BOX CONSTRUCTION SYSTEMS APPLICATION PRINCIPLES

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As industrialized construction systems, box systems are employed in structures containing a high degree of service units, such as hotels, public housing blocks, student dorms, educational buildings, commercial structures, hospitals, and elevator shafts. In terms of material, box systems are manufactured as reinforced concrete, steel, or wooden units, and in terms of the construction system as closed or as open units.

The purpose of this study is to examine the applicability of box systems, which meet the changing requirements of users, can be scaled up or down, exchanged, or can be adapted to different functions in different places, to housing structures. Box systems have the potential to prevent the natural resources of our earth from being wasted, and, whilst being environmentally friendly, provide comfortable conditions to building users. Particularly for our country, which is located in an active earthquake belt, short construction times are another big plus of this system.

KEYWORDS: Box Systems, Industrialized Building

INTRODUCTION

Following the destructions of World War II, the rising demand for housing brought the concept of mass production to the foreground. Consequently, Le Corbusier designed housing that was standardized both in term of function and aesthetics, and Buckminster Fuller responded to this new building culture with his “Dymaxion House”. Fuller’s house was a factory-manufactured product with an orthogonal layout, in which the building shell was suspended from a central vertical post, and technologies from the aircraft and automobile industries were utilized. Fuller continued his work with the idea of a mobile house complete with contents.

The idea of factory-manufactured housing was first promoted by Peter Behrens and Walter Gropius in Germany, and by Richard Neutra and Buckminster Fuller in the United States in the late 1920s and the 1930s. Research was started to quickly overcome the housing deficit that had arisen in the aftermath of WW II. A connection was established between the functions of cars and those of dwellings labeled mobile homes. With demand booming in the 1950s, many new companies were founded in the U.S. While in 1959 there were 268 manufacturers of prefabricated housing in the U.S., this number has now dropped to 34 for various reasons.

The first bathroom cell application was the prefabricated steel Dymaxion bathroom, developed in 1937 by the American engineer Buckminster Fuller. 30 years later, Nicholas

Grimshaw developed bathroom pods in a circular tower attached to a student hostel in London. Much later, possibly influenced by Grimshaw's concept, Sir Norman Foster used steel toilet cells in the HSBC Building. The use of service modules in this office building shortened construction time and improved the construction quality of modular building techniques.

Following these first steps taken by the Americans, European architects put forward a host of new ideas on housing structures between the 1930s and the 1970s. In particular the work of Jean Prouvé in this field has helped to promote modular unit design. In 1950, at the request of the French government, Prouvé carried out a study of 14 variations of two different construction types suitable for mass production based on a metal skeleton to develop various housing schemes. Featuring comparatively rich façades for its time, this mass housing catered to middle- and high-income families. At present Richard Rogers is one of the foremost architects working on functionally appealing, aesthetic, and easy-to-maintain housing modules. The focus in mass-produced housing has now begun to shift from functional flexibility and ease of construction to energy conservation. Rogers' futuristic "Zip Up" program represents the concept of sustainable architecture. In this system beams can be selected from within numerous elements to enable personalized homebuilding. Rogers' aim was to promote his idea of "autonomous human settlements"; his design included a proposal for a small ecosystem with independent wastewater and refuse removal and self-sufficient energy production.

Around the same time, the Austrian architect Leo Kaufmann developed a modular system highly suitable for housing functions. The "FRED" system designed by Johannes Kaufmann could be compared with Lego bricks. By placing modules sized 5 x 5 m side by side and one above the other, 10 different façades can be implemented. For another system called "SU-SI", very similar to the "FRED" system, a transportable prototype has been developed; the entire structure can be assembled on site in just 5 hours. In recent times Leo Kaufmann and the Swedish architect Johannes Norlander have been working on this topic. Their research regards various functions and form variations tuned to client specifications, such as garden sheds, toilets, hospitals or campsites, universities, etc.

Box Unit Systems

As with carcass construction or prefabricated structures with load-bearing wall panels, modular box unit systems are composed of a combination of rods or surface load-bearing elements. The basic problem in the modular box unit construction system is how to join the individual box together. The tolerances between the individual box units are essential. Box units systems are highly advanced as to the industrialization of building construction, in other words, they are systems with a high level of industrialization. Box units are three-dimensional spatial elements formed by the combination of wall panels and floor units. These systems, constituting an advancement of heavy and light-weight panel systems, are being preferred to achieve a high degree of completion through factory manufacture of the product, i.e. the building. The development of the box unit system makes it possible to manufacture an entire completed product in the factory.

"Box-module structures" are buildings with a fireproof and permanent design in steel and concrete construction. Here the entire structure is factory-built, then split into modules, and transported to the construction site. The features and advantages of cell-module systems can be summarized as follows:

- The units' structure consists of steel and concrete building materials and elements. Therefore these systems offer better durability and higher flexibility than conventional constructions.

- 60-98 percent of the work can be carried out in the factory.
- With the mechanization-based construction method it is possible to achieve the same quality as manpower-based workmanship.
- Prefabricated modular structures can reach the same service life as buildings constructed with traditional techniques.
- The most important advantage of cell-module constructions is that they are time-saving. Factory building enables production in a controlled environment unaffected by weather conditions.
- In box-module constructions, only the foundation and infrastructure elements are built on site.
- It only takes around 50 percent of traditional construction time to complete such structures. These constructions can be split into sections and rearranged within the building site or on a different plot; they can even be resold for use at another location.
- Realization of single- or multi-story structures (up to 7 stories) is possible, both as self-supporting structures and as additions to existing buildings.
- The dimensions of factory-built units are assigned in accordance with statutory restrictions on transport.
- These structures are built from fire-resistant materials and allow employment of a variety of materials, e.g. brick cladding, concrete floor elements, and masonry-concrete walls.
- Mechanical systems such as systems for gas, electrical power, fuel, and hot water are combined and factory-assembled as module units, and can be transported to the site without sustaining damage.
- Installation and testing of mechanical systems and the creation of a controlled space is easier in these structures as compared to conventional systems. Thus an entire school can be completed without having to rely on different gangs of workmen.
- Modular units can be applied to structures with a wide variety of functions, from residential homes to fast food restaurants.
- On-site construction is expedited. Speedy construction translates into shorter construction times, faster return of investment cost, and more benefits to the client.

Figure 1: Office Building (Detail, 2001-4)

- Disruptions during construction are avoided, and no damage to neighboring buildings caused during construction.
- This method is suitable for buildings containing a high degree of service units.
- Factory-built uniform or repetitive units provide ease of transport and ensure scale economy in production.
- Construction is not affected by weather conditions.
- Quality assurance at a high level is best achieved through off-site production and controls carried out prior to installation.
- Construction is safe due to the use of modular units, allowing inspections at the manufacturing stage.

In addition to this, construction with cell systems also provides the following features of industrialized structures:

- Structures are highly durable and can be planned flexibly to meet changing requirements.
- The construction elements are being standardized without restrictions to design. So it becomes possible to compose structures by choosing from a catalogue of ready-made elements, and to replace elements whenever required (Figure 1) (Eşsiz, Koman, 2004, Eşsiz, Koman, 2005; Gras, Armer Clarke,1994).

Classification of Box Systems

As with carcass construction or prefabricated structures with load-bearing wall panels, modular box-units are composed of a combination of rods or surface load-bearing elements. The basic problem in the modular box construction system is how to join the individual boxes together. The tolerances between the individual boxes are essential. Box systems are highly advanced as to the industrialization of building construction, in other words, they are systems with a high level of industrialization. Boxes are three-dimensional spatial elements formed by the combination of wall panels and floor units. These systems, constituting an advancement of heavy and light-weight panel systems, are being preferred to achieve a high degree of completion through factory manufacture of the product, i.e. the building (Figure 2).

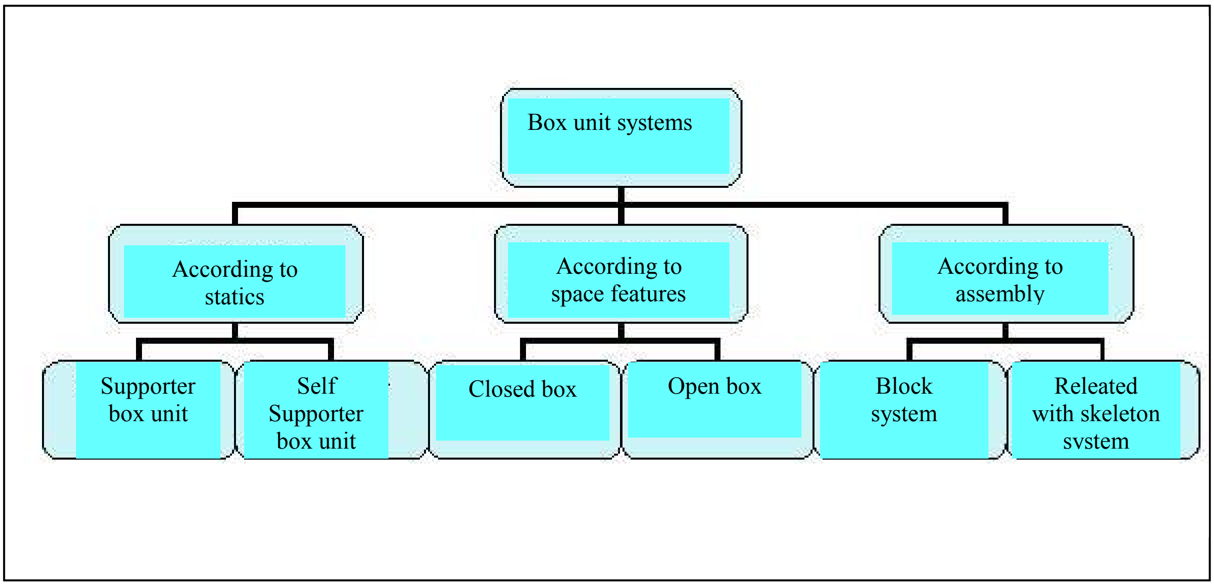

Figure 2: Classification of box unit systems (Eşsiz , Koman, 2005)

The development of the box system makes it possible to manufacture an entire completed product in the factory. “box-module structures" are buildings with a fireproof and permanent design in steel and concrete construction. Here the entire structure is factory-built, then split into modules, and transported to the construction site. Today, box systems find application in increasingly diverse fields, since the employment of such systems in construction is associated with advantages such as cost reduction, quick mounting, timely completion of works, and minimization of material losses, thus serving to create higher-quality physical spaces.

Over time, the requirements of building users are likely to change. At the same time, certain construction elements tend to wear out faster than the remainder of the structure. Therefore, the economic and ecological approach in developing countries is to extend the service life of existing buildings through whatever subsequent improvements are deemed appropriate. In developed countries, however, one feels the need to adopt buildings in order to preserve city skylines and to keep pace with technological developments. Apart from all this, buildings that become dysfunctional are liable to become environmental hazards. In the light of economic and ecological conditions, one of the principal factors to be taken into account at the design stage of present-day structures, for the reasons stated, is adaptability. Designs that facilitate potentially necessary adaptations serve to extend the functional life of buildings in the long run.

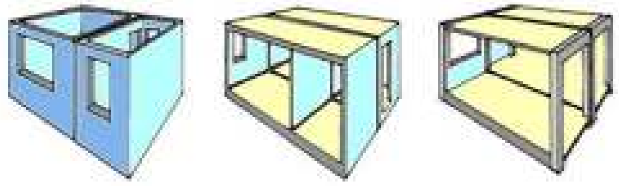

Figure 3: Classification of box unit systems

The size of the three-dimensional modules is determined by transportation and erection considerations. Accordingly, they are mostly of one- storey height (2.80m-3.00m) and 3.50m-

4.00m width, which is the maximum permitted in various countries by traffic regulations. Their length is limited due to weight constraints to 6.00m-10.00m. The resulting weight of 300-400 KN is within the limit of what heavy mobile cranes can handle at the minimum reach required for erection, namely, 10m-15m. Modules produced from lightweight concrete can be slightly larger. The three-dimensional modules can contain more finish works than other prefabrication forms. The systems that employ them can therefore fulfill, better than others, the ultimate objective of industrialization a maximum saving of human labor onsite. However, they also suffer from several limitations. A ‘friendly’ building layout, which can be effectively partitioned into three-dimensional blocks of required dimensions, is an essential for their employment. In this respect three dimensional units are much less flexible then linear or even planar elements, which can be used in almost any architectural layout with relatively minor adaptations. Another limitation of these units is their considerable weight and bulkiness, which make transportation and erection rather involved and costly process. Finally, the use of three dimensional units in buildings in excess of three or four stories requires special structural adaptations, which again make them less competitive with conventional or other prefabricated methods (Waszawskı, 1999).

With Respect to the Production of Box Units

These systems can be categorized as follows (Figure 3).

Systems with Partioned Box-Units

The prefabricated box units are transported to the building site, the assembled to form the box-unit. Box unit components are prefabricated and assembled to form the box unit in the factory. All necessary finishes are applied and thus prepared ready for use units are delivered to the site for erection.

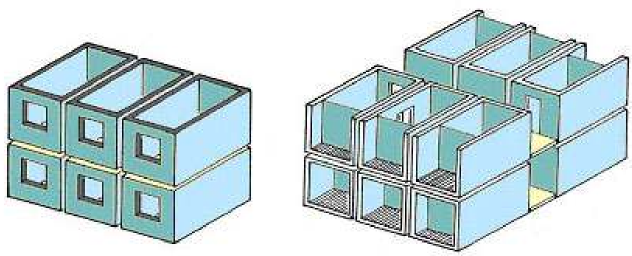

Figure 4: Box systems (Eşsiz , Koman, 2005)

Systems with Monolithic Box-Units

The box-units are is cast as a whole the delivered to the site.

With Respect to the Design of Box Units (Figure 4)

Systems with Opened Box-Units

According to Koşaner, the box units consist of load bearing cross walls or load bearing wall longitudinal walls. The opposite walls are left open. In the case where the module is left open in the longitudinal direction,” considerable advantages can be obtained. The spans are shorter and the structural stability of the building is ensured by the cross walls. Good stability in the longitudinal direction is also provided by interconnection of the units to form a closed portal frame like assembly. Also cross walls serve as separate party walls which are instrumental in increasing the degree of insulation between adjacent dwellings. Alternatively the modules may be so arranged that the dividing walls each comprise a single leaf only. In the instance where the module is left open in the longtional direction, the span of the floor imposes constraints on the structural design. For this reason, the method has not been widely used (Koşaner,1991).

Systems with Closed Box-Units

In the closed-box system a space with defined dimensions, delimited by its walls and floor, is determined. These boxes have no potential for expansion (Garas, Armer Clarke,1994). They are being produced in three types: fully closed, with open façades, and with open top. Closed boxes are completely factory-manufactured units ready for installation. Buildings constructed with closed box do not offer flexibility in terms of planning. These systems very much resemble “cross-like” systems implemented in systems with large panels, where all walls are load-bearing or “transverse” systems where the load-bearing walls are arranged orthogonally to the façade (Eşsiz, Ö., 2002a, 2002b). Closed modules permit the free combination of modules. The best known example is Habitat Montreal 67.

In closed modular box unit systems, all sides of the unit are completely delimited, thus determining the size of the space. The cell size is restricted by transportability. For road transport, the width of the cells must comply with the traffic laws. Consequently, the modules’ length in either direction must not exceed 2.40 m and 3.30 m respectively. Since the size of the space depends on its dimensions, these cells are more suitable for housing. Closed box units form a rigid structure within themselves. They are joined together just like masonry structures. By placing differently sized cells on top of each other in different ways, a number of variations become possible.

Modular Cells Independent from Structures

Modular cell elements may also be used as system complements within prefabricated or non-prefabricated load-bearing structures like frames, cores, tubular, load-bearing wall panels or hybrid systems. Here the cells are not load-bearing, but rather borne by the load-bearing structure. Those cells are elements such as kitchens, bathrooms, elevator shafts and stairwells. Since they contain the entire equipment and all workmanship is completed in the factory, they are the units with the highest degree of industrialization.

Figure 5: Green Modular Building.(http:// Schools benefit from green modular construction.htm)

Ecological Box Systems

A green home uses less energy, water and natural resources; creates less waste and is healthier for people living inside. Green Building also means a more resource efficient building process. There is reduced exposure to mold, mildew and other indoor toxins, reduced waste streams, conservation and restoration of natural resources along with enhancing and protecting ecosystems. In addition there are the economical benefits like lower operating cost, enhanced durability, less maintenance and optimized life cycle economic performance.

Building a home using modular construction is a very effective way to make the best use of materials, manufacturing efficiencies and protects the framing process from the elements. Keeping all materials dry and away from the elements helps to reduce the chance of mold and other toxins from later contaminating the indoor air quality. Local communities are looking for ways to minimize the impact of construction on local infrastructure at the building site. By building with modular construction you can reduce the traffic to a building site by delivering a house that is 80% complete in one day as opposed to having trucks delivering materials day after day. Modular construction minimizes the disturbance at the site and will reduce neighborhood traffic (http://www. sustainable environmentally friendly Modular Home Construction.htm).

Modular construction can sometimes be greener than site-built construction, due in part to reduced site disturbance, decreased on-site construction time, and less waste production as a result of factory-based material recycling(Figure 5) (http:// Schools benefit from green modular construction.htm).

Prefabrication and Modularity are new eco-buzzwords on the menu this year. From homes to furniture, designers are beginning to employ new methods of construction and transportation to cut waste and energy consumption, cut production costs, ensure safety, and achieve greater overall methods of sustainability. Consistency in dimensions and design makes modularity and prefabrication.

Figure 6: Otel-Bezau-Avusturya, Mimar; Heopold Kaufman, 1996. (Detail, 2001-4)

Prefabrication: (often relating to large scale production such as homes) is the practice of assembling parts in a factory, then transporting the complete or partial moduler to the construction site. Prefabrication also relates to small scale design such as furniture- i.e. parts of a desk are cut, stamped, drilled, and prepared in the factory then sent, with all its components, to be assembled on site. On the left site you see an example of box unit system. The hotel consist of a heterogeneous accumulation of buildings of different dates. It was to be extended by a further bedroom tract with a half for various events. Since the hotel is in use almost year round, a very short construction period was necessary. The solution was found in a series of prefabricated containers that could be stacked on top of each other. The 7.50x4.99m boxes aare self supporting, so that no primary structure or additional bracing were required.Services were laid in the voids between the cells. Only the glass bathroom walls and the wood furnishings had to be installed subsequently.The boxes and roof were erected in two days and after only a month, the extention was ready to receive quests (Figure 6) (Detail 2001-4).

Modularity: In design pertains to separate modules of the whole that can be used interchangeably. When pertaining to a home, it means that a general design is created so that modules within the exterior dimensions of a home can be moved around. In general, modular design benefits the consumer because the interchangeable components can be moved around to better accommodate your space, style, and needs. Since the modules are constructed in a factory, a higher quality of construction can be ensured than on-site, stick-built homes. The fasteners are accurately applied, materials are cut with more exactness, and since they have to withstand transport, everything is tighter and more secure. This extends the lifespan and cuts on upkeep. Modular prefabrication also saves significant amounts on their waste. While 30-40% of the material from a standart home construction site is carted off to the dump, modular homes generate only about 2% waste. That is a pretty large gap. Additionally, since the duration of construction is shorter, the cost is lower. This concept improves efficiency and ability, meanwhile achieving all of the modular prefabrication benefits.(www.Ecolect - A Sustainable Materials Community.htm)

It is faster: The construction period is reduced to three days;service installations are prefabricated and incorporated more swiftly; and building firms are less dependent on the weather and time of year.

It is more economical: The shorter assembly period represent a big potential cost savings and life-cycle costs are redued as a result of the simple method of removal and disposal.

It ensures a higher level quality: All componenets and services are installed at works to a constant quality level and with comprehensive quality controls, and the risk of accident on site is reduced.

It is environmentally friendly: Building sites are cleaner; waste products are avoid on site, and the reuse of components is simplified by the scope provided for a damage free dismantling and removal of elements (Prochiner, 2001)

CONCLUSIONS

Today, scientific and technological developments are taking place at a great pace. New technologies outdating the earlier ones are constantly introduced. As a result of these developments, the use of industrialized systems in construction has become topical. The following are the most sought features of industrialized construction systems:

- Structures must be highly durable and modifiable to be able to meet changing requirements.

-It must be possible to standardize the construction elements without restrictions to design, to compose structures by choosing from a catalogue of ready-made elements, and to replace these elements whenever required.

As industrialized construction systems, box systems are employed in structures containing a high degree of service units, such as hotels, public housing blocks, student hostels, educational buildings, commercial structures, hospitals, and elevator shafts. In terms of material, box systems are manufactured as reinforced concrete, steel, or wooden units, and in terms of the construction system as closed or as open units. Today, box unit systems find application in increasingly diverse fields, since the employment of such systems in construction is associated with advantages such as cost reduction, quick mounting, timely completion of works, and minimization of material losses, thus serving to create higher-quality physical spaces.

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