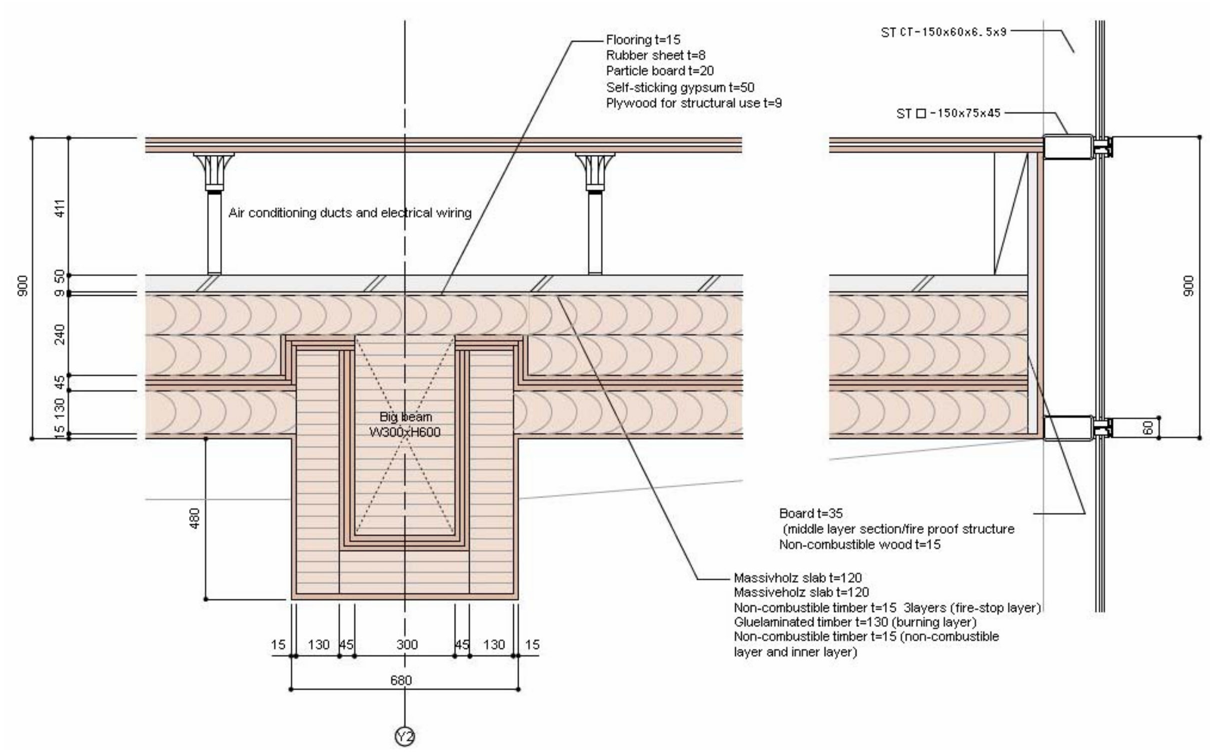


Fig 6.2.2.1.e – Detail: Beam and façade; Dimensions in [mm]

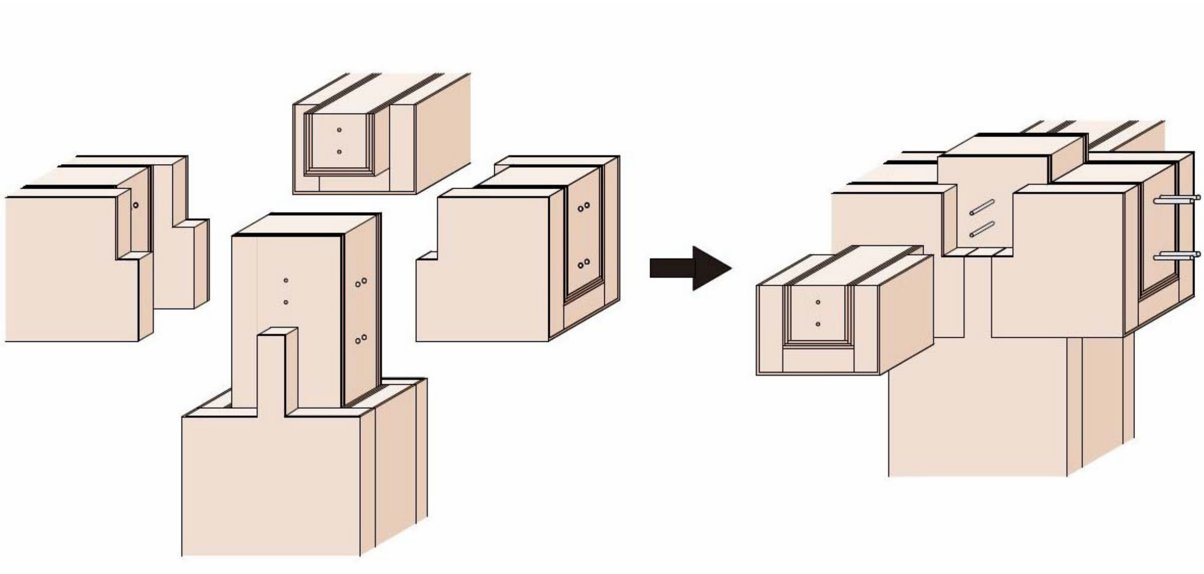
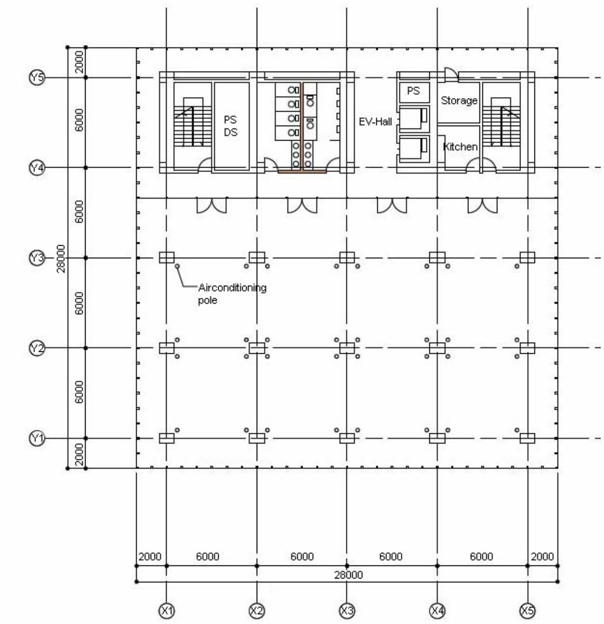


Fig 6.2.2.1.f – Axonometry - beam and column joint



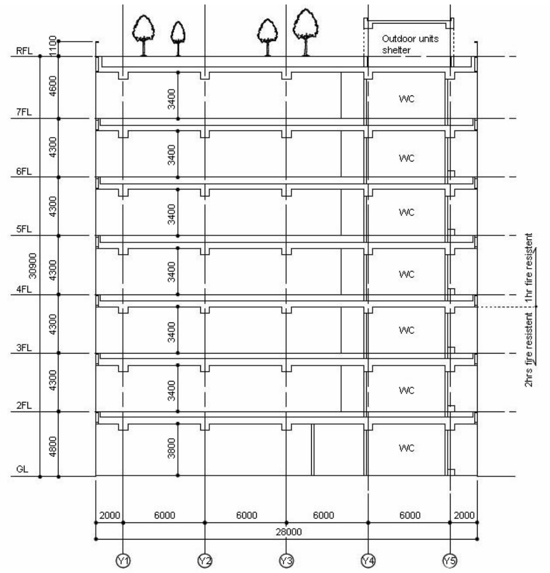


Fig 6.2.2.1.g – Ground floor; Dimensions in [mm]

Fig 6.2.2.1.h – Section; Dimensions in [mm]

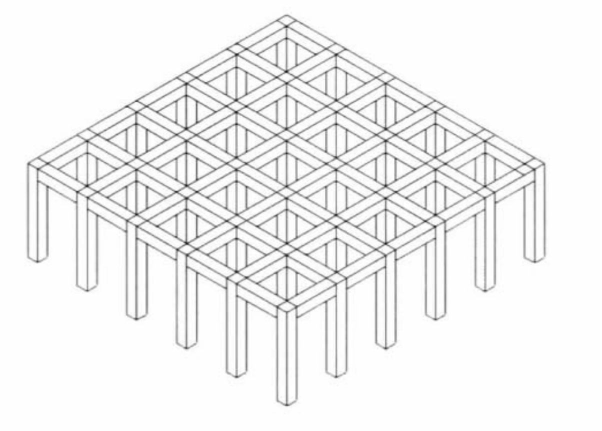


Fig 6.2.2.1.i – System-axonometry

6.2.2.2 „T"

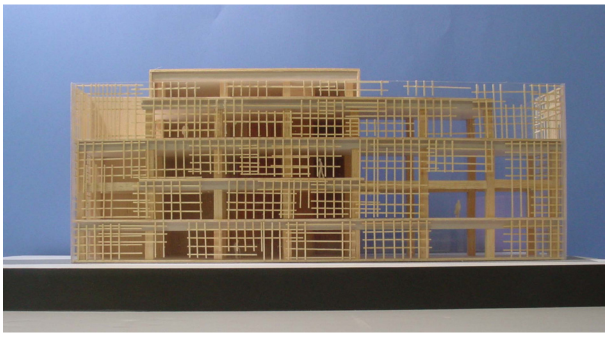


Fig 6.2.2.2.a – Model "T"

Architectural design:	YAGI Atsushi /Atsushi Yagi Architect & Ass.
Construction type:	Office + shop
Type of use:	Timber + RC
Height:	5 storeys

Introduction:
This building houses offices and a Butsudan-shop. Due to the length of the site, a huge façade offers a bright and open view.

Structure:
The short side is a frame structure, for the long side the frame structure has an attached batten-system. The battens which are "randomly" arranged (mirrored – seemingly random but they still have a system) were used before in other timber buildings. The facade is a glass façade with timber battens. Structural form is a semi-rigid connection using a large section gluelam timber frame.
Structural fire performance means to maintain the vertical bearing capacity after a fire (horizontal resistance elements may be burned). Based on this concept, horizontal resistance elements supporting vertical frame elements (wind-pressure, seismic forces) are covered with a frame, columns and beams are constructed using 6 layers of gluelam timber.

Fire resistivity:
The column and the beam have a firestopping layer (non-flammable/ noncombustible wood) and a burning layer (wood) outside the structural part, offering a one-hour fire resistance.

The vertical load is supported by the two central layers of the columns. The firestopping layer is 210×500m, plus an additional cover of 210x600 mm.
Therefore it is protected from fire and after a fire the supporting frame at the centre can maintain the vertical support ability even if this outside horizontal resistance element frame is burned down.

Plans/Details:

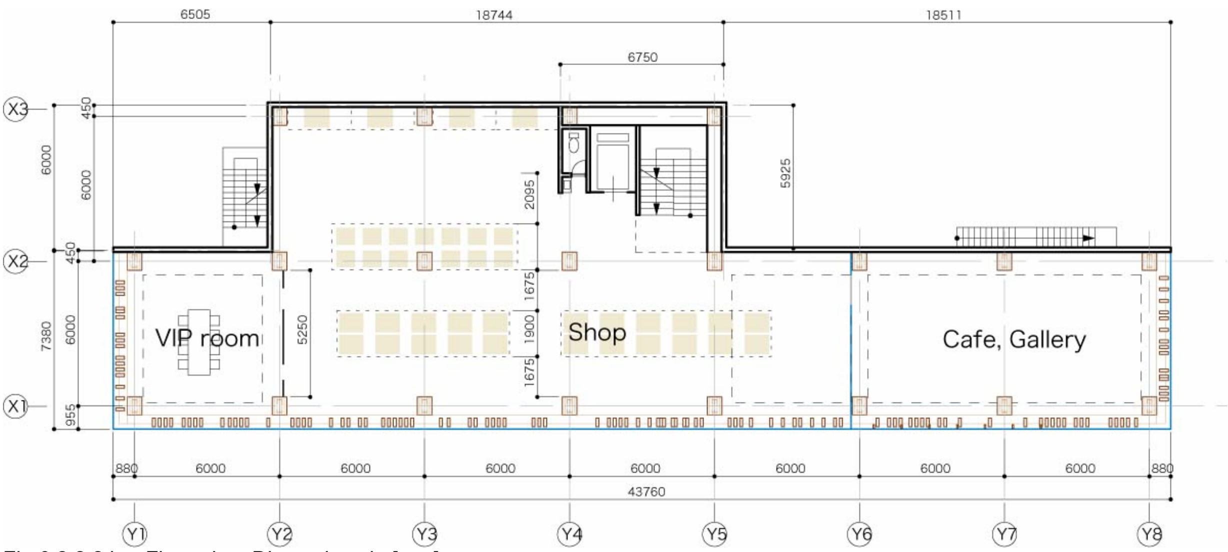


Fig 6.2.2.2.b – Floor plan; Dimensions in [mm]

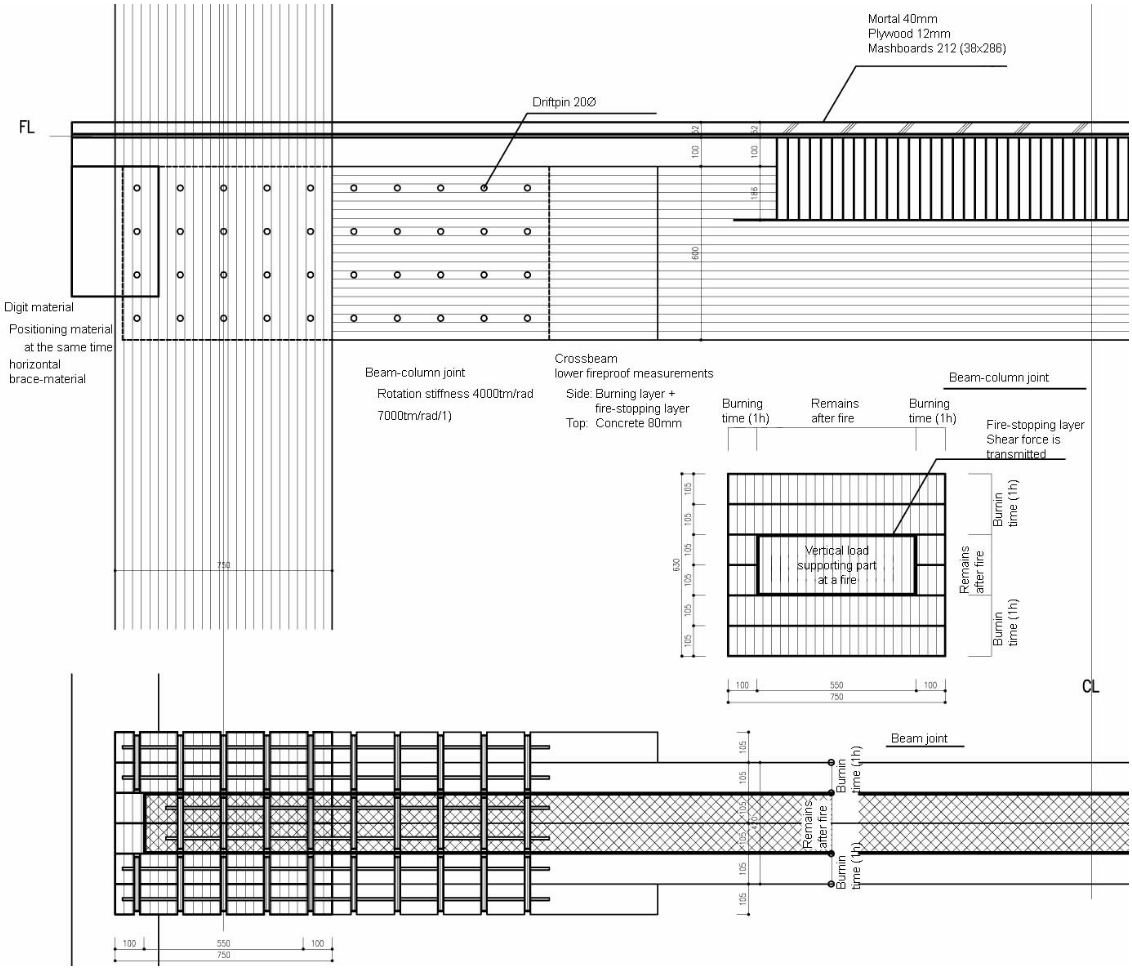


Fig 6.2.2.2.c – Detail: Construction; Dimensions in [mm]

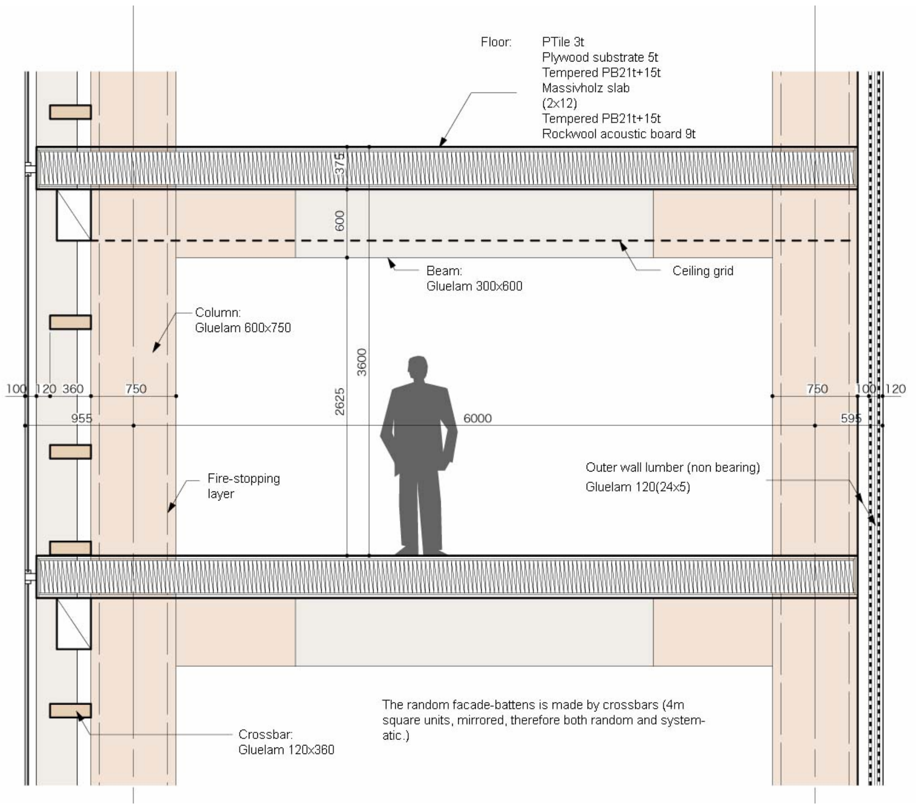


Fig 6.2.2.2.d – Detail: Section; Dimensions in [mm]

6.2.2.3 „Shimouma”

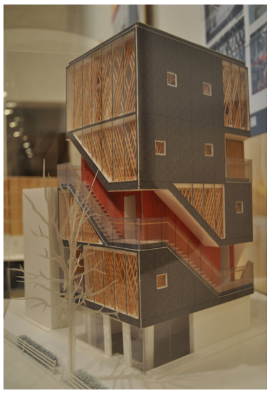


Fig 6.2.2.3.a – Model “Shimouma”

Architectural design:	KOSUGI Eijiro, UTSUMI Aya / KUS
Construction type:	1st floor: RC 2nd floor: timber
Type of use:	Residential
Height:	5 storeys

Structure:
The building’s structure is a timber frame that will be one hour fire-resistant. A pillar and a flat slab, made of laminated lumber support the vertical force, the horizontal wooden lattice of the outer covering bears the horizontal force.
As the building will be used for residential purposes, a soundproof, and vibration experiment of the floor material was conducted.

For a semi-fireproof area, where two hours on the first, and one hour fire resistance for the second - fifth floor, is required, the ground floor (commercial space) is designed to have a RC-construction, the rest up to the 5th floor (residential space) is a timber structure.

For wind and earthquake resistance, the diagonal timber lattice (Lumber 60x75mm; Douglas fir) is placed on the outside of each of the floor’s interspaces.

Column:
150x150mm or 300x300mm square columns (Douglas fir, Cedar) sheet coated with fireproof gypsum board and thermal expansion.

Floors:
Solid wood panels (no specific wood suggested); on the lower surface gypsum board; on the upper surface with self-levelling gypsum.

Roof:
Solid wood panels (no specific wood suggested); the underside is covered with fireproof gypsum board; the top of the roof is covered with noncombustible wooden tiles.

Plans/Details:

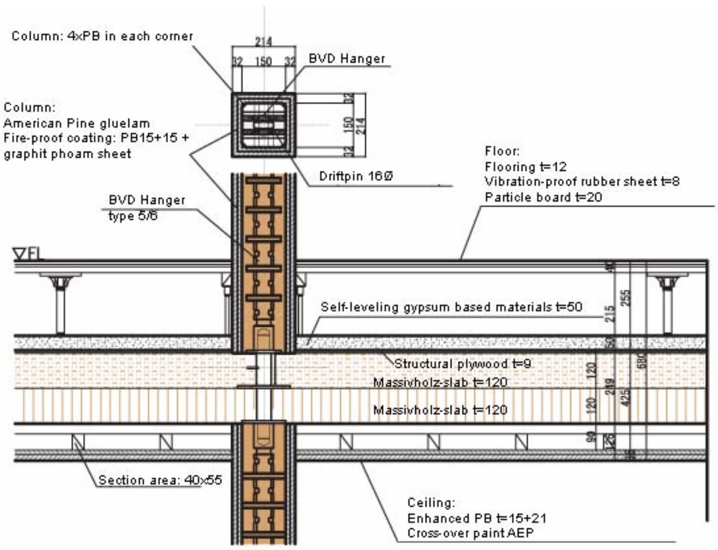


Fig 6.2.2.3.c – Detail fire-resistance; Dimensions in [mm]; “t” stands for “thick”

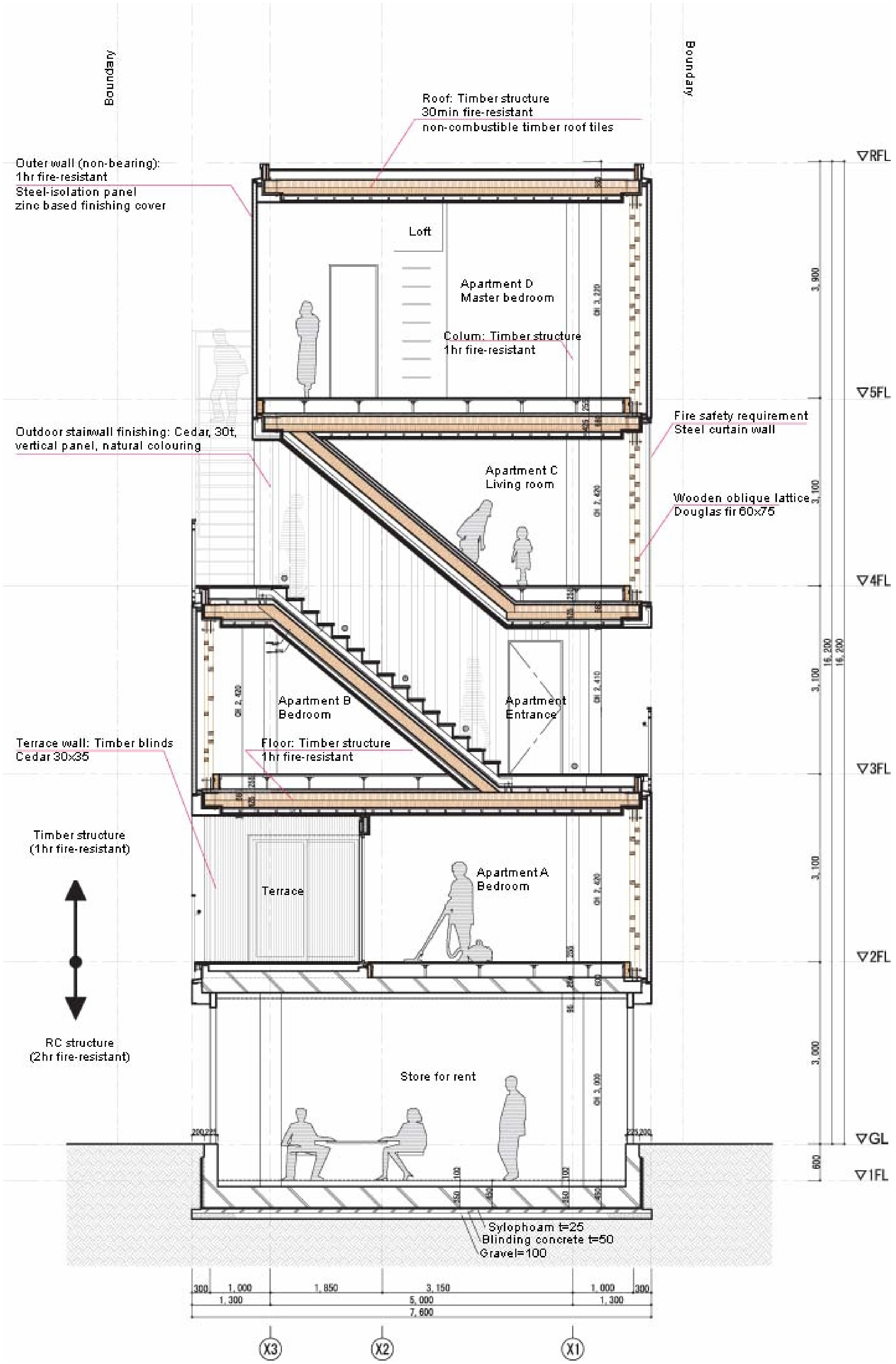


Fig 6.2.2.3.c – Detailed section; Dimensions in [mm]

6.2.2.4 „CUBE”

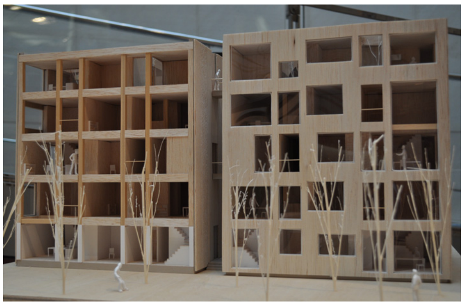


Fig 6.2.2.4.a – Sitemap “CUBE”

Architectural design:	KOSUGI Eijiro, UTSUMI Aya / KUS
Construction type:	Timber
Type of use:	Apartments
Height:	5 storeys

About:
This project tries to supply enough privacy and space but still offer an economical architecture. 10 Apartments in 15m cubes are designed, for a durability of at least 30 years.

Structure:
There are no beams, water power is transmitted with solid wood panel construction. The cubic shape and the stable wooden structure, by employing a span between two columns, increases the structural integrity.

The first two floors are two hours fire resistant, the further floors one hour and therefore fulfil the fire safety regulations.

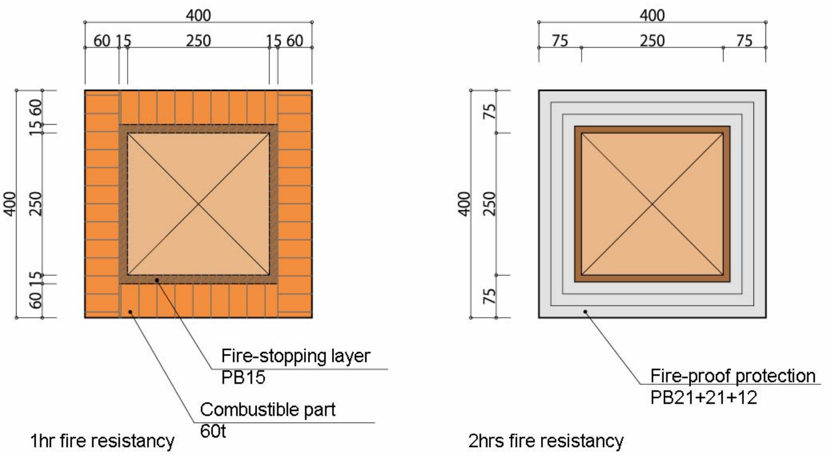


Fig 6.2.2.4.b – Fire-resistance system; Dimensions in [mm]

Plans, Details:

Fig 6.2.2.4.c – First floor; Dimensions in [mm]

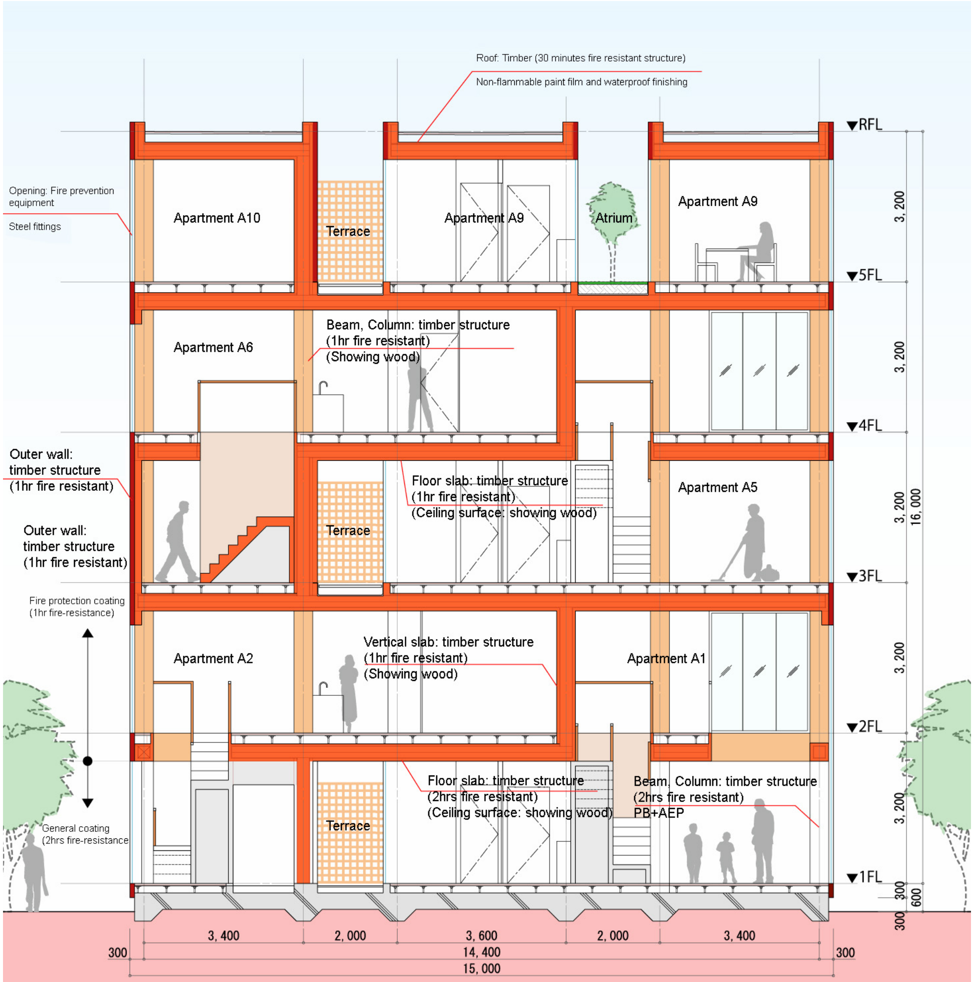


Fig 6.2.2.4.d – Section; Dimensions in [mm]

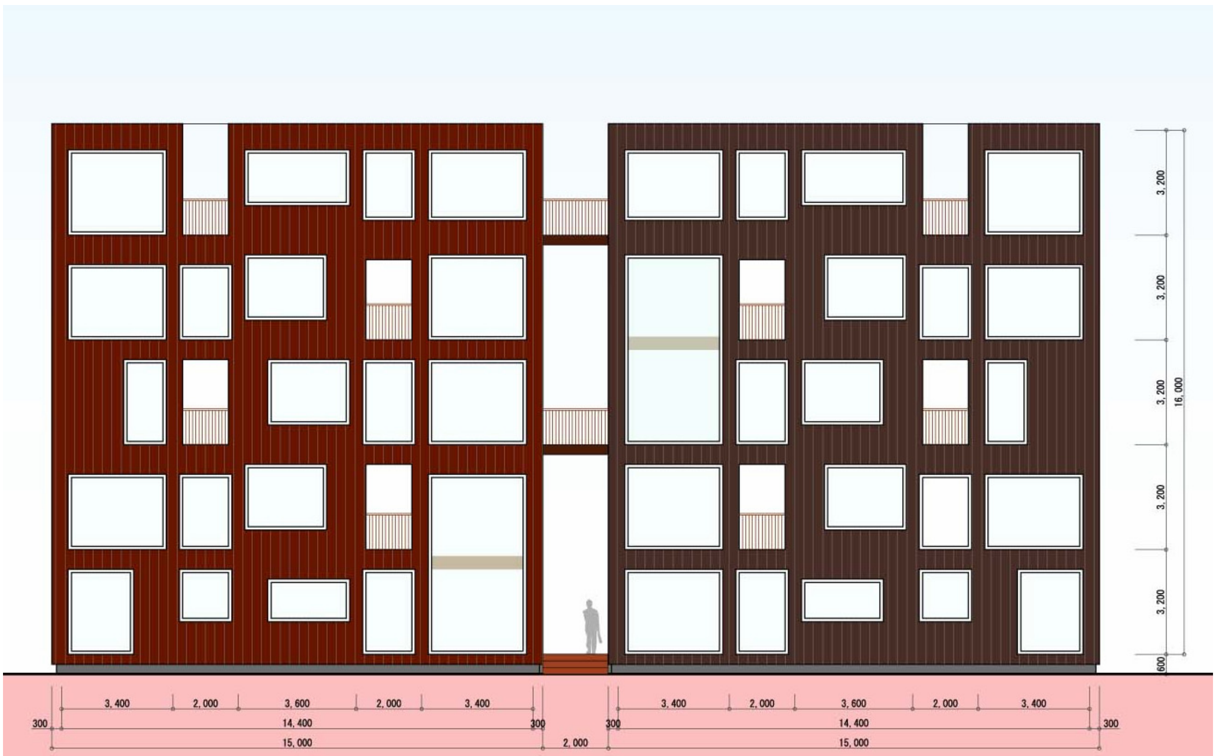


Fig 6.2.2.4.e – Elevation; Dimensions in [mm]

<u>*6.2.2.5 „Solid”*</u>

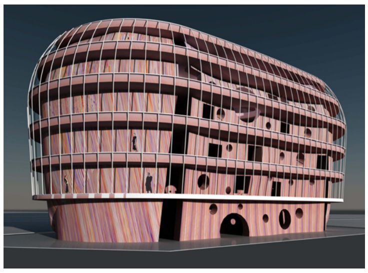


Fig 6.2.2.5.a – Model “Solid”

<u>Architectural design:</u>	KUHARA Hiroshi / KUHARA Architects
<u>Construction type:</u>	Timber
<u>Type of use:</u>	Shops, office
<u>Height:</u>	6 storeys

Introduction, structure:
A tree is softer and can be treated easier than steel or concrete – the process of shaping is much easier. Also, the degree of forming freely extends because of the possibility of adjusting the shape on the site.

By stacking blocks of wood, they become a structure. It is a reasonable construction and also economical. If the development of weather-resistant wood protection technology proceeds, it can also be used as an exterior wall.

With using laminated wood veneers (LVL) it is possible to create 2x2m wooden blocks and use them for stacking and further shaping.

1 – Preparing the blocks
2 – Stacking the blocks
3 – Carving the shape
4 – Boring a hole into the woodblock

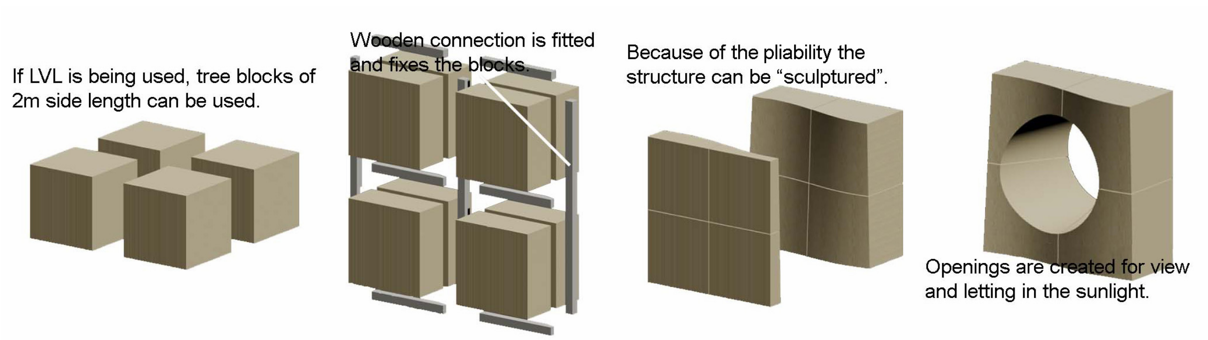


Fig 6.2.2.5.b – Creating a solid wooden wall

Plans/Details:

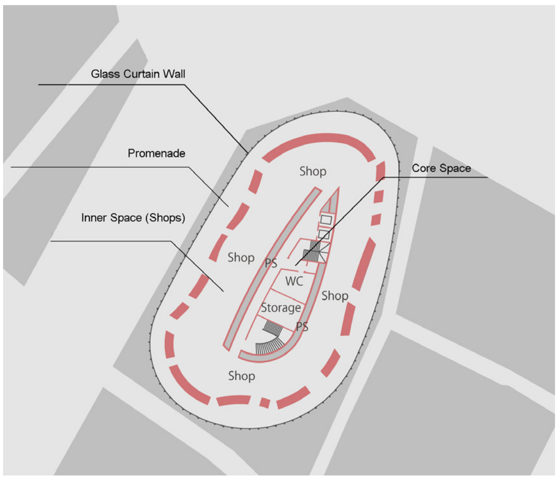


Fig 6.2.2.5.c – 1st Floor

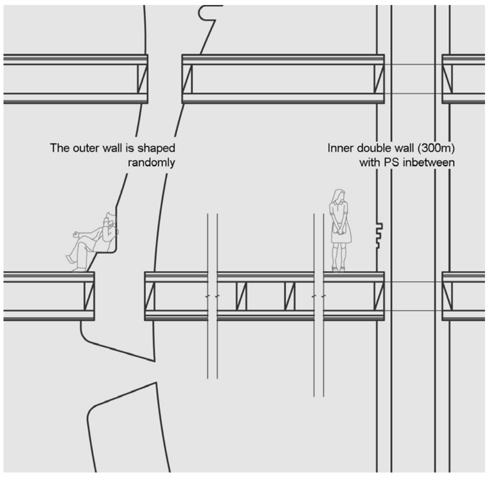


Fig 6.2.2.5.d – Detail: Section

6.2.2.6 „Helix"

Fig 6.2.2.6.a – 3D-Model "Helix"

Architectural design: KASHIMOTO Kohei / Team_KK
Construction type: LVL (Laminated Veneer Lumber)
Type of use: Apartment building
Height: 6 storeys

Introduction:
The buildings measures 21m in diameter and has a height of 30m (6 storeys).
The staircase is in the centre of the cylindrical geometry, and the main vertical movement line and the basic functions such as the elevator, the stairs, and rest rooms are included in the adjoining separate building.

It is a corkscrew shape curved surface made by LVL that rotates from the first floor by 90 degrees toward the rooftop floor. It crosses each other like the reticulation because the spiral direction is a reverse rotation (inside and outside).

Structure:
In general the use of rectangular or circular shaped beams and columns are used. But, with a rotary cutting machine another main processing method exists – Veneer can be shaved to thin boards while rotating the logs. Stacking and gluing them creates LVL.

Generally, plywood and LVL might be used as a plane material, but it is also easy to produce curved surfaces. The fibres of the veneer face the same direction, and therefore allow reasonable usage.

In this project, LVL was processed to cylindrical condition shaping a spiral form, to show one possibility of the "new woodwork", proposing the construction which utilizes "curved surface LVL".

Plans/Details:

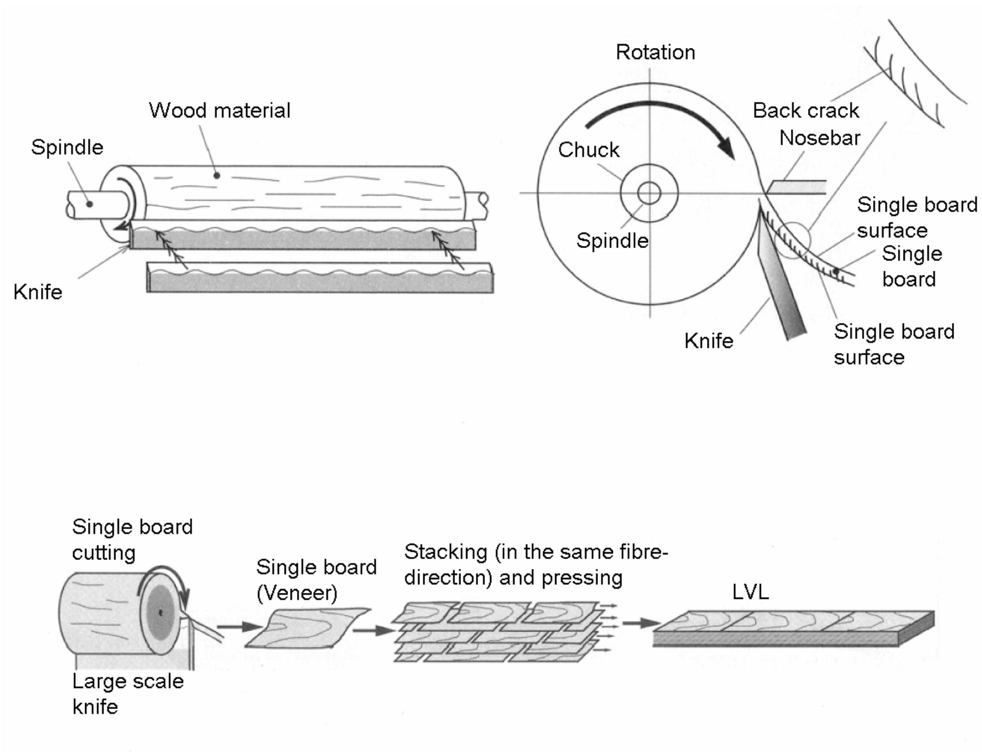


Fig 6.2.2.6.b – Process of creating LVL

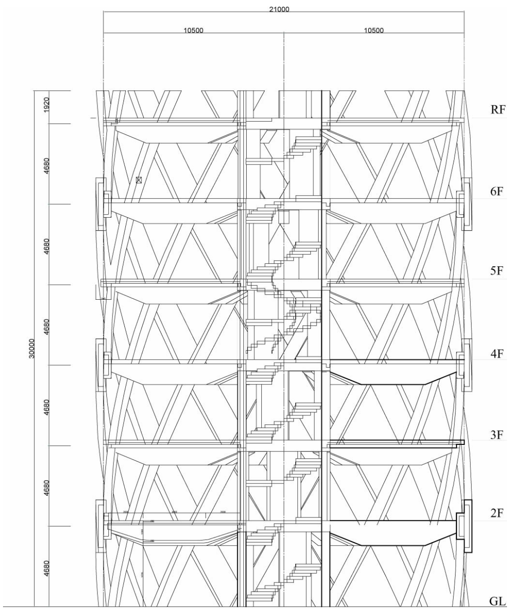


Fig 6.2.2.6.c – Section; Dimensions in [mm]

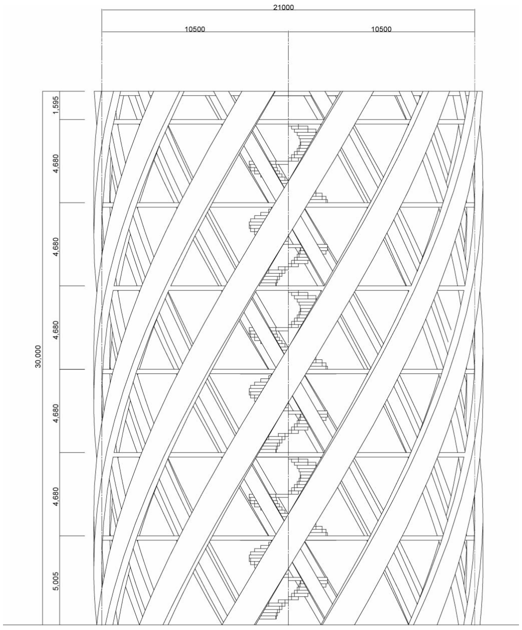


Fig 6.2.2.6.d – Elevation; Dimensions in [mm]

6.2.2.7 „Lattice”

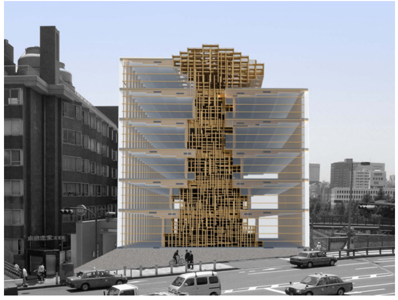


Fig 6.2.2.7.a – 3D-Rendering “Lattice”

Architectural design: YAGI Atsushi / Atsushi Yagi Architect & Associates
Construction type: Timber
Type of use: Shopping / Office
Height: 6 storeys

Introduction:
This project is composed of frame structures with shear walls, beams, lattices and a random surface.

Structure:
A solid lattice of wood forms the centre (core zone), which is the centre of construction of a building. The centre column, staircases and terraces provide a core zone that was formed by the three-dimensional random lattice, garden light, such as where toilets are located.

Because horizontal forces are borne by the core zone, there is no need for a structural wall (only the pillars are arranged). Therefore universal and open space is possible.
Small bundles of wood create the floor and beams.

Columns: 135×135mm
Beams: 200×200mm
Grating: 300×100mm
Floor: 105mm×four small sectioned laminated timber beams

Plans/Details:

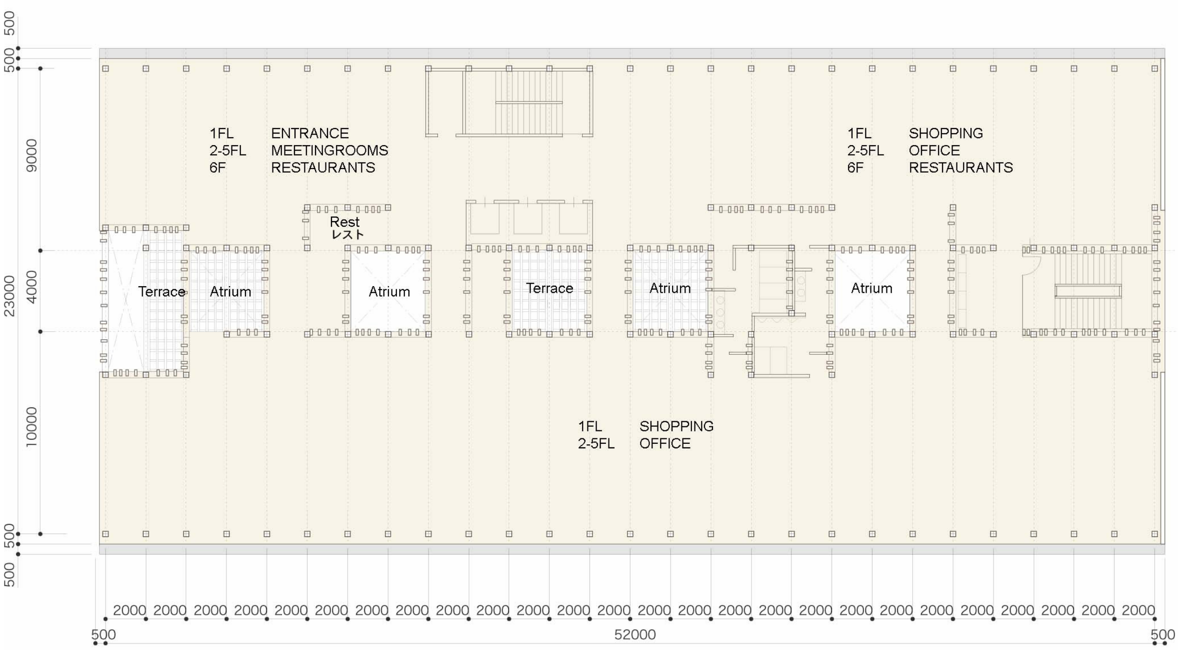


Fig 6.2.2.7.b – Floor plan; Dimensions in [mm]

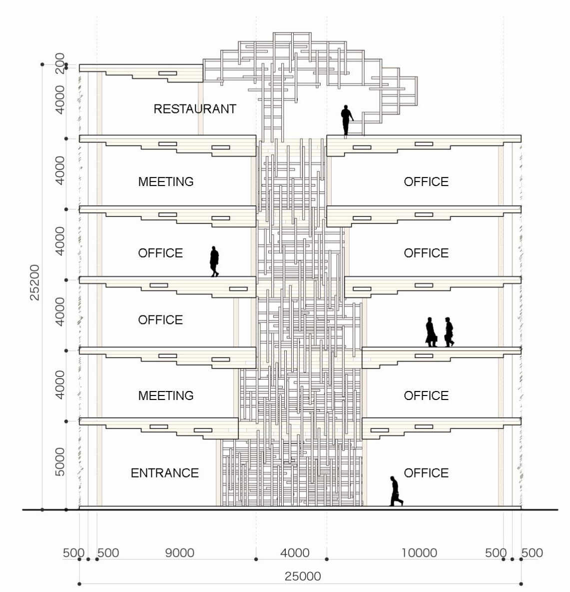


Fig 6.2.2.7.c – Section; Dimensions in [mm]

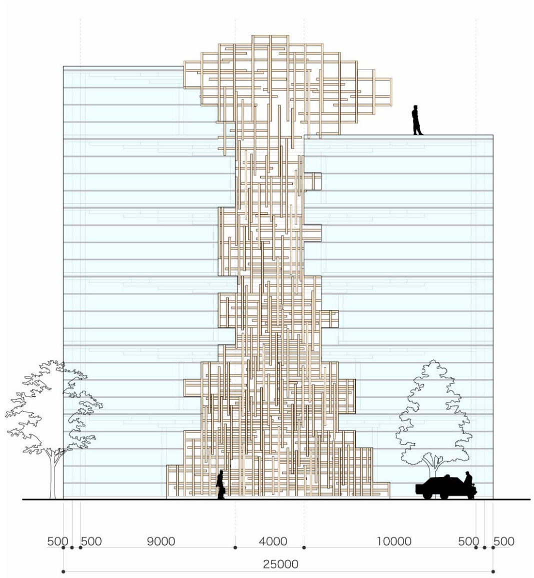


Fig 6.2.2.7.d – Elevation; Dimensions in [mm]

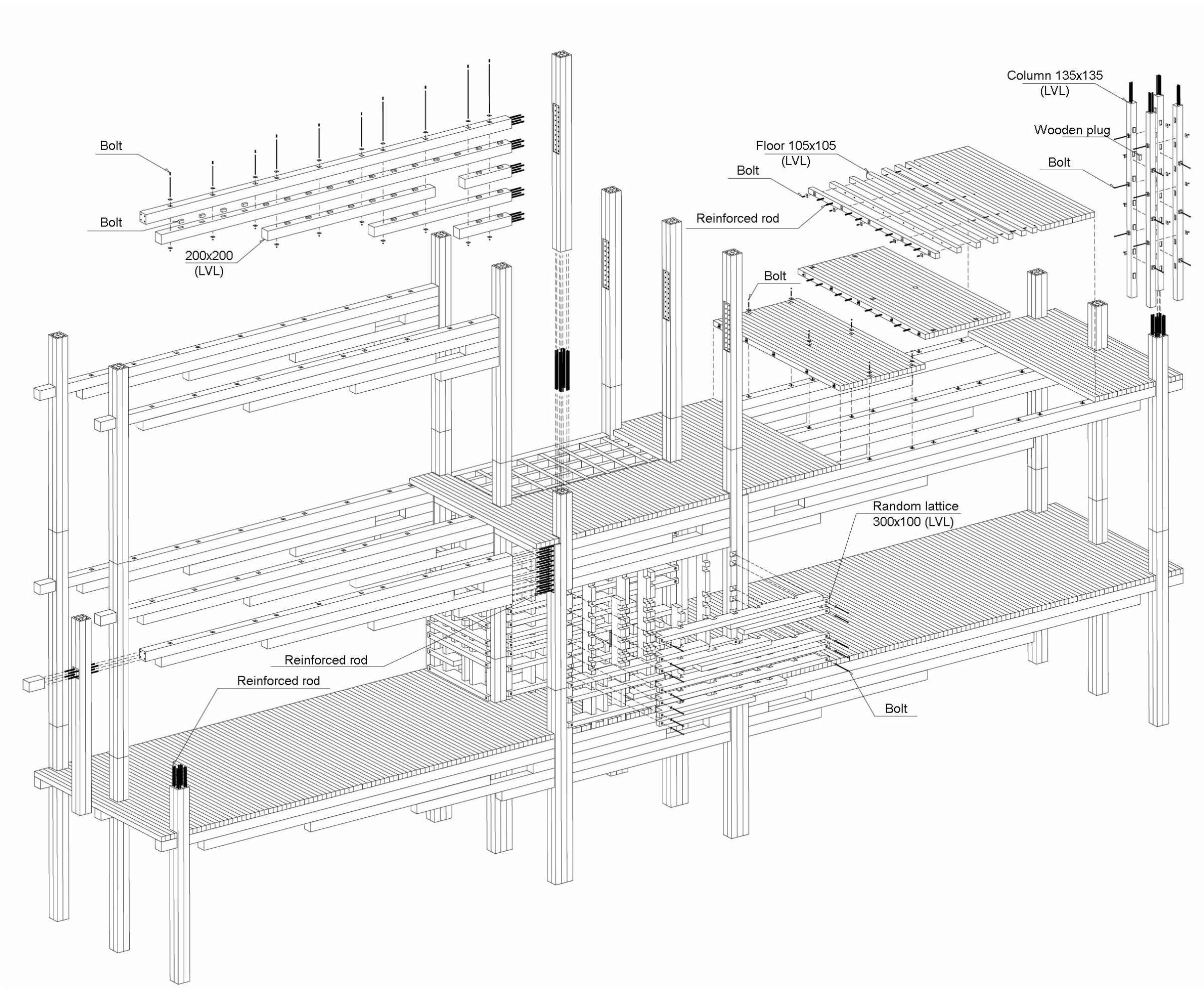


Fig 6.2.2.7.e – Stacking system; Dimensions in [mm]

7. MODE GAKUEN COCOON TOWER, TOKYO – JAPAN: A CASE STUDY

7.1 Introduction

7.1.1 About the Research

The strict safety regulations (in Japan as well as in Europe) allow only timber constructions of 4-5 storeys.
But, what if the fire resistivity can be guaranteed?
Safety can be proven to be as “good” as when using concrete and steel?
What would a high-rise building look like when constructed mainly in timber?

As a case study the Mode Gakuen Cocoon Tower, located in Tokyo, Japan, was chosen. Based on a table of forces for each floor level provided by the structural office that was involved in the development – ARUP – the needed timber profiles for the main structural parts of the building were calculated and chosen.
With the new dimensions having the same axes as the steel structure, it is possible to compare the usable space of the classrooms and lounges as well as the façade composition.

7.1.2 The Mode Gakuen Cocoon Tower

“*Mode Gakuen Cocoon Tower*” (モード学園コクーンタワー) is an educational facility located in Nishi-Shinjuku, Tokyo that accommodates three special educational establishments: Tokyo Mode Gakuen (Fashion vocational school), HAL Tokyo (Special Technology & Design College) and Shuto Ikô (Medical College).

More than 150 proposals from major construction companies had been submitted in 2004, including designs by Norman Foster and Jean Novel with only one condition which was that the project not be rectangular. And in fact, the winning design by “Tange Associates” was shaped like a cocoon. About this, Tange Associates said that ‘*the building’s innovative shape and cutting edge façade embodies our unique ‘Cocoon’ concept. Embraced within this incubating form, students are inspired to create, grow and transform*’[20].

Construction of the Tower began in May 2006 and in October 2008 the 204 metre tall tower was completed. It is the second tallest educational building in the world and the 17th-tallest building in Tokyo. The “vertical campus” accommodates approximately 10 000 students from the three schools.
Although it looks very complex, the floor plans are in fact simply shaped.
Three rectangular classrooms rotated by 120° surround an inner core consisting of a staircase, elevators and a support shaft. These rectangular rooms are arranged in a curvilinear form from the 1st to the 50th floor.

Three-storey student lounges are located between the classes, at every third floor, facing east, southwest and northwest.

Fig 7.1.a – Position in Shinjuku, ⇑N

[20] http://corporate.emporis.com/userdata/press/pdf/achicentral11.2.2009.pdf quoted according to Tange Associates, 2008

White aluminium spanning around a dark blue glass exterior like a web and being extruded the façade is protected against dirt and rain marks; also this design emphasises the Cocoon-Idea and gave the project it’s final name.

Fig 7.1.b+c – Mode Gakuen Cocoon Tower

7.1.3 The structure

The superstructure is of steel construction with concrete filled tube (CFT) columns; the basement is a composite structure of steel and reinforced concrete with concrete shear walls.

The main structure consists of an inner core (incorporating the elevators, staircases and supply shafts), three rigid diagrid frames and a top roof structure.

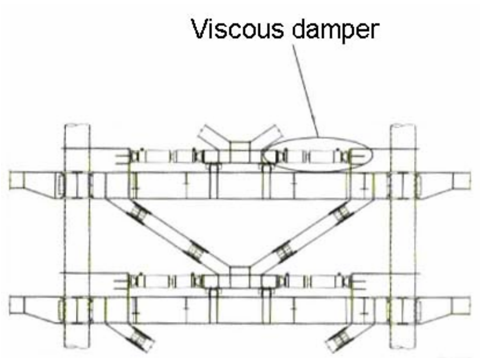


Fig 7.1.d – Viscous damper (15th ~39th floors)

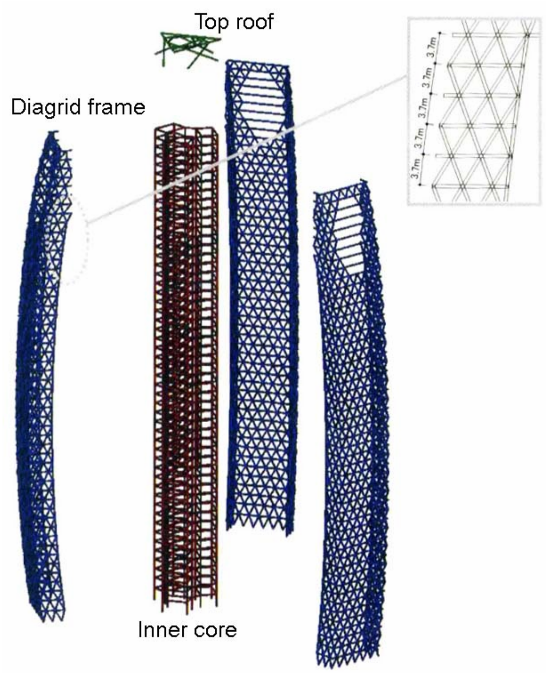


Fig 7.1.e – Structural axonometry

7.1.3.1 Inner core

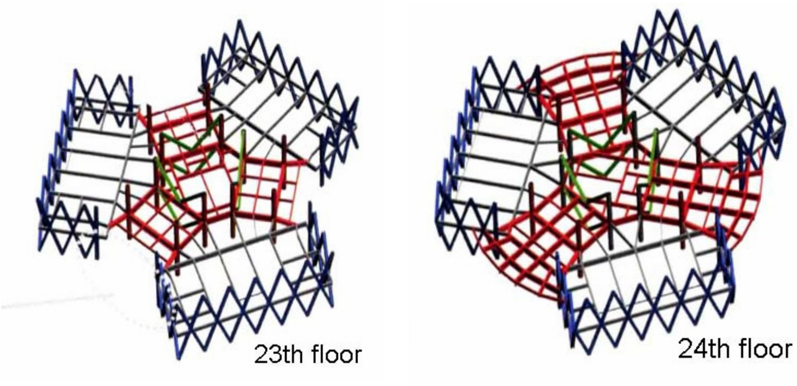
The inner core exists of 12 vertical CFT columns.
The building has quite large storey drifts in the middle storeys, due to rotation of the diagrid frames as they are only connected rigidly with each other at the top.
Therefore, to absorb seismic energy, the core is provided with six viscous dampers on each floor from the 15th to the 39th floor.

7.1.3.2 Diagrid Frames

They are 24m wide with intersections every 4 metres on each floor. In a vertical direction, the structure curves elliptically. The uniform height of each floor level is 3.70m, so the diagonal columns intersect at the same angle on each floor.
The diagonal columns have a typical I-section (400m wide/400m deep), serving the maximum of internal space possible.

7.1.3.3 Floor beams in classroom areas

They do not only support floor loads, but also connect the diagrid frames with the inner core horizontally and prevent buckling of the diagrid frames.



As the ceilings expose floor beams in most of the classrooms, the arrangement of the beams shows a parallel beam structure rigidly connected to the intersection of the diagrid frames that “bends” at the beam above the partition wall between classroom and corridor. The depth of the parallel beams could be 500mm (at a maximum span of 16m).

Fig 7.1.f – Beam arrangement

7.1.3.4 Wind-resistant beams in student lounges

The student lounges are three storeys high with a maximum width of almost 20m. Double-arched Vierendeel truss beams on each floor level, hung from the beams above, carry the weight of the glazing panel façade and resist wind pressure.

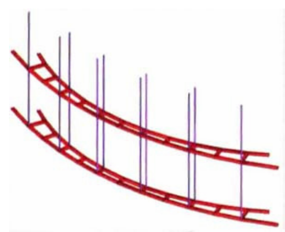
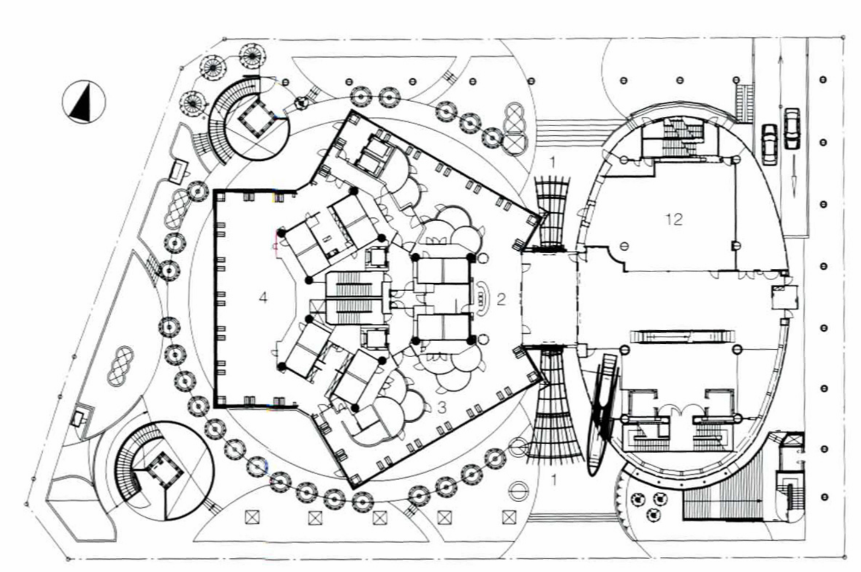


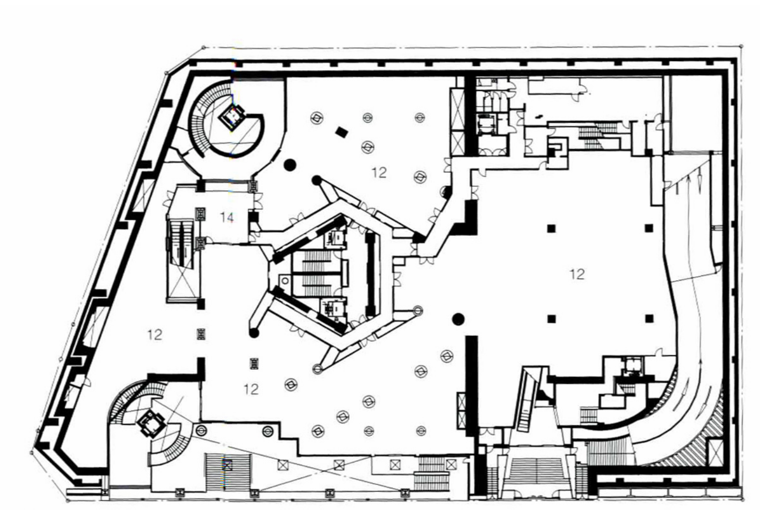
Fig 7.1.g – Wind resistant beams

7.1.3.5 Retractable roof and exterior cleaning

A 10m square helicopter landing site is provided by designing a retractable roof (in order not to “destroy” the shape and appearance of the building itself by just cutting off a flat roof).
Half of the floor is attached to a retractable roof which uses hydraulic jacks to open the roof, which takes about 8min. A gondola hanger, moving around on trails arranged in a Y-shape, is installed below the hovering space.

7.1.3.6 Plans





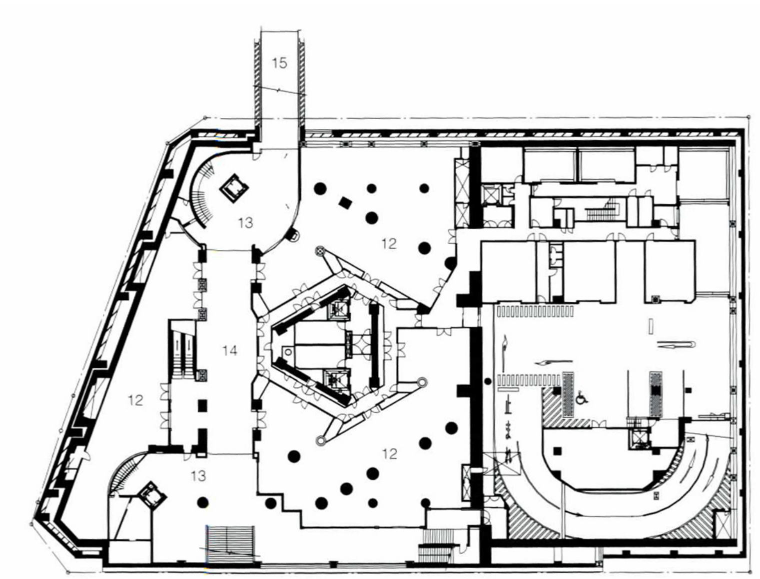


Fig 7.1.h – Floor plans (from top: -1st, -2nd, -3rd floor)

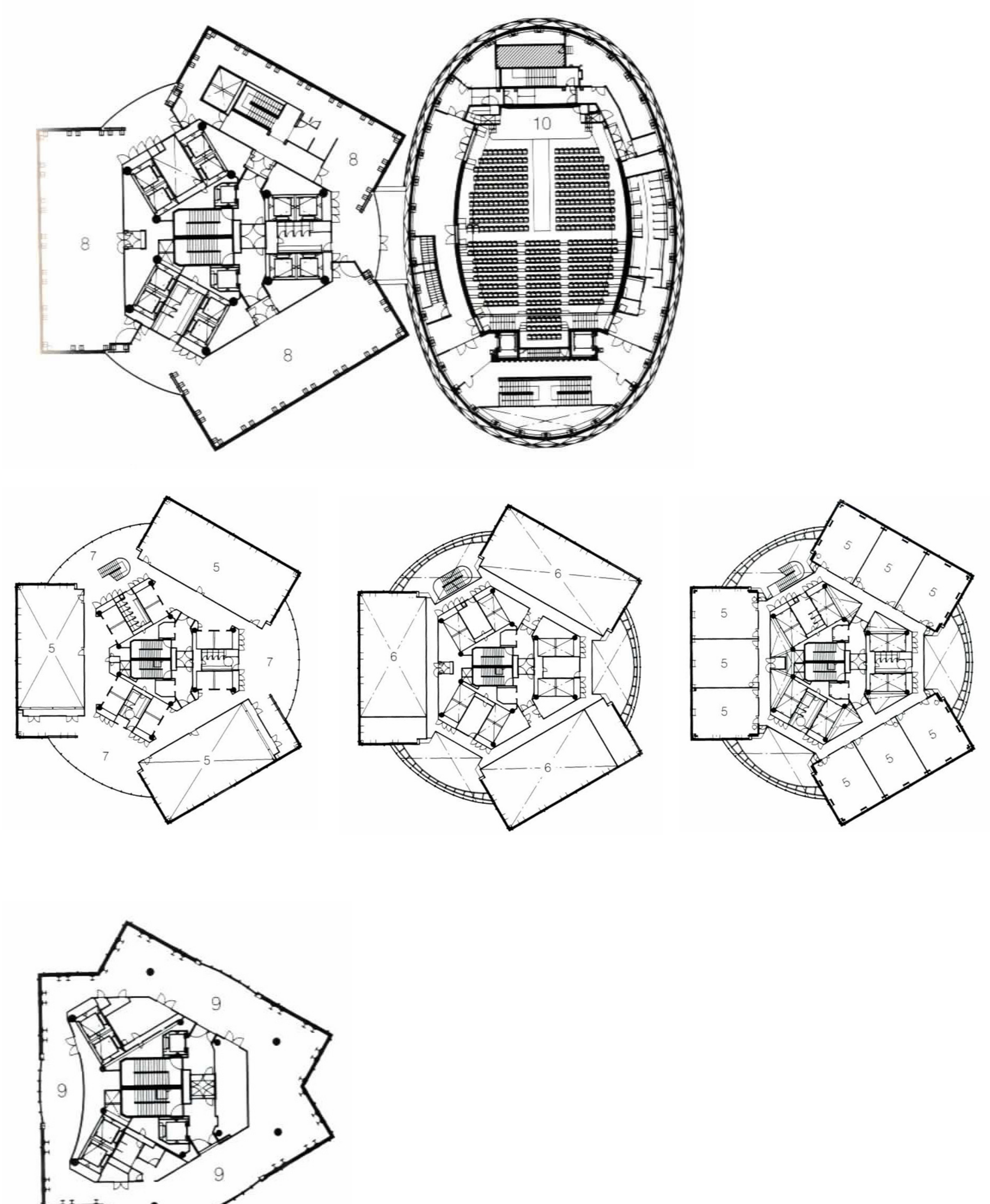


Fig 7.1.i – Floor plans (from top, left to right: 5th, 21st, 22nd, 23rd, 50th floor)

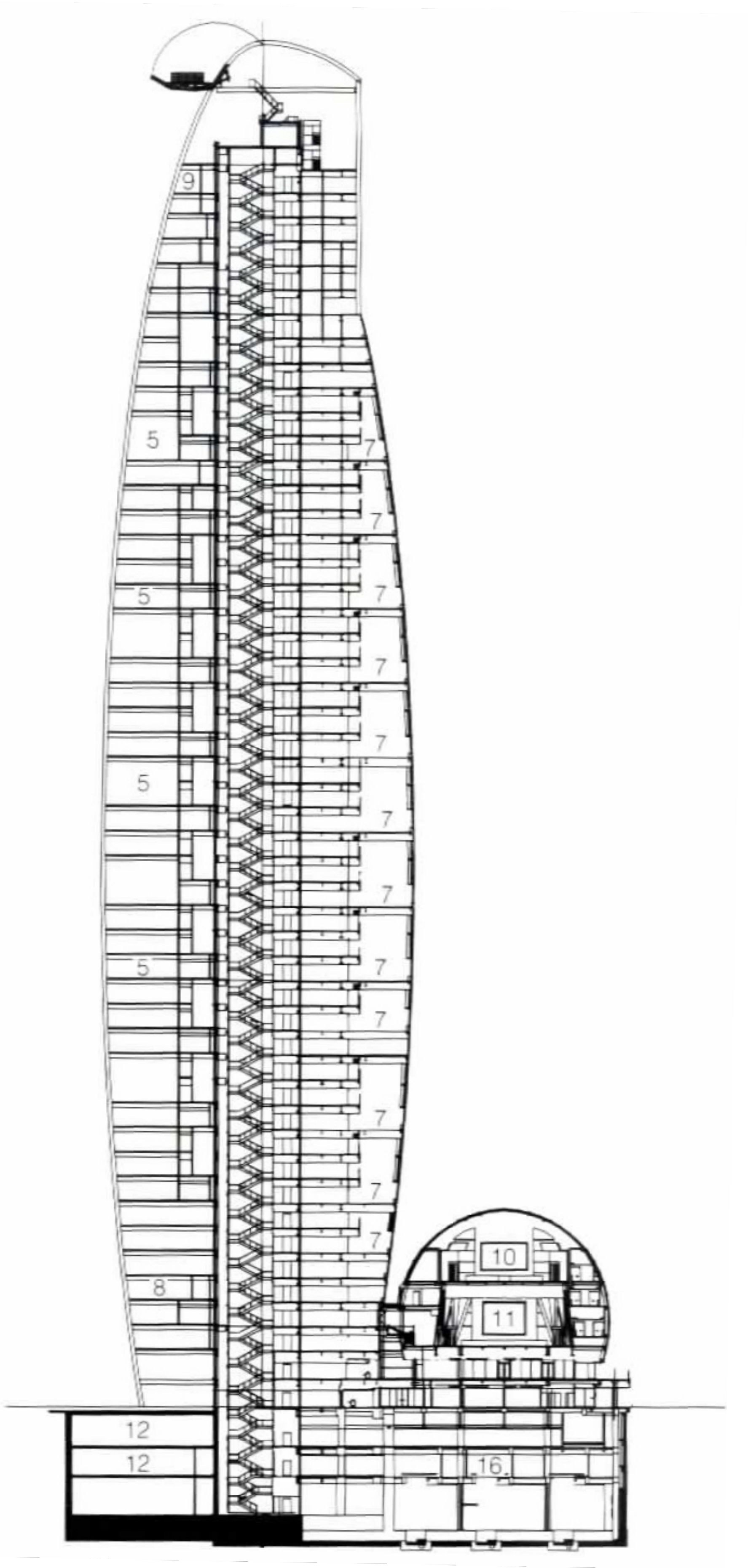


Fig 7.1.j – Section

7.2 The Case Study "Wood Tower"

7.2.1 Choosing the "right" dimensions

The choice of the building was made because of it's original rigid joint structure – a good base to use timber as a construction material.

The main structure – consisting of an inner core (incorporating elevators, staircases and supply shafts), three rigid diagrid frames and a top roof structure – was redesigned using timber. With the new dimensions that have the same axes as the steel structure, it is possible to compare the usable space of the class rooms and lounges as well as the façade composition.

Fig. 7.2.a – A wooden tower in Shinjuku?

Each section area first was calculated using a table of forces for each floor level regarding earthquake security. Then the results were calculated considering fire safety. Finally, the profile dimensions were "chosen".

"Chosen" considering architectural and aesthetic aspects:

A) When working with steel, it is possible to keep the same elevation by reducing the thickness of the members, but still showing the same elevation area on each and every floor. This offers a smooth and symmetrical surface. When using timber on the other hand, the elevation will change at some point to keep a certain sectional area. In this study, the aim was to offer a graduate transition between the different section profiles.

B) Due to the huge dimensions at the lower floors it was necessary to keep the width of the members as slim as possible to secure enough room for a smooth ambience.

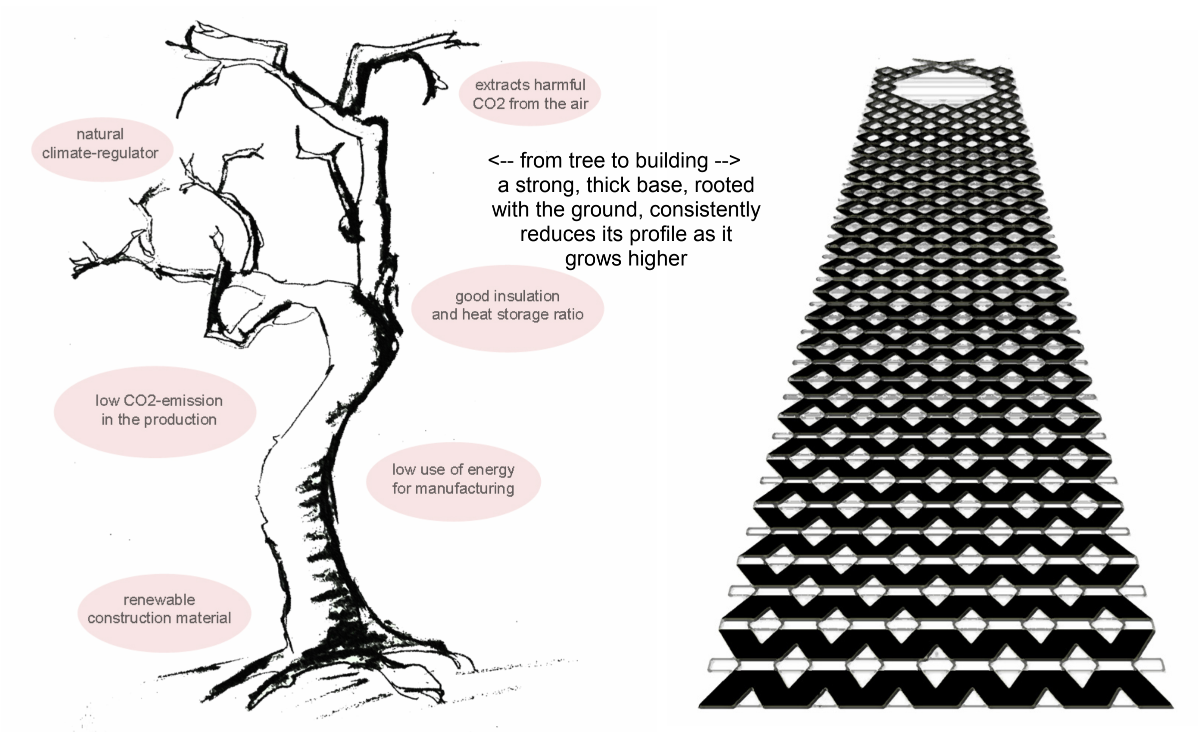


Fig. 7.2.b – From tree to building

Due to rotation of the diagrid frames, as they are only connected rigidly with each other at the top, the building has quite large storey drifts in the middle levels. Therefore, to absorb seismic energy, the core is provided with six viscous dampers on each floor from the 15th to the 39th floor. The calculations for the timber structure only apply when this damper system is in use!

Although the members of the first floors have huge dimensions, the upper floors (which incorporate the class rooms and lounges) have almost the same profile dimensions like the steel structure. To keep the dimensions of the beams as small as possible, six columns have been added to shorten the span widths.

7.2.2 Details about fire safety regulations

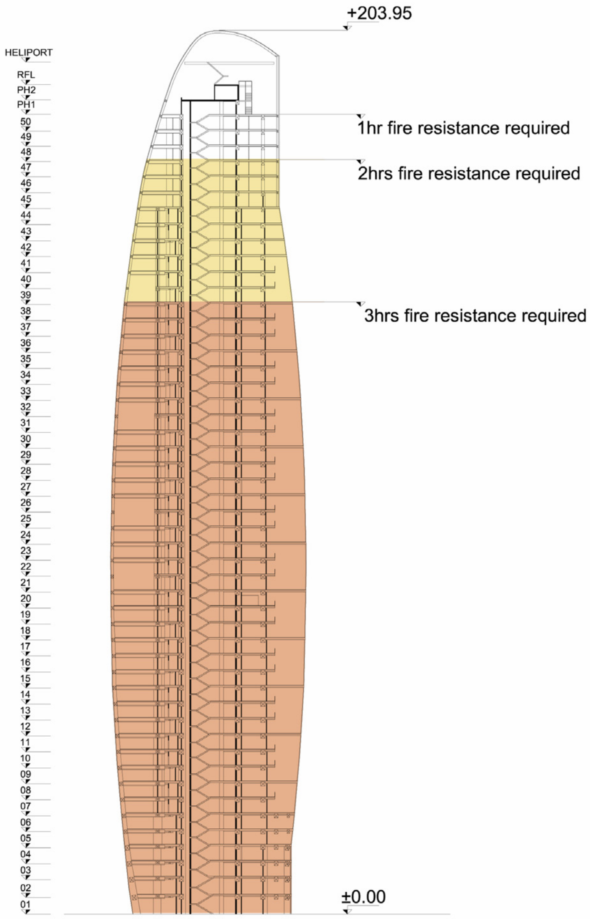


Fig. 7.2.c – Fire safety requirements in high-rise buildings

Fire safety in high-rise buildings

Depending on the floors the fire resistance has to ensure:

1hr fire resistance:
4 floors down from the top floor

2hrs fire resistance:
from 5th - 14th floor from the top floor

3hrs fire resistance:
for the rest of the building

The core (stairs)

The staircase is a fire compartment, therefore it has to be constructed using a fire proof cladding system (gypsum board, 21mm thick).

For 1hr fire resistance:
2x gypsum board cladding

For 2hrs fire resistance:
3x gypsum board cladding

For 3hrs fire resistance:
4x gypsum board cladding

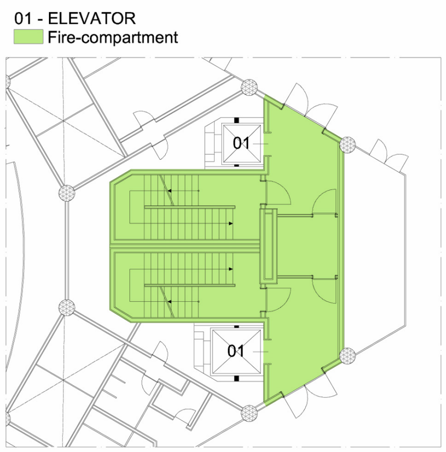


Fig. 7.2.d – Fire compartment

Columns and diagrid frames

The same demands regarding the fire resistance hours apply - with the following dimensions to add (added to three sides if square; around the showing surface if circular):

For 1hr fire resistance:
bearing section area + 60mm

By Japanese law this cladding system is allowed and used.

For 2hrs fire resistance:
bearing section area + 120mm

For 3hrs fire resistance:
bearing section area + 180mm

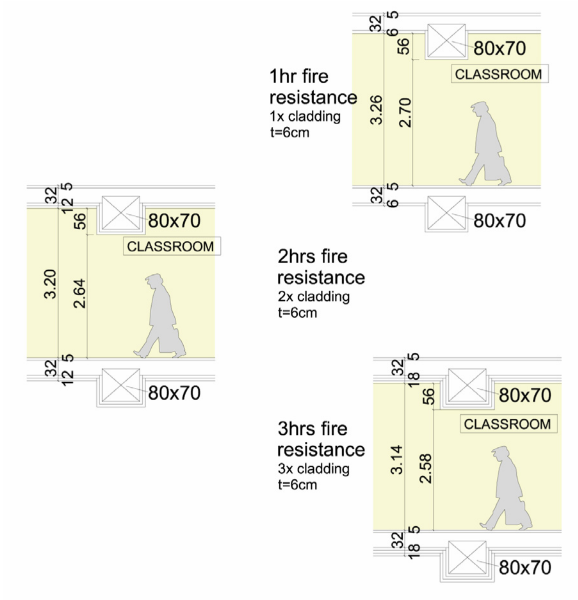


Fig. 7.2.e – Columns and beams – fire safety requirements; “t” = “thick”; Dimensions in [cm]

This kind of 2 and 3 hours fire resistance constructions are not yet allowed by law. Researches and experiments with this system showed, that it can be possible to ensure up to 3 hours fire resistance if timber were used.

7.2.3 Calculations to use timber as the main structural material

The main structure will be converted into timber:

7.2.3.1 – 12 main columns of the centre core
7.2.3.2 – Diagrid frame bordering the classrooms and lounges
7.2.3.3 – Beams (SG8) of the diagrid frame structure
7.2.3.4 – Inner main beams (SG10) of the diagrid frame structural part
7.2.3.5 – Inner sub beams (SG9) of the diagrid frame structural part

The calculations are based on a table of forces for each floor level, provided by ARUP, the structural office that was involved in the original project.
There are two kinds of data: long-term stress and earthquake stress. The long-term data was chosen, if the earthquake data was not more than twice as high as the long-term data.

7.2.3.1 Columns

First, the long-term data was the basis for calculating the dimensions of the columns. The second step considers fire-safety: the remaining area section after a fire.

FLOOR LEVEL	LONG-TERM Nmin [kN]	EARTHQUAKE Nmin [kN]
01	22 159	41 433
05	20 347	39 371
11	18 301	37 597
18	15 034	31 066
25	11 310	22 051
32	7 694	13 452
39	4 899	9 422
46	2 695	5 392

With $\boxed{A = \frac{N}{\sigma_c}}$ (A = section area; N = impact force; σ_c= stress) and by means of $L_{\sigma c}$ = *70kg/cm²* (resp. $S_{\sigma c}$ = *140kg/cm²* for after the fire) the required areas can be calculated as followed:

a) Floor 01

Nmin = 22159 [kN] = 2200 [tf]

1 - $A = \frac{2200 \times 10^3}{70} = \underline{\underline{31428{,}57 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 200cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{\varnothing = 164cm}}$

2 - $A = \frac{2200 \times 10^3}{140} = \underline{\underline{15714{,}29 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 142cm}}$

$\boxed{\text{Chosen profile FL01 – FL04: } \underline{\underline{\varnothing = 200cm}}}$

b) Floor 05

Nmin = 20347 [kN] = 2035 [tf]

1 - $A = \frac{2035 \times 10^3}{70} = \underline{\underline{29071{,}43 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 195cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{\varnothing = 159cm}}$

2 - $A = \frac{2035 \times 10^3}{140} = \underline{\underline{14535{,}71 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 137cm}}$

$\boxed{\text{Chosen profile FL05 – FL10: } \underline{\underline{\varnothing = 195cm}}}$

c) Floor 11

Nmin = 18301 [kN] = 1830 [tf]

1 - $A = \frac{1830 \times 10^3}{70} = \underline{\underline{26142{,}86 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 185cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{\varnothing = 149cm}}$

2 - $A = \frac{1830 \times 10^3}{140} = \underline{\underline{13071{,}43 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 130cm}}$

$\boxed{\text{Chosen profile FL11 – FL17: } \underline{\underline{\varnothing = 185cm}}}$

d) Floor 18

Nmin = 15034 [kN] = 1504 [tf]

1 - $A = \frac{1504 \times 10^3}{70} = \underline{\underline{21485{,}71 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 165cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{\varnothing = 129cm}}$

2 - $A = \frac{1504 \times 10^3}{140} = \underline{\underline{10742{,}86 cm^2}}$ => Profile: $\underline{\underline{\varnothing = 117cm}}$

$\boxed{\text{Chosen profile FL18 – FL24: } \underline{\underline{\varnothing = 165cm}}}$

e) Floor 25

Nmin = 11310 [kN] = 1131 [tf]

$1 - A = \frac{1131 \times 10^3}{70} = \underline{\underline{16157{,}14cm^2}}$ => Profile: $\underline{\underline{Ø = 145cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{Ø = 109cm}}$

$2 - A = \frac{1131 \times 10^3}{140} = \underline{\underline{8078{,}57cm^2}}$ => Profile: $\underline{\underline{Ø = 102cm}}$

$\boxed{\text{Chosen profile FL25 – FL31: } \underline{\underline{Ø = 145cm}}}$

f) Floor 32

Nmin = 7694 [kN] = 770 [tf]

$1 - A = \frac{770 \times 10^3}{70} = \underline{\underline{11000{,}00cm^2}}$ => Profile: $\underline{\underline{Ø = 120cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile: $\underline{\underline{Ø = 84cm}}$

$2 - A = \frac{770 \times 10^3}{140} = \underline{\underline{5500{,}00cm^2}}$ => Profile: $\underline{\underline{Ø = 84cm}}$

$\boxed{\text{Chosen profile FL32 – FL38: } \underline{\underline{Ø = 120cm}}}$

g) Floor 39

Nmin = 4899 [kN] = 490 [tf]

$1 - A = \frac{490 \times 10^3}{70} = \underline{\underline{7000{,}00cm^2}}$ => Profile: $\underline{\underline{Ø = 95cm}}$

2hrs fire resistance requires 120mm cover => Remaining profile: $\underline{\underline{Ø = 71cm}}$

$2 - A = \frac{490 \times 10^3}{140} = \underline{\underline{3500{,}00cm^2}}$ => Profile: $\underline{\underline{Ø = 67cm}}$

$\boxed{\text{Chosen profile FL39 – FL45: } \underline{\underline{Ø = 95cm}}}$

h) Floor 46

Nmin = 2695 [kN] = 270 [tf]

$1 - A = \frac{270 \times 10^3}{70} = \underline{\underline{3857{,}14cm^2}}$ => Profile: $\underline{\underline{Ø = 70cm}}$

2hrs fire resistance requires 120mm cover => Remaining profile: $\underline{\underline{Ø = 46cm}}$

$2 - A = \frac{270 \times 10^3}{140} = \underline{\underline{1928{,}57cm^2}}$ => Profile: $\underline{\underline{Ø = 50cm}}$

$\boxed{\text{Chosen profile FL46 – FL51: } \underline{\underline{Ø = 75cm}}}$

7.2.3.2 Diagrid frame

The earthquake data was the basis for calculating the dimensions of the diagrid frames as their value is more than four times higher than the long-term data. The second step uses the long-term data, considering fire-safety: the remaining area section after a fire.

FLOOR LEVEL	LONG-TERM Nmin [kN]	EARTHQUAKE Nmin [kN]
01	-10 982	-38 756
02	-10 623	-35 023
03	-7 830	-28 930
04	-7 785	-25 567
06	-6 530	-20 129
11	-4 069	-13 948
18	-2 735	-9 807
25	-1 804	-6 005
33	-1 186	-4 432
45	-774	-3 618
46	-667	-2 826

First with $\boxed{A = \frac{N}{\sigma_c}}$ and by means of $S_{\sigma c}$ *= 140kg/cm²* the required areas can be calculated as followed:

a) Floor 01

Nmin = 38756 [kN] = 3880 [tf]

1 - $A = \frac{3880 \times 10^3}{140} = \underline{\underline{27714{,}29cm^2}}$ => Chosen Profile: $\underline{\underline{170 \times 165cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{17286cm^2}}$

Nmin = 10982 [kN] = 1100 [tf]

2 - $A = \frac{1100 \times 10^3}{140} = \underline{\underline{7857{,}14cm^2}}$ => $\boxed{\text{Chosen profile FL01: } \underline{170 \times 165cm}}$

b) Floor 02

Nmin = 35023 [kN] = 3500 [tf]

1 - $A = \frac{3500 \times 10^3}{140} = \underline{\underline{25000{,}00cm^2}}$ => Chosen Profile: $\underline{\underline{170 \times 150cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{15276cm^2}}$

Nmin = 10623 [kN] = 1065 [tf]

2 - $A = \frac{1065 \times 10^3}{140} = \underline{\underline{7607{,}14cm^2}}$ => $\boxed{\text{Chosen profile FL02: } \underline{170 \times 150cm}}$

c) Floor 03

Nmin = 28930 [kN] = 2890 [tf]

1 - $A = \frac{2890 \times 10^3}{140} = \underline{\underline{20642{,}86cm^2}}$ => Chosen Profile: $\underline{\underline{170 \times 125cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{11926cm^2}}$

Nmin = 7830 [kN] = 783 [tf]

2 - $A = \frac{783 \times 10^3}{140} = \underline{\underline{5592{,}86cm^2}}$ => $\boxed{\text{Chosen profile FL03: } \underline{\underline{170 \times 125cm}}}$

d) Floor 04

Nmin = 25567 [kN] = 2557 [tf]

1 - $A = \frac{2557 \times 10^3}{140} = \underline{\underline{18264{,}29cm^2}}$ => Chosen Profile: $\underline{\underline{170 \times 110cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{9916cm^2}}$

Nmin = 7785 [kN] = 779 [tf]

2 - $A = \frac{779 \times 10^3}{140} = \underline{\underline{5564{,}29cm^2}}$ => $\boxed{\text{Chosen profile FL04: } \underline{\underline{170 \times 110cm}}}$

e) Floor 06

Nmin = 20129 [kN] = 2013 [tf]

1 - $A = \frac{2013 \times 10^3}{140} = \underline{\underline{14378{,}57cm^2}}$ => Chosen Profile: $\underline{\underline{150 \times 95cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{6726cm^2}}$

Nmin = 6530 [kN] = 653 [tf]

2 - $A = \frac{653 \times 10^3}{140} = \underline{\underline{4664{,}29cm^2}}$ => $\boxed{\text{Chosen profile FL05 - FL10: } \underline{\underline{150 \times 95cm}}}$

f) Floor 11

Nmin = 1394843 [kN] = 1395 [tf]

1 - $A = \frac{1395 \times 10^3}{140} = \underline{\underline{9964{,}29cm^2}}$ => Chosen Profile: $\underline{\underline{130 \times 80cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{4136cm^2}}$

Nmin = 4069 [kN] = 407 [tf]

2 - $A = \frac{407 \times 10^3}{140} = \underline{\underline{2907{,}14cm^2}}$ => $\boxed{\text{Chosen profile FL11 – FL17: } \underline{\underline{130 \times 80cm}}}$

g) Floor 18

Nmin = 9807 [kN] = 981 [tf]

$1 - A = \frac{981 \times 10^3}{140} = \underline{\underline{7007,14cm^2}}$ => Chosen Profile: 110×60cm

3hrs fire resistance requires 180mm cover => Remaining profile area: 1776cm²

Nmin = 2735 [kN] = 274 [tf]

$2 - A = \frac{274 \times 10^3}{140} = \underline{\underline{1957,14cm^2}}$ => Chosen profile FL18 – FL24: 110×60cm

h) Floor 25

Nmin = 6005 [kN] = 601 [tf]

$1 - A = \frac{601 \times 10^3}{140} = \underline{\underline{4292,86cm^2}}$ => Chosen Profile:
90×50cm

3hrs fire resistance requires 180mm cover => Remaining profile area: 756cm²

Nmin = 1804 [kN] = 180 [tf]

$2 - A = \frac{180 \times 10^3}{140} = \underline{\underline{1285,71cm^2}}$ => Chosen profile FL25 – FL31: 100×60cm
(=Remaining profile area: 1 536cm²)

i) Floor 33

Nmin = 4432 [kN] = 445 [tf]

$1 - A = \frac{445 \times 10^3}{140} = \underline{\underline{3178,57cm^2}}$ => Chosen Profile: 70×50cm

3hrs fire resistance requires 180mm cover => Remaining profile area: 476cm²

Nmin = 1186 [kN] = 119 [tf]

$2 - A = \frac{119 \times 10^3}{140} = \underline{\underline{850,00cm^2}}$ => Chosen profile FL32 – FL38: 80×60cm
(=Remaining profile area: 1 056cm²)

j) Floor 45

Nmin = 3618 [kN] = 362 [tf]

$1 - A = \frac{362 \times 10^3}{140} = \underline{\underline{2585,71cm^2}}$ => Chosen Profile: 50×50cm

2hrs fire resistance requires 120mm cover => Remaining profile area: 676cm²

Nmin = 774 [kN] = 78 [tf]

$2 - A = \frac{78 \times 10^3}{140} = \underline{\underline{557,14cm^2}}$ => Chosen profile FL39 – FL45: 50×50cm
(=Remaining profile area: 676cm²)

k) Floor 46

Nmin = 2826 [kN] = 283 [tf]

1 - $A = \frac{283 \times 10^3}{140} = \underline{\underline{2021,43cm^2}}$ => Chosen Profile: 30×50cm

2hrs fire resistance requires 120mm cover => Remaining profile area: 156cm²

Nmin = 667 [kN] = 67 [tf]

2 - $A = \frac{67 \times 10^3}{140} = \underline{\underline{478,57cm^2}}$ => Chosen profile FL46 – FL52: 50×50cm

(=Remaining profile area: 676cm²)

7.2.3.3 Diagrid frame beams (SG8)

The earthquake data was the basis for calculating the dimensions of the diagrid frames as their value is between twice and four times higher than the long-term data. The second step uses the long-term data, considering fire-safety: the remaining area section after a fire.

FLOOR LEVEL	LONG-TERM Nmax [kN]	EARTHQUAKE Nmax [kN]
05	3 887	12 711
07	2 125	5 669
14	1 621	3 758
23	1 166	2 751
27	953	2 178
38	368	1 544
45	369	1 984
47	479	1 646

With $\boxed{A = \frac{N}{\sigma_c}}$ and by means of $S_{\sigma c} = 140kg/cm^2$ the required areas can be calculated as followed:

a) Floor 05

Nmin = 12711 [kN] = 1272 [tf]

1 - $A = \frac{1272 \times 10^3}{140} = \underline{\underline{9085,71cm^2}}$ => Chosen Profile:
110×85cm

3hrs fire resistance requires 180mm cover => Remaining profile area: 3626cm²

Nmin = 3887 [kN] = 389 [tf]

2 - $A = \frac{389 \times 10^3}{140} = \underline{\underline{2778,57cm^2}}$ => Chosen profile FL02 – FL05: 110×85cm

b) Floor 07

Nmin = 5669 [kN] = 567 [tf]

$1 - A = \frac{567 \times 10^3}{140} = \underline{\underline{4050{,}00 cm^2}}$ => Chosen Profile: $\underline{\underline{90 \times 45 cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{486 cm^2}}$

Nmin = 2125 [kN] = 213 [tf]

$2 - A = \frac{213 \times 10^3}{140} = \underline{\underline{1521{,}43 cm^2}}$ => $\boxed{\text{Chosen profile FL06 – FL10: } \underline{85 \times 70 cm}}$

(=Remaining profile area: 1 666cm²)

c) Floor 14

Nmin = 3758 [kN] = 376 [tf]

$1 - A = \frac{376 \times 10^3}{140} = \underline{\underline{2685{,}71 cm^2}}$ => Chosen Profile: $\underline{\underline{70 \times 40 cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{136 cm^2}}$

Nmin = 1621 [kN] = 162 [tf]

$2 - A = \frac{162 \times 10^3}{140} = \underline{\underline{1157{,}14 cm^2}}$ => $\boxed{\text{Chosen profile FL11 – FL17: } \underline{80 \times 65 cm}}$

(=Remaining profile area: 1 276cm²)

d) Floor 23

Nmin = 2751 [kN] = 275 [tf]

$1 - A = \frac{275 \times 10^3}{140} = \underline{\underline{1964{,}29 cm^2}}$ => Chosen Profile: $\underline{\underline{60 \times 35 cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{000 cm^2}}$

Nmin = 1166 [kN] = 117 [tf]

$2 - A = \frac{117 \times 10^3}{140} = \underline{\underline{835{,}71 cm^2}}$ => $\boxed{\text{Chosen profile FL18 – FL24: } \underline{75 \times 60 cm}}$

(=Remaining profile area: 936cm²)

e) Floor 27

Nmin = 2178 [kN] = 218 [tf]

$1 - A = \frac{218 \times 10^3}{140} = \underline{\underline{1557{,}14 cm^2}}$ => Chosen Profile: $\underline{\underline{60 \times 30 cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{000 cm^2}}$

Nmin = 953 [kN] = 95 [tf]

$2 - A = \frac{95 \times 10^3}{140} = \underline{\underline{678{,}57 cm^2}}$ => $\boxed{\text{Chosen profile FL25 – FL32: } \underline{75 \times 55 cm}}$

(=Remaining profile area: 741cm²)

f) Floor 38

Nmin = 1544 [kN] = 155 [tf]

$1 - A = \frac{155 \times 10^3}{140} = \underline{\underline{1107{,}14 cm^2}}$ => Chosen Profile: $\underline{\underline{50 \times 30 cm}}$

3hrs fire resistance requires 180mm cover => Remaining profile area: $\underline{\underline{000 cm^2}}$

Nmin = 368 [kN] = 37 [tf]

$2 - A = \frac{37 \times 10^3}{140} = \underline{\underline{264{,}29 cm^2}}$ => $\boxed{\text{Chosen profile FL33 – FL39: } \underline{65 \times 50 cm}}$

(=Remaining profile area: 406cm²)

g) Floor 45

Nmin = 1984 [kN] = 198 [tf]

$1 - A = \frac{198 \times 10^3}{140} = \underline{\underline{1414{,}29 cm^2}}$ => Chosen Profile: $\underline{\underline{50 \times 30 cm}}$

2hrs fire resistance requires 120mm cover => Remaining profile area: $\underline{\underline{156 cm^2}}$

Nmin = 369 [kN] = 37 [tf]

$2 - A = \frac{37 \times 10^3}{140} = \underline{\underline{264{,}29 cm^2}}$ => $\boxed{\text{Chosen profile FL40 - FL46: } \underline{50 \times 40 cm}}$

(=Remaining profile area: 416cm²)

h) Floor 47

Nmin = 1646 [kN] = 165 [tf]

$1 - A = \frac{198 \times 10^3}{140} = \underline{\underline{1178{,}57 cm^2}}$ => Chosen Profile: $\underline{\underline{50 \times 25 cm}}$

2hrs fire resistance requires 120mm cover => Remaining profile area: $\underline{\underline{26 cm^2}}$

Nmin = 479 [kN] = 48 [tf]

$2 - A = \frac{48 \times 10^3}{140} = \underline{\underline{342{,}86 cm^2}}$ => $\boxed{\text{Chosen profile FL47 – FL52: } \underline{50 \times 40 cm}}$

(=Remaining profile area: 416cm²)

7.2.3.4 Diagrid frame part - inner main beams (SG10)

The axis-distance (= w) is 4m;

1.) The length of the beams (= l) is 10.50m [longest part (around 23rd floor)].

$$\boxed{M = \frac{1}{8} \times ql^2}$$

M = moment
q = ω x w
ω = 400 + 360 = 760[kg/m²] = 0.76[t/m²]   (ω = dead load + live load)

$$M = \frac{1}{8} \times 0.76[t/m^2] \times 4[m] \times 10.50^2[m^2]$$

$M = \underline{\underline{42tf}}$

$$\boxed{Z = \frac{M}{lf_b}}$$

Z = section modulus
lf_b = 100 kg/cm²

$$Z = \frac{42 \times 10^5}{100} = \underline{\underline{42\,000cm^3}}$$

$$\boxed{Z = \frac{1}{6}bd^2}$$

b = breadth (width) of a rectangular beam
d = depth (height) of a rectangular beam

=> Presumption: “d” is 70cm =>

$42\,000 = \frac{1}{6} \times b \times 70^2$ =>

$b = 51.43cm$ => $\boxed{b = \underline{52cm}}$

$$\boxed{\delta = \frac{5}{384} \times \frac{ql^4}{EI}}$$

δ = deflection
E = elastic modulus
I = moment of inertia of cross-section

$\delta = \frac{l}{500} = \delta_a$ => 1 050/500 = $\underline{\underline{2.1cm}}$

$\frac{l}{500}$ = for glued-laminated timber or LVL

$$I = \frac{5}{384} \times \frac{7.6 \times 4 \times 1050^4}{100\,000 \times 2.1} = \underline{\underline{2\,291\,133cm^4}}$$

$\boxed{I = \frac{bd^3}{12}}$ => Presumption: “d” is 70cm =>

=> $2\,291\,133 = \frac{b}{12} \times 70^3$ => $\boxed{b = 80cm}$

=> $\boxed{\text{Chosen profile: 70×80cm}}$

=> Plus fire resistance cover:

$\boxed{\text{FL01 - FL38: + 18cm cover at the shown surface}}$

$\boxed{\text{FL39 – FL48: + 12cm cover at the shown surface}}$

$\boxed{\text{FL49 – FL52: + 6cm cover at the shown surface}}$

2.) The length of the beams is 5m [shortest part].

$$\boxed{M = \frac{1}{8} \times wl^2}$$

$\omega = 400 + 360 = 760[kg/m^2] = 0.76[t/m^2]$

$M = \frac{1}{8} \times 0.76[t/m^2] \times 4[m] \times 8{,}00^2[m^2]$

M = 24.32tf

$$\boxed{Z = \frac{M}{lf_b}}$$

$lf_b = 100kg/cm^2$

$Z = \frac{24.32 \times 10^5}{100} = 24\,320cm^3$

$\boxed{Z = \frac{1}{6} bd^2}$ => Presumption: “d” is 60cm =>

$24\,320 = \frac{1}{6} \times b \times 60^2$ =>

b = 40.53cm => $\boxed{b = 41cm}$

$$\boxed{\delta = \frac{5}{384} \times \frac{wl^4}{EI}}$$

$\delta = \frac{l}{500} = \delta_a$ => 500/500 = 1.0cm

$I = \frac{5}{384} \times \frac{7{,}6 \times 4 \times 500^4}{100\,000 \times 1{,}0} = 247\,396cm^4$

$\boxed{I = \frac{bd^3}{12}}$ => Presumption: “d” is 60cm =>

=> $247\,396 = \frac{b}{12} \times 60^3$ => $\boxed{b = 14cm}$

=> $\boxed{\text{Chosen profile: } \underline{\underline{60\times40cm}}}$

=> Plus fire resistance cover:

$\boxed{\text{FL01 - FL38: } \underline{\underline{\text{+ 18cm cover at the shown surface}}}}$

$\boxed{\text{FL39 – FL48: } \underline{\underline{\text{+ 12cm cover at the shown surface}}}}$

$\boxed{\text{FL49 – FL52: } \underline{\underline{\text{+ 6cm cover at the shown surface}}}}$

7.2.3.5 Diagrid frame part - inner sub beams (SG9)

The length of the beams is 8m;

$$\boxed{M = \frac{1}{8} \times wl^2}$$

$\omega = 400 + 360 = 760[kg/m^2] = \underline{0.76[t/m^2]}$

$\delta = \frac{l}{500} = \delta_a$ => $800/500 = \underline{\underline{1.6cm}}$

$$I = \frac{5}{384} \times \frac{7.6 \times 4 \times 800^4}{100\,000 \times 1.6} = \underline{\underline{1\,013\,333cm^4}}$$

$\boxed{I = \frac{bd^3}{12}}$ => Presumption: “d” is 60cm =>

=> $1\,013\,333 = \frac{b}{12} \times 60^3$ => $\boxed{b = \underline{\underline{55cm}}}$

=> $\boxed{\text{Chosen profile: } \underline{\underline{60\times55cm}}}$

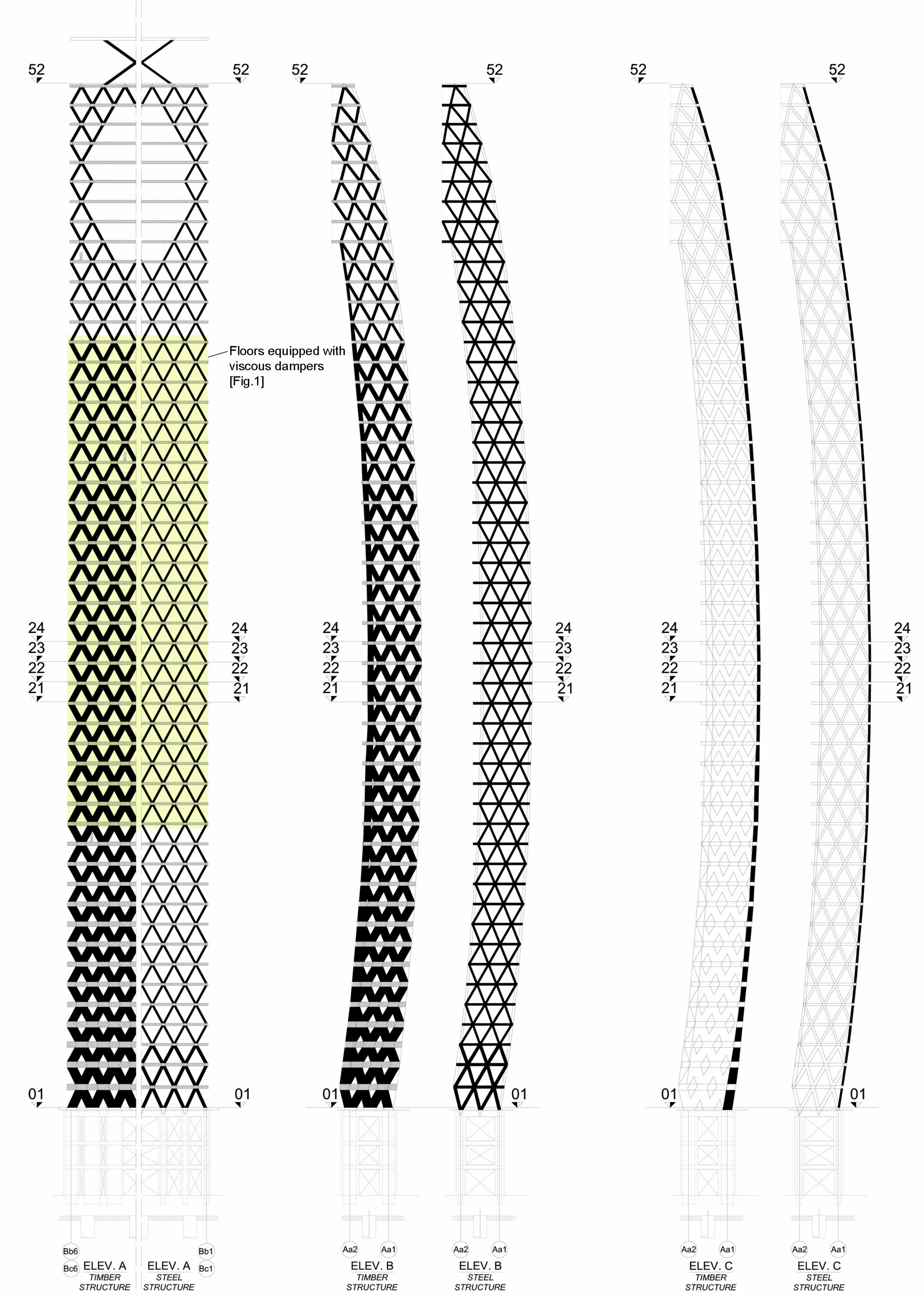
=> Plus fire resistance cover:

$\boxed{\text{FL01 - FL38: } \underline{\underline{\text{+ 18cm cover at the shown surface}}}}$

$\boxed{\text{FL39 – FL48: } \underline{\underline{\text{+ 12cm cover at the shown surface}}}}$

$\boxed{\text{FL49 – FL52: } \underline{\underline{\text{+ 6cm cover at the shown surface}}}}$

7.2.4 Plans and Details



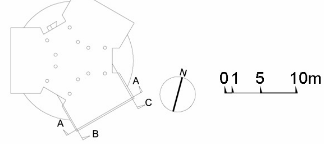


Fig 7.2.f – Comparing timber (elevations: left) with steel (elevations: right)

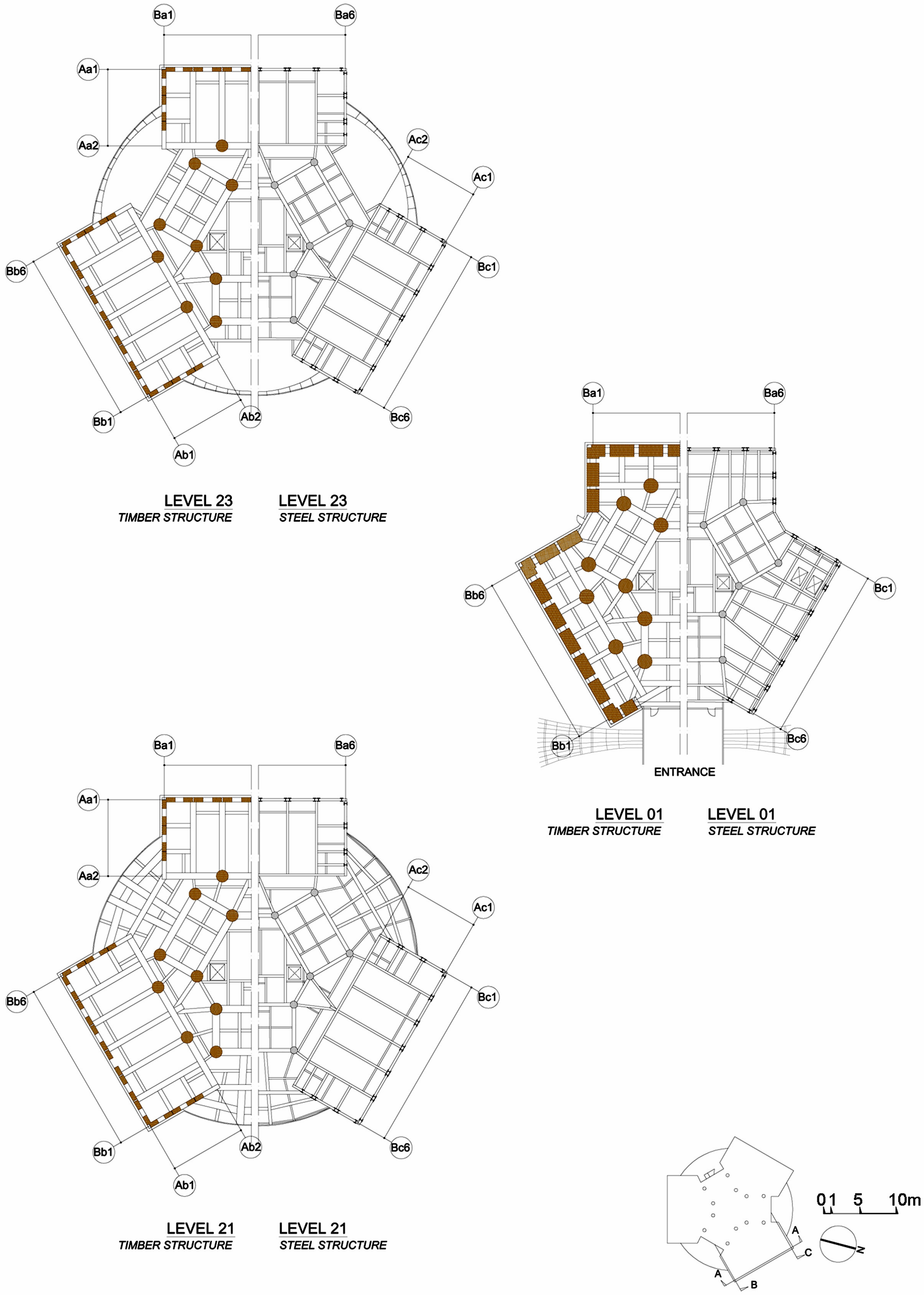


Fig 7.2.g – Comparing timber (floor plans: left) with steel (floor plans: right)

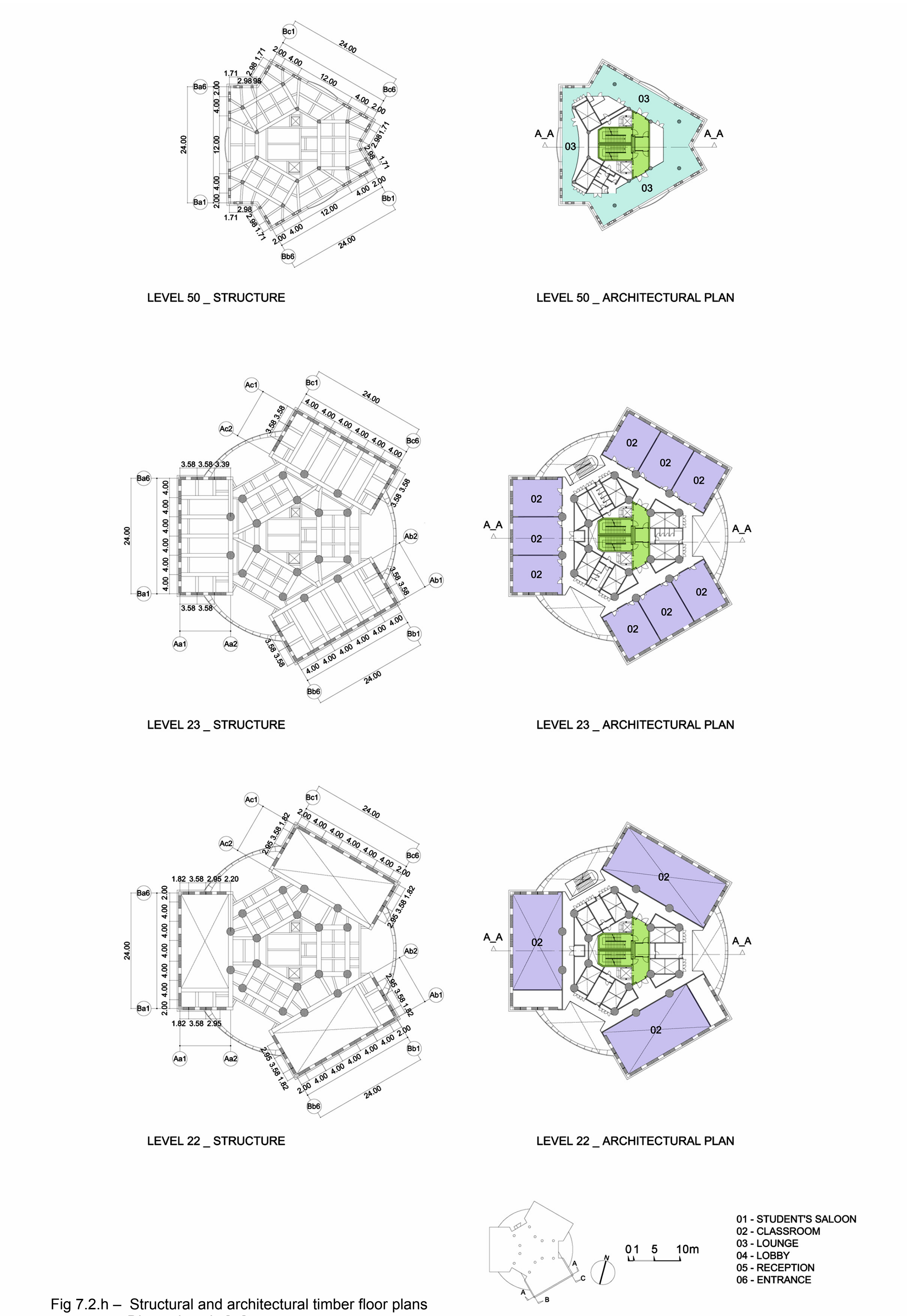


Fig 7.2.h – Structural and architectural timber floor plans
Dimensions in [m]

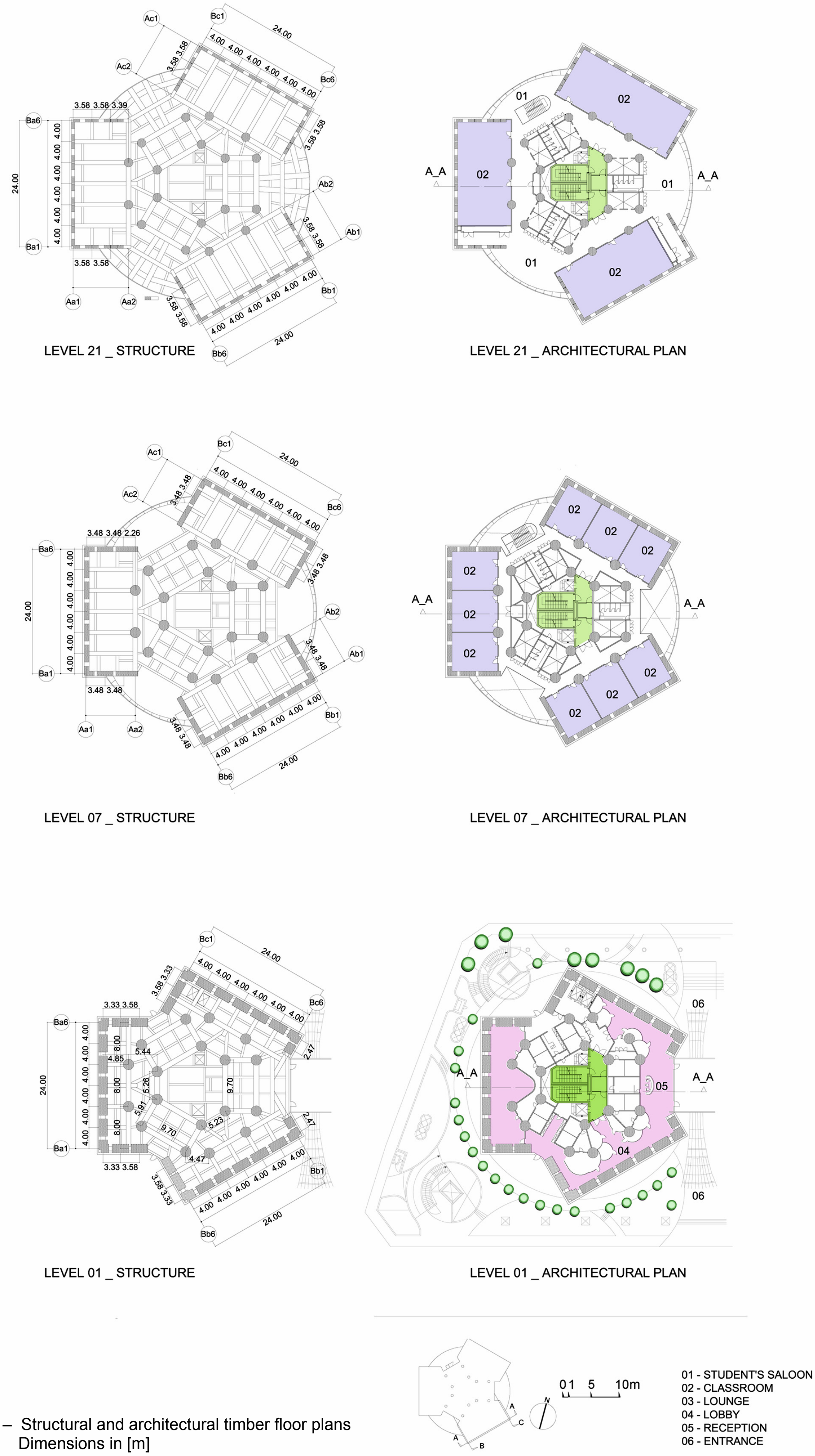


Fig 7.2.i – Structural and architectural timber floor plans
Dimensions in [m]

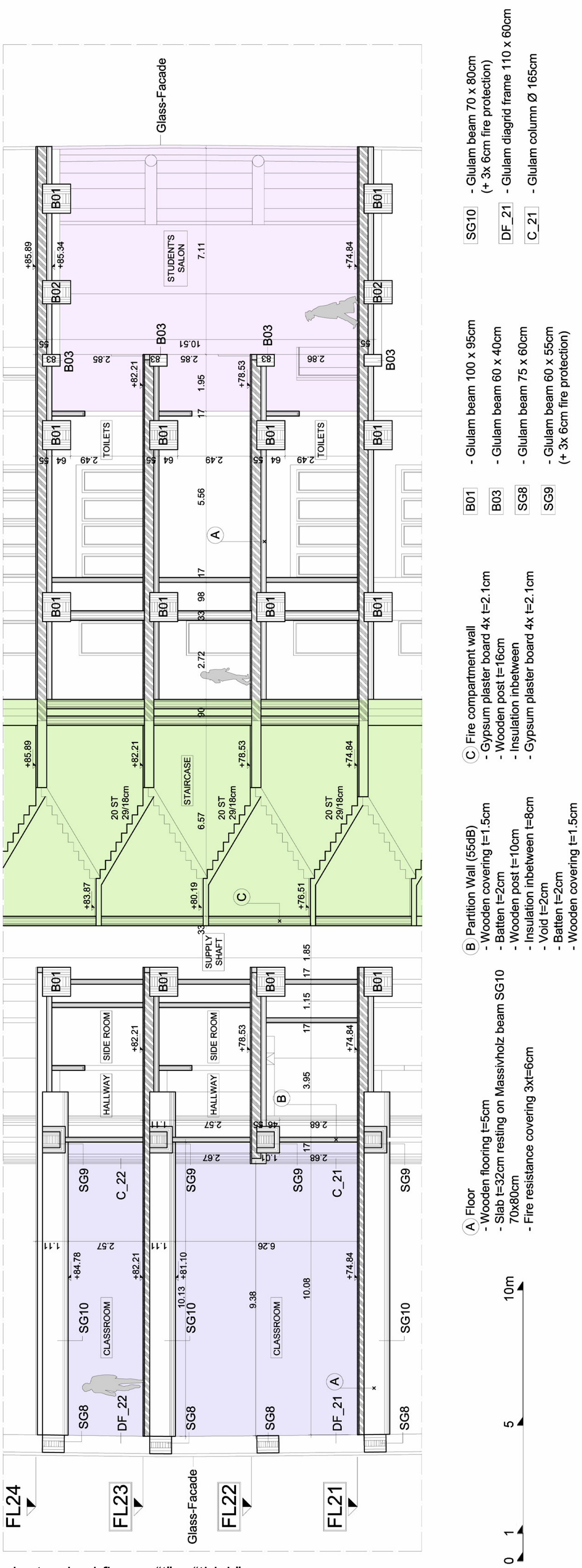


Fig 7.2.j – Detailed section through standard floors; “t” = “thick”

7.2.5 Model photos

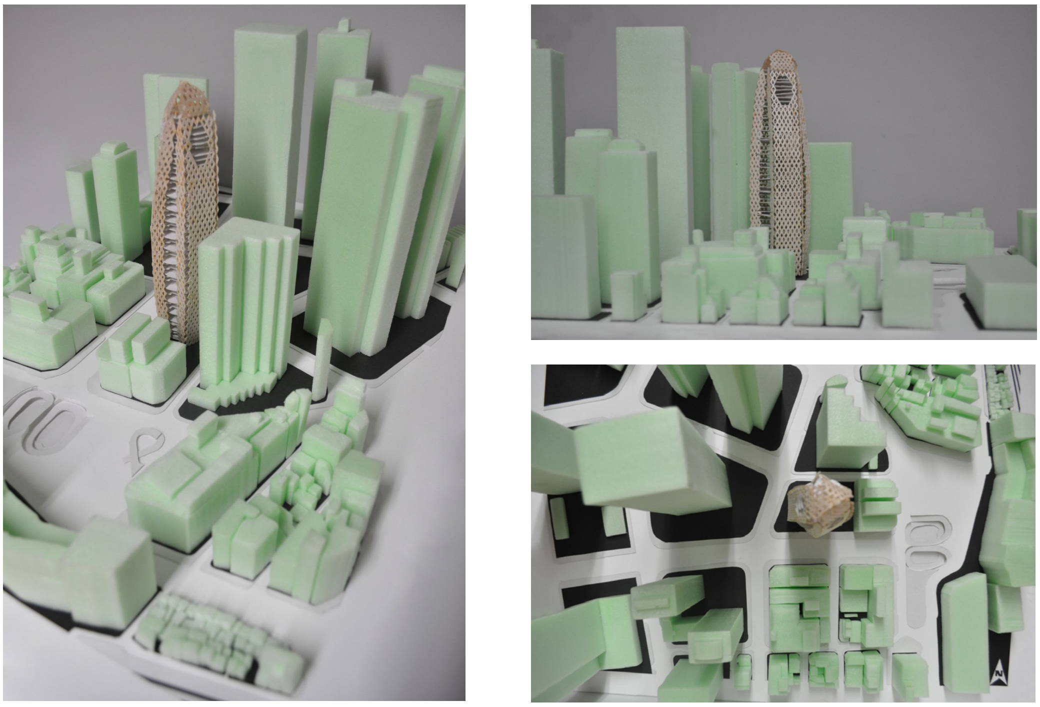


Fig 7.2.k - 7.2.m – Topographical scale model of Shinjuku (built in scale 1:1 000)

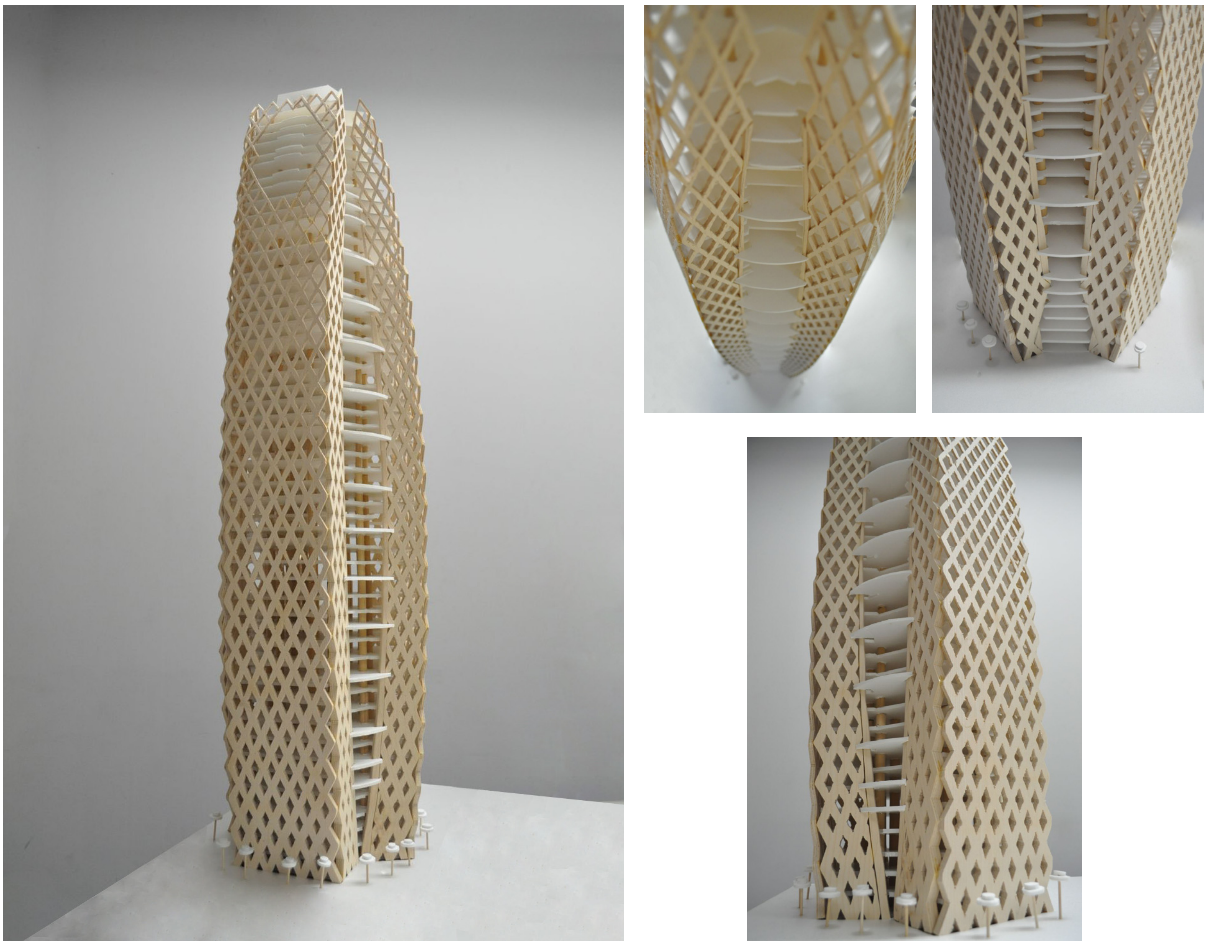


Fig 7.2.n - 7.2.q – Constructional model of the timber cocoon tower (built in scale 1:200)

7.2.6 Addendum

The existing table of forces refers to the material **steel** – therefore the calculations are very hypothetical.

When using timber instead - due to a *lower dead load* and a *different rigidity* and *different natural period* - other data would apply and the dimensions would be smaller than in these calculations. For a general overview though the steel data has been used.

From a static point of view - and if fire regulations would allow it - this project could be fully developed, and actioned.
However, two things need to be considered when going deeper into detailed planning:
The deformation of wood should be considered and even more interesting are the joints. Due to the huge dimensions, the greatest problem might be how to connect the diagrid frames with beams and columns to create a static unity. As this case study is only scraping the surface of the theme “high-rise timber constructions”, it has not gone into detail about joints.

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