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An overview of modern Japanese wood construction – Interaction with tradition

Moderner japanischer Holzbau - ein Überblick

Costruzione in legno moderna giapponese - visione generale

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1 Introduction

In any culture, in any field, the current state of the art must be a consequence of accumulated past events. Traditionally, Japanese architecture shows its evolution clearly upon contact with overseas cultures. In this small country, geographically isolated by surrounding oceans, such historical events are relatively distinctive and influential. In other words, the evolution of its architecture represents the interaction between the internationality and locality. Observing such implications might give us an interesting impulse for our timber construction, oscillating in the waves of global standardisation.

Here, we concentrate on the lateral load bearing system, a particularity in Japan architecture, and make a survey on its evolution through three different terms: traditional structure, post-war standard housing systems, and "revision of tradition" as one of the latest tendencies.

First of all, a brief chronological description will be given, and then detailed explications about different systems will follow.

2 Brief overview of lateral load bearing system

Independently with the change of times, monumental buildings are realised as particular events with the leading technology of each period, but are often too unusual to generally reflect the cultural situation. Instead, small and middle size buildings provide the representative information about the concerned regions and periods. For this category of buildings, the structural span cannot be a critical problem, but Japanese builders are never free from the regional criteria – the significant horizontal loads of frequent earthquakes and typhoons. In this paper, we will focus our attention on the evolution of the lateral load bearing systems.

Figure 1: Kiyomizu-dera built on timber pilotis, early 17th century in Kyoto (photo: Wolfgang Winter).

Figure 2: Ryu-ten*, early 18th century in Okayama.*

Regarding the history of Japanese architecture, we cannot ignore the influence of oversees cultures. Nevertheless, for this archipelago, the contact with other cultures was only intermittent and not always imposing. With such occasional interactions with foreigners, Japanese architecture developed slowly, keeping its identity until the end of the national isolation policy under the Tokugawa Shogunate (1603-1867).

Through this long period, the lateral load-bearing system – a type of semi-rigid framing without diagonal elements (Figs.1 and 2) – was principally unchanged with the exception of same modifications such as the appearance of additional girders with 2-storey buildings popularised after the 17th century. This does not mean that the builders in this seismic zone did not know the efficiency of bracing for building stiffness. In fact, some types of buildings and scaffoldings had been solidified by diagonal elements.

Although the semi-rigid bearing wall was long appreciated, a strong earthquake in 1891, soon after the opening of Japan, had provoked the change of this tradition. Deeply influenced by newly imported occidental building art, they began to apply braces and metal connectors to timber constructions. Different from the prior semi-rigid systems needing elements of large dimension, this one can realise necessary stiffness with slender members. This was one of appreciated aspects through the following period of material shortage by the wars.
On the occasion of the earthquake in 1950, the Building Standard Law obliged the use of braces and metal connectors. This is the lateral load bearing system of what we call the conventional system today. Excluding some traditional monuments or buildings for special occasions, the conventional system has almost completely replaced the prior system. At present in Japan, about 45.000 houses are built in this system monthly [1]. This number is equivalent to 82 % of all timber houses. Other houses are realised on the basis of the platform and several prefabricated methods.
It is obvious that braces and shear panels are efficient to increase lateral stiffness of buildings, but it is premature to devaluate the traditional semi-rigid faming that survived for many centuries. Besides the above mentioned westernisation of building art, a movement to revitalise the flexible behaviour of the traditional system already arose before the coded standardisation of bracing. This discussion was unfortunately interrupted by the underdeveloped dynamic analysis method of those days and also by the Pacific War. In post-war Japan, timber construction could not be a principal academic subject until an enthusiasm for large-span timber buildings developed in the last decade of the 20th century. Following this temporary boom declined with the last economic crisis, the interest in the traditional system began rising again. Though it is still a minor current, the renaissance of traditional systems is now certainly underway, and many interesting lateral load bearing systems are already realised by interpreting the traditional system. If we can name the wide-spread conventional system “modern” type, it might be said that the latest tendency proclaims the dawn of the “post-modern” era in timber engineering.
By illustrating details, the examples representing the above mentioned systems, including the author’s projects, are presented as follows.

3 Traditional semi-rigid framing

Concerning 2-storey houses built at the beginning of the 19th century, Figs. 3 and 4 show the composition of its vertical structure. These buildings still remain and are now designated as a cultural property testifying the traditional art of building.
Each column is directly placed on an independent stone footing without connecting dowels. Principal columns (150/150 to 195/195) have a 2-storey height and receive the horizontal members lying at each floor level. Besides the floor framings, we can find an additional beam just below the second floor. Disproportional to the span (about 3.6 m), its maximal depth can reach up to 60 cm. It is considered that this beam plays an important role not only to bear the upstairs load, but also to increase the lateral stiffness due to its large intersection with columns. Both ends of the beam are firmly inserted into the columns in the manner like Fig. 5.

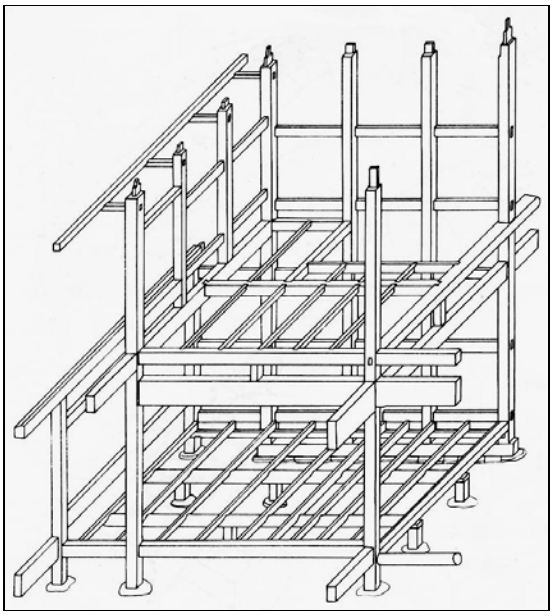

Figure 3: Lateral load bearing system of Takagi house*, early 19th century in Nara (source: Architectural Institute of Japan,* Kouzouyou kyouzai*, Tokyo, 1985).*

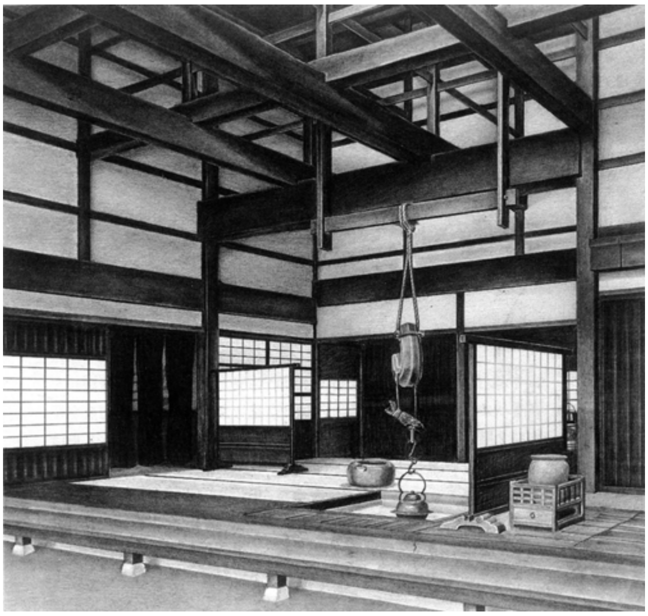

Figure 4: Kita house*, 19th century in Ishikawa (source: T. Nakagawa,* Nihon kenchiku midokoro jiten*, Tokyo-dou shuppan, Tokyo, 1990).*

The wall contains several slender horizontal girths penetrating the columns. The joint of these girths with the columns is illustrated in Fig. 6. After the girths are inserted into columns, small wedges are thrust between the girth and column. It is needless to say that this detail allows occasional retightening of structure. These wedges are always of conifer woods that can be easily crushed. Usually, such wall framing is filled with mud plastered on a bamboo trellis.

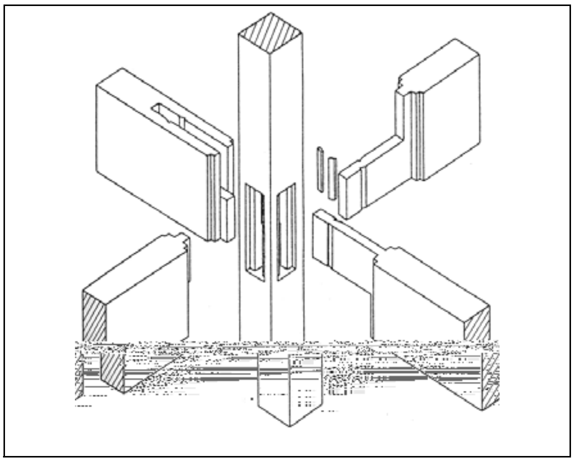

Figure 5: Traditional joint "column – four beams" (source: Mokuzou kenchiki kenkyu forum, Encyclopedia of wood architecture*, Gakugei shuppan, Kyoto, 1995).*

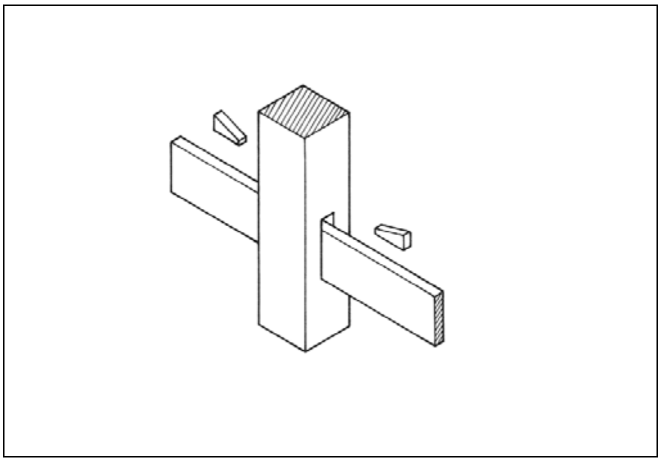

Figure 6: Traditional joint "column – girth" (source: Mokuzou kenchiki kenkyu forum, Encyclopedia of wood architecture*,Gakugei shuppan, Kyoto, 1995).*

As it is shown in the above example, the Japanese traditional timber buildings do not have efficient stiffening elements such as braces. Even though the contact surface area of the columns and beams was increased and the use of wedges tightened the joints, we cannot expect high stiffness to avoid critical deformations from earthquakes. It is considered that such a structural system survives the quakes by the following properties:

- Low stiffness framing has a longer natural period (0.7 to 1.0 sec.) than the predominate period of usual earthquakes (Tottori: 0.1 to 0.4 sec., Geiyo: 0.1 to 0.5 sec.) [2, 3]
- Energy dissipation by friction and compressive deformation of timber (wedges) at joints (Fig. 7)

Though many timber buildings unfortunately collapsed during the earthquake of Kobe in 1995 because of its unusually long predominate period (0.3 to 1.0 sec.) [2, 3], the period of most earthquakes is in range of 0.1 to 0.5 sec. The natural period of traditional buildings is long enough to avoid the resonance that can cause important damages of buildings.

Figure 7: Ductile deformation of a traditional timber house damaged by Kobe earthquake in 1995 (photo: Shigeo Ohira).

It is also important to mention that traditional timber buildings do not always have such a flexible system. For example, in the case of a fire-resisting warehouse in Figs. 8 and 9, the walls consist of ceramic tiles with plaster joints. This wall type appeared and became popular at the beginning of the 19th century. The structural stiffness is given by diagonal elements in order to allow the nonflexible finishing with ceramic tiles. With respect to these examples, we can observe that Japanese traditional builders did not blindly repeat their semi-rigid flaming, but selected the structural systems intentionally.

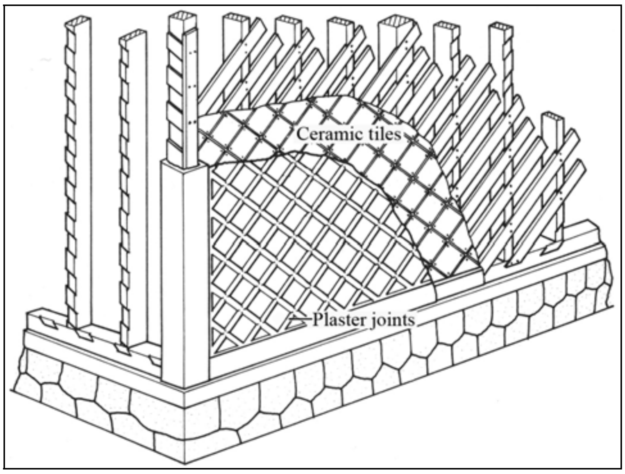

*Figure 8: Detail of warehouse wall "*Namako-kabe *wall" (source: Mokuzou kenchiki kenkyu forum,* Encyclopedia of wood architecture*, Gakugei shuppan, Kyoto, 1995).*

*Figure 9: Warehouse with "*Namako-kabe *wall" (photo: Yasunao Hayashi).*

4 Conventional system after 1950

Figure 10 presents a prototype of a "seismic proof house" proposed by a Japanese architect, T. Ito, after the historic earthquake in 1891. This architect, trained in the USA, proposed the use of braces and a continuous foundation. We can consider this proposal as an archetype of the present conventional system. This house with eclectic appearance was long exhibited in Tokyo for enlightenment and represents the then current evolution of building art that followed the earthquake. In those days, many architects and engineers were engaged in the problem of stiffening timber buildings.

Figure 10: A seismic proof house proposed by Tamekichi Ito soon after the earthquake in 1891 (source: S. Matsumura, Jutaku ga dekiru sekai no shikumi*, Shoukoku-sha, Tokyo, 1998).*

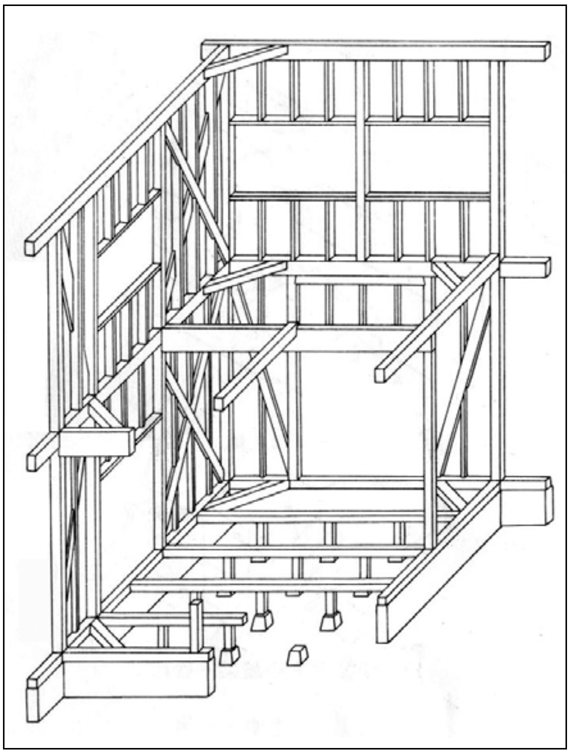

Figure 11 and 12: A common individual house in the conventional system after 1950.

Figures 11 and 12 show a common structural system of contemporary houses. The specification of this system was defined by the Japanese Building Standard (initially in 1950) and by the Government Housing Loan Corporation. This structural system, including its variants, is built in large quantities under the name of "*Zairai* (conventional system)". Though this system itself is not so specific as we describe it here, the recent producers focus their efforts on the rationalisation of production within the framework of the standards as follows [4]:

Joints: Though the lateral load bearing system is completely different from the traditional one and the use of metal fasteners is generalised, the form of joints remains traditional. In the conventional system, the traditional timber-to-timber joints and metal fasteners (clips, ties, straps, and anchors) are used together. The ends of timbers are assembled in the traditional way and reinforced by fasteners against transient loading (Fig. 13).

In recent years, the troublesome manufacture of traditional joints is being increasingly replaced by the "pre-cut joint" method, meaning machine manufactured joints (Fig. 14). In many cases, machine tools are controlled by CAD-CAM. Almost all home manufacturers adapted "pre-cut" in order to shorten the execution and to reduce the cost.

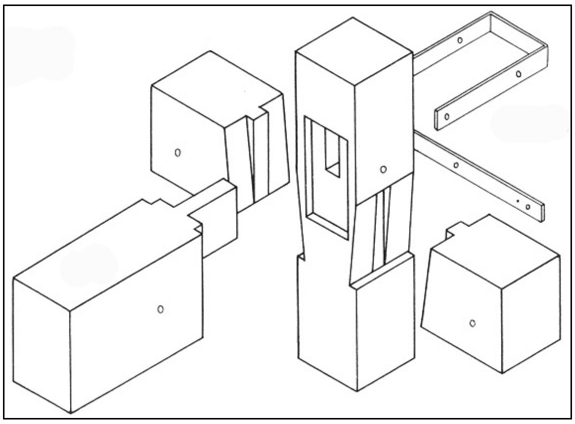

Figure 13: A common joint in the conventional system (source: Mokuzou Kenchiki Kenkyu Forum, Encyclopedia of wood architecture*, Gakugei Shuppan, Kyoto, 1995).*

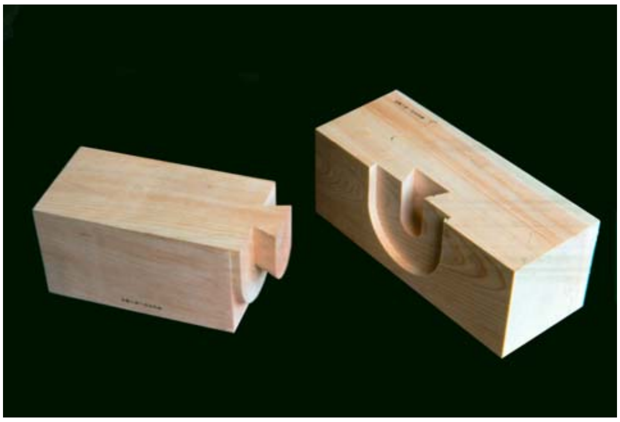

Figure 14: Pre-cut joint (photo: Wolfgang Winter).

Dimensions: In order to optimise the pre-cut manufacture of joints, unifying the dimensions of some elements can be an effective solution. For example, some home manufacturers developed structural systems without any 2-storey columns. In this case, the height of horizontal members was homogenized to reduce the variation of columns. Such composition increases the number of joints disadvantageously, but can reduce the on-site works like the platform construction method.

Material: The Performance Based Code applied to dwellings in 2000 mandates 10 year guarantees against structural defects. Since the enactment of this code, home manufacturers replaced ordinal sawn lumbers with dimensionally stable products, such as GLT and LVL. These engineered woods are often employed not only for large dimension elements like beams but also for small elements. In 1999, the volume of imported GLT was 357.000 m^3. After the code application, the import of G.L.T increased rapidly up to 647.000 m^3 in 2002 [5].

Besides GLT and LVL, we can also observe the increase of plywood consumption. Plywood is mainly used for subflooring, but recently many manufacturers began using it for walls instead of braces. These plywood shear panels are employed especially for external walls, in order to enable flexible interior organization. That is to say, the clear difference between the conventional system and the platform method is disappearing.

These rationalisations of production are usually done by large manufacturers. Associated with their marketing potential, they can effectively improve their commercial competence. This cut-throat price war causes the market share of small size builders and skilled carpenters to diminish. While the quality of industrialised products becomes higher, the loss of artisanal craft is inevitable in the current situation. The overall number of carpenters decreased from 937.000 to 706.000 during 15 years between 1980 and 1995 [6].

5 Interpretation of traditional system

Aging historical buildings, progressing analysis methods, and increasing interest in cultural heritage: there are now enough motives to revive the advantages of traditional structure systems. By testing or by simulating, researchers are on the way to describing its structural behaviour in our technical language. Their discovery is causing a change of timber structural design.

Figures 15 to 18 show an individual house designed by the author [7, 8]. The vertical structure is a combination of framework and shear walls. Large glazed openings are planned toward the court and a river running beside the site. To compensate the lack of stiffness of the timber frames around the openings, an idea from the traditional structure – continuous beam – was applied. As it is presented in the figures, each structural member was composed of Douglas fir lumber with the same thickness. The dimension lumber, imported in large quantities for the two-by-four method, is a very economical building material. The necessary members were assembled by superposing and nailing these boards. For example, the columns are made with four layers of planks and beams have two layers. The butted joints between the planks are placed at the position where the bending moment by long-term loading disappears. This configuration allows the continuous beams to penetrate the centre of the columns without any complicated joint manufacture (Figs. 17 and 18) and enables a ductile structure. Even if the form, materials, and joints do not follow the tradition, the structural design was enriched with a traditional concept.

Figure 15 and 16: House in nailed planks post-beam, Shizuoka, Japan (architect: Y. Amino, engineer: L. Caspescha, photo: T. Narita).

Figure 17 and 18: Structural details, House in nailed planks post-beam.

Figures 19 to 21 present another project using a structural vocabulary drawn from the traditional system [9]. This is a small pavilion built for the tea ceremony on the shore of Lake Geneva. In order to integrate the pavilion in the beautiful surroundings, the author proposed a structure system without walls and diagonals with the intention of realising a visual dialog between the inner and outer space. Instead of stiffening members, a series of free standing columns were employed. These columns are rigidly fixed at the base by the proposed joint detail with minimal fasteners (Fig. 21). The floor is positioned about 40 cm higher than the foundation. Filling this gap, floor beams (also 40 cm high) are fixed along the four sides of the floor framing. On one side of these beams, cut-outs with the same width as the column are given in regular intervals. The base of each column is inserted in these cut-outs. Instead of improving the performance of these joints by metal reinforcement, the number of columns and the depth of the joints were increased in order to reduce the local stress. Here, it is important to always keep the joints tight. For this reason, every element was prepared relatively dry in a workshop, then transported to the lake shore, and assembled immediately. After assembly, the high and constant moisture from the lake swelled the timber members, and tightened the joints. The traditional timber-to-timber rigid joint was interpreted and applied to this project by substituting the swelling of timber for the role of wedges and increasing the structural safety by reduction of local stress.


Figure 19 and 20: Tea pavilion, La Tour de Peilz, Switzerland (architect: Y. Amino, architect collaborator: M. Inoue, construction: Atout Bois Charpente, photo: C. Cuendet).

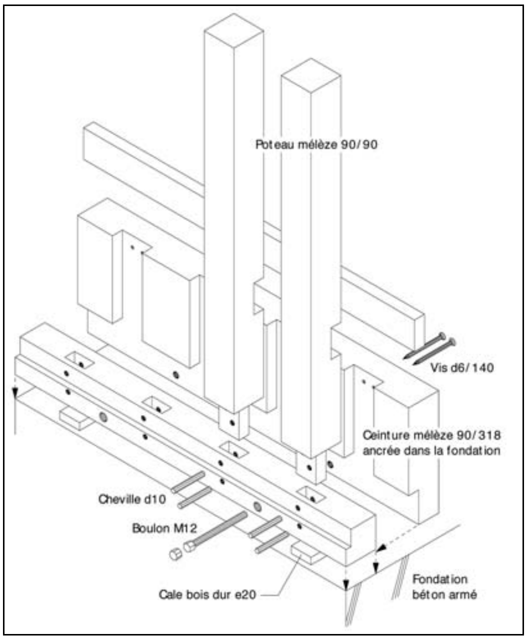

Figure 21: Joint detail of free standing columns, tea pavilion (source: Y. Amino [9]).

The next example shows the result of a research project carried out by T. Shiratori et al [10] at the Swiss Federal Institute of Technology, Laboratory of Timber Structure directed by Prof. Natterer. T. Shiratori, interested in the function of the traditional beam intersection with multiple columns, proposed a solid wall structure stiffened only by girths (Figs. 22 to 24). Using abundant low-grade woods, for example material from thinning, the wall plane is composed of columns in a staggered arrangement. This wall is banded by the girths from both sides with the help of bolts. Since every girth consists of three pieces of hardwood with triangular cross-section, the initial slip can be eliminated by being fastened by bolts. These slip-less girths realise higher initial stiffness through its moment resistive properties and recovering capability after seismic loading. The applied seismic energy is absorbed not only by friction between pieces, but also by local compressive deformation of the girths (ductile deformation). Even if the girths are damaged, re-tightening the bolts can eliminate again the play between the girths and columns. Experimental results demonstrated successfully the expected performance for practical applications.

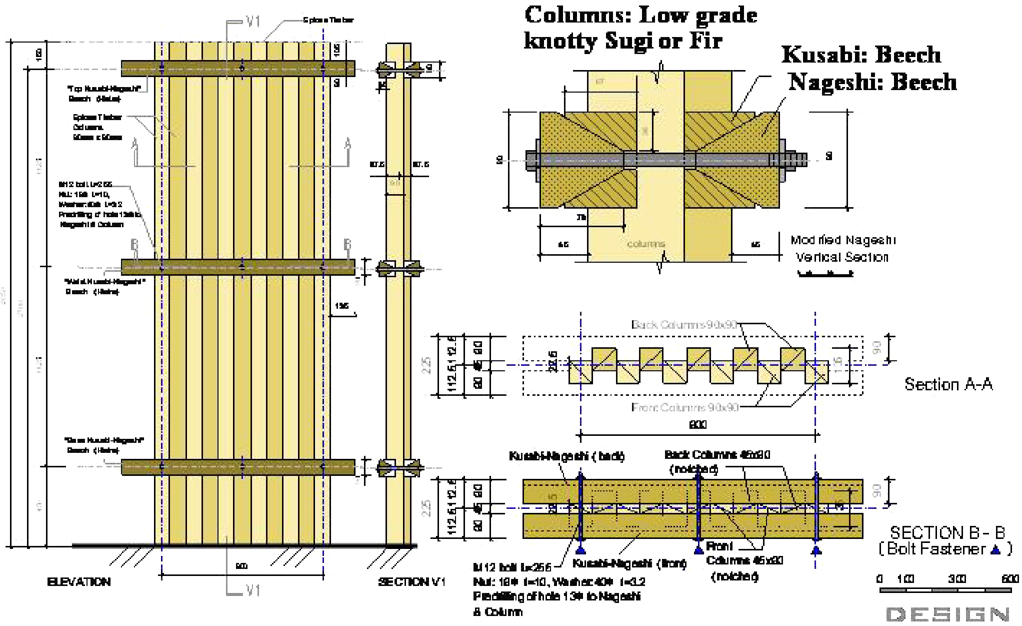

Figure 22: Kusabi-Nageshi *joint system with staggered columns studied by T. Shiratori.*

Figure 23: Shearing test of the proposed wall at EPFL-IBOIS (photo: T. Shiratori).

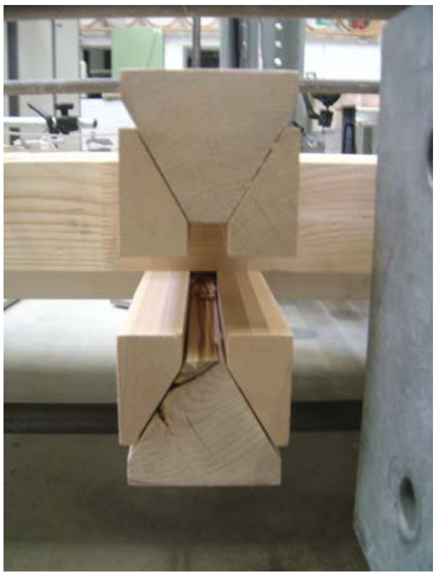

Figure 24: Joint detail "staggered columns – girths" (photo:

T. Shiratori).

Department of Structural Design and Timber Engineering (directed by Prof. W. Winter), Vienna University of Technology (TUWien), the author's place of employment, a study on the application of semi-rigid framework to multi-storey timber buildings is being carried out (Figs. 25 and 26) [11]. Superposition of planks allows joint-less posts. Through these posts, principle beams also run without structural seams. At the crossing points of the posts and girders, triangular wedges were inserted in accordance with a traditional method. Here, K. Tavoussi is studying a ductile framework with an energy-damping property that can avoid fragile collapse of the structure by excessive horizontal dynamic load.

Figure 25: 2-storey frame tested by K. Tavoussi et al. at TUWien – ITI.

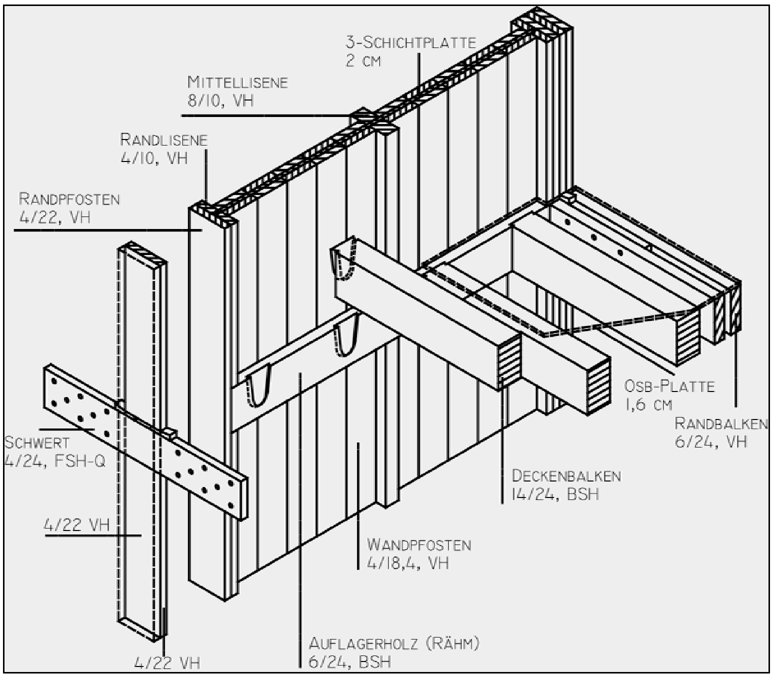

Figure 26: Joint detail of the frame stiffened by wedges (source: K. Tavoussi [11]).

6 Perspective

The contrasting overview of the Japanese tradition and modernity raises questions not only about the local architecture, but also about the coexistence of global standardisation and local tradition.
We observed the development of new structural vocabularies based on the traditional building art that was long ignored because of analysis methods which was then still underdeveloped. This movement is different from nostalgic revivalism, but is carried out in the framework of the scientific verification of traditional methods. Such an objective attitude, widening our vision, deserves our continued appreciation.
On the other hand, our architectural society is moving into uncharted territory with global standardisation. Here, the rationalisation of production and logistics is valued more than architectural logic and creativity.

Though these two aspects seem conflicting at present, it is worth keeping standards open to tradition and locality. Architectural development must be accumulative and reversible rather than supplanting and irreversible. Let's remember Gropius' reminder that tradition comes from the Latin word “tradere” which also means to continue [12].

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