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OPEN BUILDING TOOLKITS

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ABSTRACT: Timber frame structure systems using glued laminated timber have become a widespread construction method for detached houses throughout Japan. SE-structure® is one of these systems and for its integration of design-prefabrication-installation-quality control and seismic design has been chosen for the construction of a pilot project in Italy:. The SI (support/infill) system has been implemented with SE-structure® system, in a European context. The structure of the building was conceived as an example of system building based on an open system, applicable to residential building.

KEYWORDS: open building, building system, system engineering, seismic design

1 INTRODUCTION

The industrialization of house's production in Japan, particularly in the field of detached houses, which really started in the 60's is often said as the most advanced in the world. Indeed various industrialized construction methods, most of which were only experimental or had only short lives in the actual market in other countries, have been extensively applied in the house's production in Japan.
In residential wooden construction that still now accounts for the largest share of detached houses, like so much of its traditional culture, Japan has developed a highly efficient technological adaptation of an age-old building techniques where:

1. Design and construction were an organic part of the same process;
2. Modular coordination was the key to customary design and the building process;
3. Prefabrication of the parts was the basis of the building process;
4. On site assembly was a rapid, precision operation.

As the most time consuming part of the prefabrication process was the cutting of mortise and tenon joinery holding together the timber frame, the introduction of industrially precut timber framing has become the predominant house construction method.
Industrially precut frame-structures are manufactured by on-site assembly of columns and beams and other structural parts (i.e. shearing walls, floor panels), to which non-structural outer-wall panels are attached to form a shelter.

2 SE-STRUCTURE SYSTEM FEATURES

The SE-structure® system has taken the traditional Japanese method of building wooden frames to a higher level.

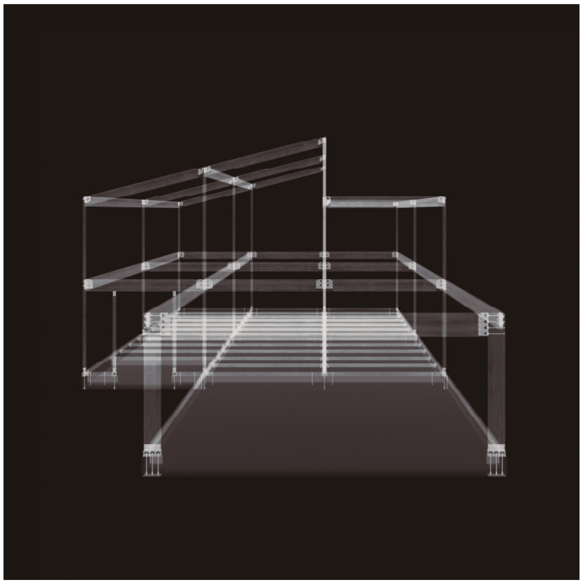

Figure 1*: X-ray view of SE-structure building*

Since 1997 up to now, using SE-structure®, 18.000 buildings have been built in Japan by a network that currently includes over 500 construction firms with a consistent group of about 600 architects and engineers duly trained to integrate it in their design. Seven licensed pre-cut factories produce the glulam pillars, beams and

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panels and a couple of factories delivers the metal connectors.
The SE-Structure® hardware was developed and patented in the early 90s by NCN (New Constructor's Network) of Tokyo, and dedicated to structural design and to the manufacturing of numerically controlled components. The same software that conducts a 3D structural analysis, sends the data to production once the structure has been verified in order to ensure the maximum precision of all the elements.

2.1 From onsite to offsite construction

Peculiarities of onsite construction include the following:

- *One-of-a-kind production*: manufacturing uses repetition or similarity between each product in the factory. Product fitting on the jobsite is unique every time.
- *Site production*: By virtue of the location being on the jobsite exposed to the elements and vulnerable to forces outside of factory control, construction is inefficient in its fitting.
- *Temporary organization*: each project is one-off, requiring a temporary site organization of labor, location of material and tools, and temporary support facilities as office, computer restrooms, and bris thateak areas. The location of the parts and assemblies are not carried over into the next project.
- *Regulatory agency*: An organization that carries out the inspection process from the municipality with jurisdiction over the location of the building.

Prefab architecture works to resolve the issues of peculiarities of construction. Both waste reduction and value generation must be taken into consideration to make a prefabrication solution work. Offsite fabrication in buildings suggests that parts come together in the factory to a level in which assembly can occur with ease onsite. The drawback is that buildings are not standardized; therefore establishing fitting parts is still an expensive portion of labour and time. For building construction to progress and take advantage of the benefit of factory production, fitting must be expedited leaving final assembly to craft of construction as much as possible in the factory and as little as possible onsite. A movement toward more interchangeable parts and the increase in production favouring direct assembly onsite versus fitting parts onsite will increase productivity.

2.2 Mass customization

- Component-sharing modularity: same fundamental components with appearance variability within each discrete product (changing cladding options initially from project to project)
- Component swapping modularity: same configuration of appearance with ability to swap out component function (changing cladding options post-occupancy)
- Cut-to-fit modularity: varying length, width or height of a product by cutting to size based on a fixed module (standardized cladding that can be increased or reduced in size in production)
- Mix modularity: a base structure that supports a number of attachments, sometimes called "platform design" (base frame to which numerous cladding materials and systems can be attached)
- Bus modularity: a base structure that supports a number of attachments, sometimes called "platform design" (base frame to which numerous cladding materials and systems can be attached)
- Sectional modularity: parts are all different but share a common connection method (cladding panels may vary, but the connection to frame is always the same

2.2.1 Grids

Grids for SE-Structure® structural design and building construction are established so that onsite and offsite work might be coordinated. This is performed with prefabrication of the glulam frame based on axial (not modular) grids.
Eventual modular grids (for other components) allow for dimensional coordination across elements offsite and onsite. It is necessary, when intending to use extensive prefabrication of components, to design the building from the start on a reference grid related to the intended model.

2.2.2 Setting

SE-Structure® prefabricated building elements (glulam beams, pillars, OSB panels, metal connectors, floor panel) arrive to the site ready to be placed. Setting and assembling elements is the final step in the process of construction including hoisting, positioning adjusting, connecting, and stitching. Elements designed for prefabrication of structure

2.2.3 Tolerances

SE-Structure® tolerances exists to accommodate the normal manufacturing and installation inaccuracies that occur in construction as the result of moisture, thermal differential movements, material discrepancies, and human error during assemblies.

Concrete
Dimension of footing
Squareness of residential footing
Variation in level of beam
Wood
Floor evenness
Wall plumbness
Metal joints
Dimension

Table 1*: SE-Structure® dimensional tolerances*

2.2.4 Craning

For most assemblies, elements will be lifted directly from the flatbed trailer to their final location. Cranes lift the element and carefully locate its place onsite. Onsite crew guide elements into place and make connections.

In Japan rental of large cranes is expensive, and therefore the machines are used as much as possible when procured.
In Italy we used both truck mounted hydraulic cranes and electric tower cranes.

2.2.5 Foundations

SE-Structure®, foundations are linear footings and continuous footings. Site-cast foundations are never entirely plum; certainly they are much less precise than elements that have been factory produced. Therefore, setting the elements on foundations includes shim to achieve level.

2.2.6 Components of SE-Structure® System

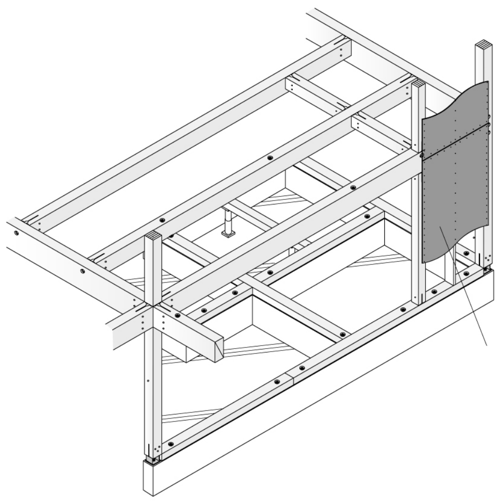

Figure 2 *Assembly of shearing panels*

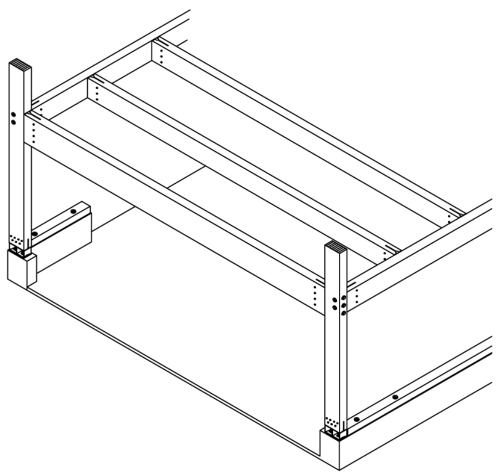

Figure 3 *Assembly of glulam frame and metal connectors*

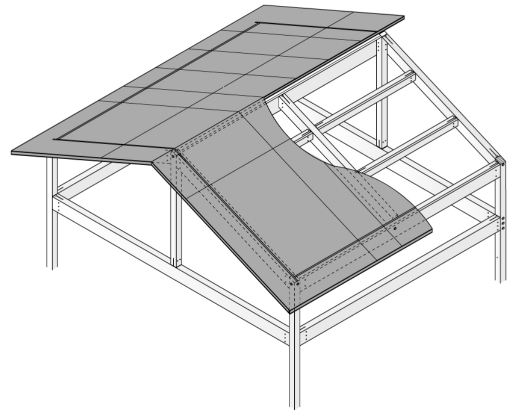

Figure 4 *Assembly diagram of roof panels.*

2.2.7 Joints

One of the main features of the system is the use of drifted pined joints with insert gusset plate provided with lagscrewbolts (LSB).

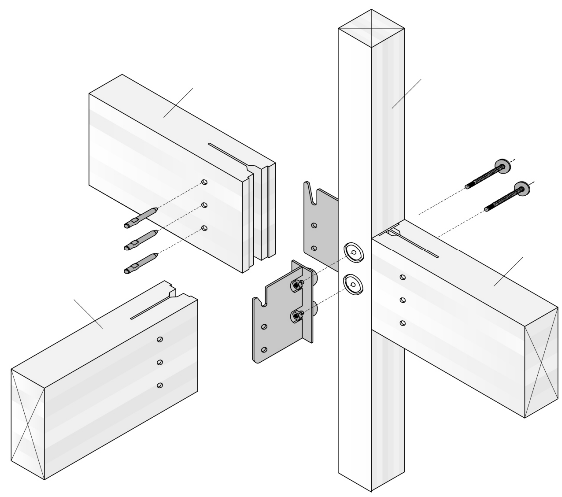

Figure 5*: SE-structure detail of connection between: beams, pillars and connectors*

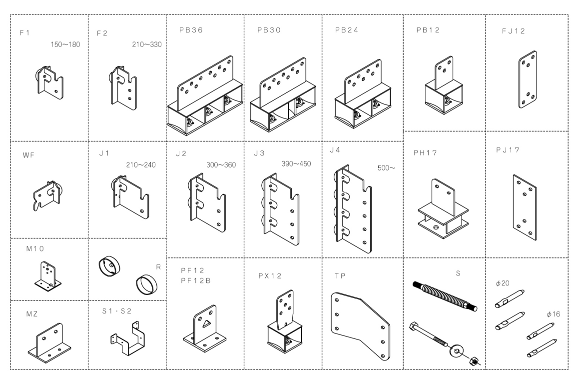

Figure 5*: SE- structure connectors*

2.3 From Century Housing System (CHS) to SI (support/infill) system

The Century Housing System (CHS) was developed in Japan in the 80's and it's a design and construction approach devised to extend building longevity that classifies and organizes the placement of building component systems. Based on modular coordination and the concept of durable years as it relates to each sub-system, sub-systems with few durable years can be replaced without damaging components with longer durable years.

The most common result was to simplify the system in two levels (unchangeable 'support'/changeable 'infill').

The SI (support/infill) system has been successfully implemented with SE-structure® system, particularly for the production of detached houses by MUJI, a major Japanese retailer since 2004.

***Figure 6**: Assembling a building frame in Japan*

3 DESIGNING AND BUILDING IN ITALY

The project was divided into several stages with at first an analysis and comparison between the structural codes in Italy and Japan and later the design of a residential complex consisting of three semidetached houses.

Finally, a building that had been previously completely engineered with a planning permission for the construction in RC and brick has been, so to speak, reengineered for the SE-structure® system.

The building frame (also skeleton) precut and shipped from Japan was successfully assembled onsite by a crew of local craftsmen and integrated with – exterior walls – cladding – interior finishes and mechanical systems – plumbing and HVAC – (also infill).

They are treated as separate building subsystems, as a construction system would enable each part to be easily replaced as these subsystems have a different lifecycle span and can be provided by an efficient supply chain and manufacture that are already on the market and only need to be integrated (i.e. bathroom pods, compact HVAC system with control devices, movable partitions).

The SE-Structure® was quite easy to process and to assemble with ordinary tools; and this experience demonstrated that the quick erection of solid and durable structures – even in seismic areas – is possible even for non-highly skilled manpower.

3.1 Advantages and disadvantages of timber frame construction

As a result we avoided, without dedicating excessive additional design and engineering time, potential problems often associated timber frame construction methods with a traditional procurement process such as modifications of general arrangement drawings based on masonry construction, lack of experienced builders and erection crews, deficiency of site quality control.

- Quick erection times
- Reduced site labour
- Reduced time to weather the structure
- Earlier introduction of following trades
- Low embodied energy
- Recyclable
- Reduced construction waste through efficient controlled manufacturing
- Low volume of waste on site requiring removal
- Can be built to exceed 60-year design life
- Energy efficient when constructed to current standards
- Fast heating due to low thermal mass
- Reduced time on site reduces environmental nuisance and disruption to local residents
- Factory controlled quality assurance in fabrication
- Efficient use of material due to controlled engineering and fabrication
- Reduced construction time translates into reduced risk exposure

***Table 1**: Advantages of timber frame construction*

• Traditional procurement process
• Additional design and engineering time
• Modification of general arrangement drawings if based on masonry construction
• Lack of experienced builders and erection crews
• Lack of experience of following trades
• Transportation and carriage access
• Exposure to weather before enclosed
• Work of following trades
• Deficiency of site quality control
• Combustibility of timber requires vigilant quality control to achieve required fire rating of separating and compartment walls
• Susceptibility to decay of timber when exposed to excessive moisture

***Table 2**: Potential problems with timber frame construction*

***Figure 8**: Assembling a building frame in Italy*

4 OPEN BUILDING TOOLKITS

The combination of timber frame structures, using glued laminated timber and discrete subsystems in what can be defined "Open building toolkits", shows how to bring some of the salient features of efficient manufacturing and industrial design to the construction sector. This should allow for significant savings in construction and maintenance costs, fewer errors and rework, more choices and value to the customer, new product and services that can be configured and assembled in mobile factories, at construction sites, etc.

Therefore it could be fruitful to:

1. Improve the speed, scale and quality of housing supply. Particularly the ease to switch between different footprints and site shapes, flexible plans, easy integration with the cladding system.
2. Use resources more effectively by separating the construction of houses into the building frame, exterior wall, interior finishes and mechanical systems and dividing a construction system in which each part is as replaceable as its durability of life. To apply the integrated building technology to housing.
3. Make it possible to design diverse residential units that are adapted to the occupants' lifestyles and demands through a structural system, which provides freedom in designing exterior walls and organizing layouts, and systematic dimensional coordination.

In the 1950' and 60' many systems buildings were built in the world, but recently few people mentions about building systems. It is one of the reasons that systems building supplied many monotonous buildings. However we are convinced that we can obtain diverse attractive buildings by assembling building subsystems. The architect must become skilful in combining building subsystems. Systematic design with planning grid is defective for that. The building was designed, using open building subsystems. The structure of this building was conceived as an example of a system building based on an open system, applicable to residential buildings.

In the project, the building frame – skeleton – , exterior walls – cladding, interior finishes – infill – and mechanical systems – plumbing – were treated as separate building subsystems, and a construction system was devised that would enable each part to be easily replaced or moved as its durability or life. The mechanical equipments installed in houses are becoming ever more advanced and interfacing with the building frame and interior finishes in increasingly complex ways. However, they must be made and installed in such a way that they can be properly inspected and replaced because mechanical systems and interior finishes differ in durability from the building frame.

Based on that experience, a scheme in which the mechanical systems and the building were separated was devised. A systems-building approach, using a grid and dimensional coordination, was taken, and the result can be called systems housing.

The building frame is a structure of columns and beams.

The standard floor level for a unit is set at 240mm above the floor of the building frame, and the resulting space is used for pipes. The floor is built by a special method that improves the insulation of percussive sounds. Using. them before they wear out. Improving the replaceability of equipment parts and pipes lengthens the life of the entire house. The sanitary systems can therefore be freely located, and there is greater flexibility when undertaking remodelling work. The structural plan and the plan of the mechanical systems are coordinated so that pipes and ducts do not need to pass through walls, floors, and beams of the building frame.

Modular coordination consistent with systems building is practiced throughout the building in order to promote efficient design and production by diverse teams working in parallel. Modular coordination functioned quite effectively because the building frame, exterior finishes and interior finishes were designed at different stages. Grid planning was also an important means of exchanging information in the process of designing with the participation of prospective occupants. For that reason, grids and dimensions that are commonly used were selected for the interior finishes.

4.1.1 Construction system for free planning

Each unit is freely designed within a building frame that consists of timber columns, beams and floor panels but includes no walls (with the exception of shearing panels). The construction system was devised so as to give architects freedom to locating the exterior walls and organizing the layout. Systematic dimensional coordination make it possible to provide diverse unit designs adapted to the lifestyles and demands of occupants.

The design of the units could begin after the building frame and the residential building had been designed and continue while the building frame is constructed. This procedure is based on a housing construction method called the *two-stage supply method*, which assumes the participation of the occupants. Independent coordinators make adjustments between the design of each unit and the design of the building as a whole. Most coordination work is a matter of interpreting the rules of design.

Diversity means both variation in plan at the time of construction and sufficient flexibility to be able to adapt to later changes in lifestyle. This project is intended to improve the life of the housing as a whole by making it possible to freely remodel the units in response to changes in lifestyle of family composition. The building frame must also be able to adapt to advances in mechanical equipment, and the high floor height make it possible.

4.1.2 Compact heating/cooling/water

Most people understand the advantage of building a very energy-efficient house - lower energy costs and reduction of fossil fuel use. Another advantage in building tight, energy-efficient homes is they need smaller heating and cooling systems than houses with air seeping in because the structure isn't tightly sealed.

However, when a house is built with minimal air leakage, it is essential to have an excellent ventilation system to maintain a healthy environment inside.

All-in-one systems are often called "Magic Boxes" because they combine all the functions of an HVAC system in one unit. One of the truly revolutionary systems is. These Heat Pumps, which functions as a ventilation system with heat recovery, also includes space heating and cooling and provides the household's hot water supply. (Heat recovery means that the heat -- or cooling -- already created for the stale air in the home is not lost. The temperature is transferred to the incoming fresh air.) This type of system is compact, provides healthy indoor air, and reduces energy costs.

Figure 9*: Assembling a building frame in Italy: the exposed solid wood floor/ceiling panels and the glulam frame nearly completed*

5 CONCLUSIONS

This kind of building systems could be instrumental in speeding up the delivery of new housing and making it affordable to people of all ages and incomes, including the self-employed. The typology is timber frame and core residential – adapting a tried and tested development model from such system buildings. By excluding internal fit-outs, the cost (to the developer/house-builder) of building new homes could be reduced by roughly up to 40 per cent, and the duration of construction be reduced by 25 per cent – delivering faster, cheaper housing. Just as importantly, this typology gave users more autonomy in creating homes they really wanted.

SE-structure® timber frame system and core residential is built in two phases:

Phase 1 includes the external envelope, party walls between flats, cores and common areas only;
Phase 2 includes all internal fit outs, and is undertaken by the home owner.

The developer/housebuilder delivers flats which are ‘ready to camp in’: they satisfy Building Regulations including thermal/acoustic insulation and fire regulations, and are fit to live in from day one. This provides maximum flexibility for new owners: those short of money can fit-out their flats over time, according to their finances; keen DIYers can choose to do much of the fit-out themselves, which will also keep costs down; and those short of time can choose to have the entire fit-out carried out by small contractors whom they appoint. It also means maximum flexibility in layouts: a single buyer might start off with a huge studio flat, adding partitions to create more rooms as and when needed – for example, when starting a family or to rent out a spare room.

ACKNOWLEDGEMENTS

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