

*Mass Customisation and Personalisation in
Architecture and Construction*

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**AUTOMATION, ROBOTICS, SERVICES:
EVOLUTION OF LARGE-SCALE MASS
CUSTOMIZATION IN JAPANESE BUILDING
INDUSTRY**

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Abstract

Japanese prefabrication and construction automation are often presented as genius and advanced strategies that were developed by companies, innovators and governmental institutions in the 70s, 80s and 90s of the last century. Often it is also discussed why large-scale industrialization and automated construction have only been successfully applied in Japan, and why innovators in other locations and environments cannot manage to build up similar structures. One helpful contribution to these discussions and questions can be given by an evolutionary view on the subject. Just as Takahiro Fujimoto describes today's performance of the Toyota Production System as a consequence of evolution (Fujimoto, 1999), the existence of large-scale and highly automated prefabrication of individual

buildings in the Japanese housing industry can be described as the outcome of a long-term learning and development process. Japan's advanced Prefabrication industry has been formed by a combination of continuous incremental and disruptive innovations and a unique socio-economic and socio-cultural environment (desire for new, fast changing markets, earthquakes, reduced human resources, service attitude) stepwise over time.

1. INTRODUCTION

Organizational culture in Japan is traditionally based on collective, non-hierarchical and informal decision-making (“ringi seido”), bringing information from customers and production directly to management and product design, allowing thus the company's organization to evolve and adapt over time. Although in Japan the term “Mass Customization” is not used, Japanese prefabrication companies are among the strongest performers, concerning the production of small batches of both consumer goods and individual customer-oriented and value-added buildings by industrialized, highly flexible and automated production systems. Mass Customization is a method which is historically deeply woven into Japanese organizational culture and service thinking. It has been developed so naturally out of history, mentality and culture, that it is even difficult to find an explicit expression for this strategy in Japanese science.

2. FROM JAPAN'S TRADITIONAL ORGANIZATIONAL CULTURE TOWARDS TPS AND TOYOTA HOME

Since prefabrication has been deeply connected to Japanese architectural culture and tradition, the Japanese timber construction can be considered as an early example of

high-level prefabrication in the building industry. Additionally, Japanese tradition is closely related to a strong favour for order, standardization and systematization. An important activator for early prefabrication can be found in the famous Ken, a 1:2 relation proportion and measurement system. Furthermore, Tatami mats, the traditional Japanese floor finishing, principally follow strict grids and order systems (Osamu, 1994). Having usually an edge length of 85/170 cm Tatami mats can be combined in a lot of variations in order to shape the room's dimension, which will end-up always in an exact number of mats, a necessity since the mats had continuously been changed between the rooms, according to their current usage. Two layouts became common: The Syugijiki-Layout always has two Tatami mats in its centre, surrounded by a number of additional mats, whereas the Fusyugijiki-Layout places several mats parallel in a strict orientation.

Today it is still usual, that a room size is expressed with the number of Tatami mats instead of square meters. Contemporary Japanese architects are at the same time familiar with these rules and measurement systems, and standardization often results in a particular multilevel grid, which can be found not only in the building's foot print but also as underlying rhythm in its elevations as well as its decorative and built-in parts, such as religious corners, wardrobes or shoji-screens (traditional Japanese sliding doors), allowing an easy combination or reconfiguration of rooms. Even some urban master plans follow these incremental measures since each building unit is related to a multiplication of Tatami mats. This very Japanese favour for standardization and measurement systems, generated a supportive environment for prefabrication already centuries ago, and up to today, engineers and architects have managed to keep this culture alive and advanced its state of the art.

First Approaches to Mass Production: Premos Home

The ignition for large-scale factory-based mass production of buildings gave Kunio Maekawa in the late 1930's with his Premos Home (Reynolds, 2001). He can be considered as the pioneer of modern Japanese prefabrication. Maekawa pointed out that a contemporary home should not just accommodate its inhabitants resting, eating and sleeping, but it should also facilitate cooking and cleaning, adequate light, ventilation and heat. New American houses often included those facilities. With their electric ranges, washing machines, refrigerators, flush toilets, heating and insulation, Maekawa also acknowledged that Japan was still a poor country and couldn't yet afford all these conveniences, but he hoped that mass production would soon bring them into Japanese homes.

Like many modernists, Maekawa believed that the building industry could emulate the automobile industry. He believed that "in the face of the current shortage of four million houses in our country, industrialization is the only far-reaching solution". The name of the project "PREMOS" was an acronym: "pre" for "prefabrication", "M" for Maekawa, "O" for Kaoru Ono, his structural engineer and professor at Tokyo University, and finally "S" for Sani'in Manufacturing Company. The project was a collaborative effort (joint venture). The first two Premos-Units were completed in 1946. The earliest full-scale version was known as "model #7". While maintaining the living unit of the Tatami mat as the basis for these minimal 52-squaremeter-units, Maekawa incorporated a system of self supporting honeycomb panels covered by plywood sheeting and shallow wood trusses to support the roof. Until 1952 the joint-venture produced more than 1,000

units in several variations but all based on the major ideas of “model #7”. (Matsukuma et al., 2006; Reynolds, 2001)

Influences of Local and Cultural Specifics

Kunio Maekawa established a technical basis for modern Japanese prefabrication. Nevertheless, a number of local characteristics gave an additional impact on the development of prefabrication in Japan. Important for the wide acceptance of prefabrication was also the ability of this culture to transform itself. A number of historical Japanese cities experienced dramatic changes during their (often rapid) evolution, e.g. by natural disasters like fires or earthquakes. Another habit characteristic for Japan was to also change the capital with the introduction of a new emperor. Entire cities were quickly moved and relocated, requiring strong and effective systems of measurements and sophisticated prefabricated frames in order to allow rapid and affordable transformation and relocation processes. Thus, major governmental and religious buildings were prefabricated using standardized and industrialized construction methods.

In contrast to European cultures where a transformation of historical buildings is generally connected with a loss of local spirits (*genius loci*), the Japanese culture has developed a spirit of continuous renewal. A major gash in Japan's history has been in 1867, when its stability was harshly tested. After centuries of international isolation, the country fostered the opening. This was followed by a rapid transformation into a modern industrial nation in order to maintain its power as an independent state.

However, this should not be the last challenge. It was at the end of World War II, when almost 30 % of Japan's housing had been destroyed. Due to the dramatic housing

shortage, the immediate and rapid deployment of shelter was required, initially prefabricated and characterized by poor quality. These uncomfortable living conditions dominated Japan in the post-war era. After covering that demand, people gradually started to increase their standards by asking for safe and durable high-quality houses. Again, one of the answers was prefabrication, where the industry managed to transform itself shifting from delivering prefabricated homes with poor quality to a premium class strategy of delivering individual, earthquake resistant and service-accompanied homes.

Sekisui Heim M1: Design for Production

Kazuhiko Ono developed in 1968, as part of his doctoral thesis at the Tokyo University, the legendary M1 system of Sekisui Heim. This three-dimensional modular kit was famous for its genius simplicity. It could reduce the complexity in order to allow industrial line-based production. The M1 was a prototype for merging multiple qualities, design and production aspects. The "units" based on steel frames perfectly suited to the industrial production and low number of components could generate a variety of possible solutions for the customer. In the 1970s, the M1 reached an annual and steady production of more than 3,000 units per annum allowing the investment in advanced automation.

Toyota Production System and Toyota Home

A further milestone in the evolution of mass customized building production has been set up by Toyota and the application of the legendary Toyota Production System (TPS) (Monden, 1983) into manufacturing of space units. After the Second World War, the Toyota Motor Corporation was initially seeking methods to increase its productivity

rapidly. During several visits in the factories of Ford and General Motors, managers of Toyota came to the conclusion that a production concept based on mass and variation production would never successfully and efficiently, especially under Japanese conditions (Ohno, 1988). In their eyes, the ability of a fast adjustment to the frequent change of market needs in Japan was essential for a new production system. Under these circumstances Toyota started to invent its own market-based production system, tailored on Japanese requirements: The Toyota Production System. The revolution was the extension of conventional material, and information flows (“Push Production”), into a new concept, based on current demands (“Pull Production”).

In a pulling production, the assembly line delivers only products, which were demanded to avoid stocks and overproduction. An integrated communication system called “Kanban” was developed to support the new information and material flow. The important aspect is that this process is basically triggered through the demand by a customer. Thus the factories’ output is “pulled” by customers, instead of former “pushing”, when the output has been defined by the factory management and storage capacities. The complete synchronization of production and customer demands also requires a strict synchronization between factory and suppliers, since previous work steps are only being executed on the request of subsequent steps, and that just-in-time and just-in-sequence.

Another achievement of Taichi Ohno was the application of a “zero-wastage-policy”. Since Japan got only a few economical supports after the Second World War, he was requested to find an efficient way to work with existing resources. Therefore, he disclosed seven major waste producers in his concept. The most common waste-producer according to Ohno was over-production: a product is being delivered without a

customer's demand. Finally in the 1970s, Toyota started to develop its housing business with Toyota Home, and started to produce prefabricated houses, transferring thus the Toyota Production System from its automotive section to the industrialized and production line-based manufacturing of buildings. During the following decades, all other main players of the prefabrication industry followed this newly set trend, installing the basic ideas of TPS in their plants, products and organizations.

Automated and Robotized Production as Sales Argument

In this section it has to be mentioned, that Japanese people in general have a very positive attitude towards, automation, robotics and technology. Several historical occurrences have shaped a unique view on advanced technologies. For example, in the 16th century the Japanese developed their own types of timepieces, i.e. "Wadokei" (Yoshida et al., 2005), which allowed people to adjust time measurement to their individual rhythm of work. Later on, the "Ningio Karakuri" which can be considered as the predecessors of modern automation and robotics in Japan, they had been popularized as mechanized toys for entertainment (Wißnet, 2007). Automation and Robotics in Japan gradually gained the image of being designed to serve people, and not the other way around. Furthermore, during times of extensive automation in the 20th century, companies rather shifted people into their service and development sections, than laying them off.

Furthermore, concerning upcoming challenges as the demographic change and population decline in Japan, again robotics (Service Robotics) and personal assistance technologies are widely accepted today as a potential solution. In Japan, the fact that a house is fabricated by using automation, robotics and other advanced technologies, has

extremely positive influence on the image of the producing companies and their products. Moreover, the steady success and increased automation of the main prefabrication companies like Sekisui House, Daiwa House, Sekisui Heim and Toyota, has been followed by a visible increase of their quality. So after decades of reliable products and services, the Japanese had developed a strong trust in their prefabrication companies.

Sekisui Heim – ERP Systems and BIM

After the successful application of the Toyota Production System (TPS) in the fields of building manufacturing, Sekisui Heim followed Toyota and adapted and refined TPS.

However, in the 1980s Sekisui came up with another essential innovation: the parent company Sekisui Chemical developed an innovative computer-based Enterprise Resource Planning (ERP) system for controlling the production and logistic flow. This ERP system was subsequently transferred to the Sekisui Chemical's subsections.

In the housing section, this ERP system laid the foundation for HAPPS (Heim Automated Parts Pickup System) (Furuso & Katano, 2006). The system translates floor plan and design requirements of architects and customers directly into production plans and data needed to operate automated production. It can also be used today, to develop new platforms, components and solution spaces. It assures a complete communication between suppliers, work steps on different sections, timing and feeding of the 400-meter-assembly-line. Therefore, HAPPS chooses for one building approximately 30,000 parts out of 300,000 listed items, arranging them just-in-time and just-in-sequence for production. Nowadays, Sekisui has one of the world's most advanced BIM systems, allowing more than 90% of all design and parts related information, to be directly

translated into production and assembly operations. Further Sekisui already uses BIM to manage delivered building products over time: customer relations, maintenance, upgrade offers, rearrangement and deconstruction.

3. JAPANS PREFABRICATION INDUSTRY TODAY

Japans housing industry is among the strongest worldwide. However, it has undergone a steady change and decline since the 90s. A maximum production peak was reached in 1994 with 573.173 newly constructed owner occupied housing units. Later in 2000 about 450,000 units were constructed and in 2009 the construction went down to just 318,000 units. During the peak times, the percentage of prefabricated houses, those being entirely prefabricated, was about 18 to 19 %. The today's quota has been decreased depending on the region to just 13 to 15 %.. However, also in conventional construction, a high amount of prefabricated elements are being used, which increases the actual percentage of prefabrication in the whole building industry, although, it is hard to express this phenomenon in numbers. The prefabrication of entire buildings could be broken down into about 80 % steel-based building kits, 15 % wood-based building kits and 5 % concrete-based building kits.

Table 1: Housing Maximum Production Peaks of Main Players of the Prefabrication

Industry

	Sekisui House	Daiwa House	Sekisui Heim	Toyota Home
Units/ year	78,275 (1994)	44,500 (2007)	34,560 (1997)	5,024 (2006)
(Peaks)				

Source: Yearly Financial Reports of Companies

Sekisui House which is still the main player in Japan's prefabrication industry, reached its peak in 1994 with a production of 78,275 housing units. In this year Sekisui's quota of the total building construction market was 5.3%. It is interesting to see that both Sekisui House and Daiwa House, the second largest Player in Japan's prefabrication industry, try to encounter the decline in the market by going into a developer position. Houses and apartments are developed, planned and constructed, in order to rent them later to customers. These houses and apartments are also based on mass customizable housing kits and ensure that the capacities of expensive automated production facilities are utilized to a maximum. Figures 1-4 are recent pictures from today's factories of the described main players, showing various scenes from the highly automated production processes that those companies have deployed, in order to produce enormous amounts of highly customized buildings.

Table 2: Housing Production of main Players in 2009

	Sekisui House	Daiwa House	Sekisui Heim	Toyota Home
Detached Houses (sold to customers)	17,389	8,586	10,300	4,302
Apartment Houses (sold to customers)	5,699	3,511	4,250	
Houses and Apartment Units (built and rent to customers)	32,000	29,021		
Houses sold with other brand names		1,729		

(Subdivisions)

Total	55,088	42,847	14,550	4,302
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Source: Yearly Financial Reports of Companies

4. TOWARDS ADVANCED SERVICE SYSTEMS

To manage the decrease in demand and to build up new ways of value creation, all main players are focusing more and more on the buildings' utilization phase, building performance and advanced Building Information Modelling (BIM), for managing the building life-cycle services. Sekisui House is working on modular upgrade packages for older model lines, allowing their owners to easily and continuously upgrade both building design and performance. Daiwa House cooperates with companies like Cyberdyne (HAL) and Toto (Intelligent Heath Toilet), in order to develop assistive technologies and advanced health care services related to residential applications. Sekisui Heim tries to gain a leading position in matters of sustainable low energy houses and builds up a system for reverse logistics and building re-customization with its Reuse House System. Furthermore, Sekisui Heim has built up together with its suppliers a BIM-based information management system, which allows dynamic data-management of the building, components, customers, maintenance and services. Toyota Home gradually improves its graded warranty and service models, with the intention of a long-term building maintenance and facility management. In case that Japans prefabrication industry continues towards a successful implementation of the mentioned life cycle services, and connects them to approved mass customization structures and customer integration strategies, a new prototype of construction industry based on the fusion of mass customization and building/household related services will be

introduced. The focus won't be on material, resource and labour input exclusively, but rather on a long-term customer relations and product-service systems.

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Figure 1: Coin Processing. First workstation in the production process of Sekisui House: The whole production process is highly automated and shows similarities to automotive manufacturing.



Figure 2: Robots position various steel components automatically to onto a laying table for frame elements. The laying table then carries the frame into the automatic welding station. Thus every 3-5 minutes a new basic frame element is generated.



Figure 3: Interior view of one of the two supply sides which flank the production line. The components and materials are supplied from the left side just in time and just in sequence to a small “preparation” area which can be seen on the right side. The preparation area is located next to the production line. Sekisui Heim.



Figure 4: On the 400m production line, the steel frame chassis passes several workstations. There Components and workers wait to complete the chassis just in time and just in sequence. A factory completes about 150 units (= 10-15 Houses) per day. The maximum speed of production is one unit every 1.5 minutes. Sekisui Heim. Sekisui Heim.