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VOLUME 1



Organizers:

The Chinese Research Institute of Construction Management

North China Electric Power University

Beijing, China

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INDUSTRIALISED, FLEXIBLE AND DEMOUNTABLE BUILDING SYSTEMS: QUALITY, ECONOMY AND SUSTAINABILITY

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Abstract: Industrialised / Flexible / Demountable (IFD) Building Systems stand as key methods to achieve quality, economy and full sustainability in architecture: INDUSTRIALISED, to amortise a process capable of simplifying the production and reaching a high level of quality; FLEXIBLE, to accommodate functional changes over time and in the space without destroying partitions or/and exterior walls; and DEMOUNTABLE, to meet the needs for reconfiguration or even relocation without demolition. Factory-made components can easily incorporate the precise detailing required for an adaptable construction, as proposed by a series of building systems presently or prospectively available worldwide and as demonstrated by some prototypes already operational notably in the Netherlands and in Japan.

Keywords: Building Systems; Industrialised Strategies and Technologies; Adaptability; Sustainability; Quality; Joints and Jointing; Open Systems; Individualisation

1 Introduction

The idea of producing buildings along an assembly line has fascinated architects and engineers ever since the Fifties. However, even if most components and some sub-assemblies are actually industrialised in many countries, construction is still an expensive trade-oriented site-intensive handicraft activity.

The 21st Century is now observing a major backlash against that situation. In the United States, notably, many young architects are clearly saying “No” to the actual way of building and proposing instead the way cars, airplanes and ships are built: *“We need a new vision of process, not just product... The world, and our clients, have seen what has been accomplished in other manufacturing fields : ships, airplanes and cars. Higher quality and added scope and features are there, along with lower cost and shorter time to fabricate. The old equilibrium between cost and time no longer holds. The mandate for change has now shifted to architecture. We cannot continue to build architecture at ever higher costs, longer schedules, and lower quality. We must act”* (Kieran and Timberlake 2004).

Applied to architecture, the strategies and technologies of industrialisation can generate better buildings at a lower cost, offering quality architecture to the vast majority of people. There is a plus: the precision that goes with factory production can generate simple and demountable dry-joints. Dry joints are essential to achieve without any demolition the partial or total reconfiguration required to accomodate the unavoidable changes affecting all human activities.

The Netherlands are paving the way in that direction. They recently added the sustainability agenda to the adaptability approach developed in the early Seventies by Niklas Habraken (explained in section 5.2): the Dutch government is promoting the development of “Industrialised, Flexible and Demountable” Systems (IFD). The IFD approach is warmly embraced by a number of functionally oriented architects and construction managers in the Netherlands and in the European Union.

The purpose of this paper is to explore the application of that IFD approach to the various types of building systems presently or prospectively available worldwide.

2 Industrialisation

Industrialisation is a generic organization based on quantity and offering an individualised finished product (Richard 2005).

(a) *A generic organisation* means grouping all the participants (manufacturers, assemblers, designers, managers, distributors, installers, etc.) into a continuous interaction, either as employees, sub-contractors or partners.

(b) *Based on quantity* means aggregating a large market to feed the continuity and to amortize the investment in a process capable of simplifying the production (Richard 08.2005).

(c) *Offering an individualised finished product* means addressing diversity through mass-customisation. Four strategies are available and frequently used by the other industries to generate individualisation within mass production: Flexibility of the Product, Flexibility of the Tool, Multipurpose Framework and Combinability (Richard 2006).

2.1 Industrialisation = Quality and Economy

Ideally, the large number of units to produce (quantity) distributes the cost of a process into very small fractions. In return, this process reduces the number of operations, simplifies them and brings more precision. The result is better quality at a lower cost, exactly like what happened in most of the other industries.

In Japan, industrialised housing production appeared a few decades ago: 3D modules and panels are factory-made on continuous assembly lines quite similar to the ones in the automobile industry and the outputs are easily customised. *“All the assembly lines visited demonstrate the capacity to accommodate the requirements of each client through flexibility of the tooling and combinability, reaching a high level of mass customisation. Each manufactured house in Japan is designed and produced according to the buyers’ needs and demands, while the design components are fully standardised or mass-produced”* (Richard and Noguchi 2006). One of these industries, Sekisui Chemicals, allows not only the possibility of dismantling the units to upgrade the house, but also to recycle and even relocate them. Toyota’s Housing Group is offering a “Super Skeleton & Intelligent Infill”, where the infill can be modified to respond to changing lifestyles within a support structure that does not change.

The costs of Japanese manufactured houses are $\pm 8\%$ more than with traditional in situ constructions, but the quality is incomparably higher and the after-sale services a major asset.

2.2 Industrialisation = Sustainability

Industrialisation is a force that can be a partner to sustainability. Eight points are backing that statement: the first three are related to an economy of means, the next four to factory production and the last two to adaptability over time and space (subject of section 4).

(1) The global organisation is feeding a continuous production using the same methods, knowledge and experience; instead of forming a new group for each new project (often with participants that have never worked together).

(2) Simplified processes take over from the long sequential handicraft operations of traditional construction and thereby reduce the total energy involved in the project.

(3) Working inside a factory avoids losing time over severe weather conditions.

(4) Modular coordination, bulk purchasing and factory applied finishes reduce wastes by 40 to 100% in comparison with the traditional construction site (Tam et al 2006).

(5) Factory conditions assure better quality control, thereby avoiding some unnoticed defects that require later repairs.

(6) The precision that goes with factory production reduces the site assembly operations while keeping the construction site clean and free of debris.

(7) Flexible components/sub-systems using dry-jointing methods allow for planning changes without the usual destruction of partitions associated with renovation.

(8) Demountable components/sub-systems using dry-jointing methods allow for a major reconfiguration and/or relocation of the building without demolition waste.

3 Industrialised Building Systems

In an industrialised building industry, the products are not buildings but mainly Building Systems. A Building System is a set of parts and rules where the details are solved so as to generate many different and customized buildings (Richard, 2005). Therefore, the construction method is not re-invented each time a building is planned, as it is still the case with the traditional set of “working drawings”.

An Industrialised Building System implies maximal factory production, leaving only the final assembly to be done at the site. Although, in some cases, the factory will be brought to the site as described in section 7.3-“I”.

The main parts of the building system are its sub-systems, which generally correspond to the main functions of the building. A building system is usually composed of five sub-systems: STRUCTURE, ENVELOPE, PARTITIONS, SERVICES and EQUIPMENT.

Some components or sub-systems are often merged into a single element, in order to further simplify the operations while reducing the costs. For instance, a load-bearing sandwich panel might meet both structural and envelope criteria, a modular closet kit can provide a partition between two rooms of the same apartment when the appropriate soundproofing measures are taken, etc. Integration within the sub-systems is also a necessity, as each sub-system must also offer provisions to interface with the other sub-systems.

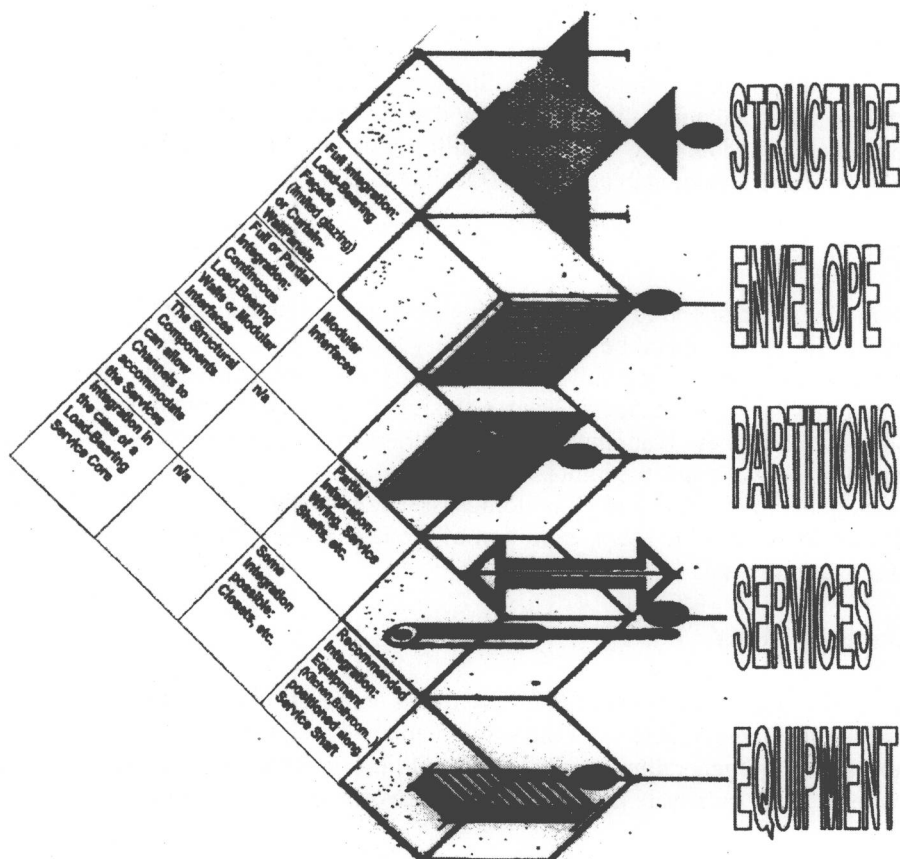


Figure 1 Integration within the sub-systems

Many systems do not include some sub-systems: either because a sub-system is outside their technological scope or to leave it to many options, in order for instance to be compatible to different environments. There is then an opportunity for many manufacturers to offer options and participate to the system, as long as their dimensions and their interfacing details are compatible: that is the realm of the “Open Systems”.

An open system can exchange parts, components and even sub-systems outside its original production environment. They are then considered “interchangeable”. Interchangeable parts, components and sub-systems are the constituents of an Open System. Open Systems are advantageous: they offer more choice to the user and a larger market to any manufacturer that abides by the rules in terms of quality (performance criteria), dimensions (modular coordination) and interfaces (compatibility). In the European Community, there is a large movement towards the exchange of products and components within an Open Systems agreement, a movement called ManuBuild: *“The ManuBuild vision is of a future where customers will be able to purchase high quality, manufactured buildings having a high degree of design flexibility and at low cost compared to today. For the first time, inspirational unconstrained building design will be combined with highly efficient industrialised production..... ManuBuild targets a radical breakthrough from the current ‘craft and resource-based construction’ to ‘Open Building Manufacturing’, combining ultra-efficient (ambient) manufacturing in factories and on sites with an open system for products and components offering diversity of supply in the market”* (ManuBuild 2006).

4 Industrialised, Flexible and Demountable (IFD) Systems

There is a constant need for change in each and every building: society and technology are in perpetual evolution whereas individuals are different from their neighbours and different from themselves over time. Very often a building program becomes obsolete even before the building is completed.

Industrialised Building Systems offer increased adaptability to change through the precise jointing features of the factory-made components or sub-systems. Since most factory-made components or sub-systems are designed to facilitate site installation, they can also be dismantled and generate change without any partial or total demolition, thereby addressing the sustainability agenda and contributing to the formation of Industrialised, Flexible and Demountable systems (Quah et al 2004).

4.1 Flexible Systems

A building system that can respond to changing living patterns will be considered “flexible”: usually, all the sub-systems besides the Structure will be involved.

For instance, the bedrooms of young children are visually close to their parents whereas the contrary will be demanded when they become teenagers. Then, a flexible partition sub-system with provisions to integrate the wiring will allow for a new planning layout with the same components, without destroying gypsum board walls or having to “wet-tape” the joints.

Flexible systems generate “user friendly” buildings: freedom of choice for the first-use users, opportunity to modify the layout for successive users, evolution of the layout over space and time, individualisation and elimination of renovation waste.

4.2 Demountable Systems

A system capable of major reconfigurations or even of a complete dismantling for rebuilding somewhere else will be considered “Demountable”. All the sub-systems will be involved, including the structure.

Demountable systems are generating “multi-lives” buildings that can be reconfigured to new functions or relocated elsewhere: their sub-systems are suited for worthwhile re-use and wasteful demolitions are eliminated.

5 Specificities of IFD Systems

Most Industrialised Building Systems presently or prospectively available worldwide are or could be made Flexible and Demountable; but at a different degree. Two conditions must be met: dry joints and adaptability framework.

5.1 Dry Joints

Dry-joints call for disciplined detailing. Structurally, those joints will most likely be bolted, although post-tensioned bars could be used but their dismantling is much more complex as the tension has to be progressively reduced to zero. The operations are quite easy with precast concrete as that material is offering fireproofing and soundproofing by definition; an easy-to-crush lightweight grouting should then be used to fill the connection nests. In the case of a steel structure, the simple solution would be embedding the components into a concrete overall, instead of the usual gypsum cladding or sprayed layers. For the exterior wall panels and the partitions sub-systems, the interfaces can be sealed with a “peel off” compound although many sub-systems will offer integrated gaskets. Dry connections can be expressed architecturally or concealed.

5.2 Adaptability framework

The SAR (Stichting Architecten Research) approach, developed by Niklas Habraken, is offering an appropriate framework to generate adaptability in architecture. It is based on a common denominator called “Support Structure” and allows for variations to accommodate the individual needs through the permutation of “Detachable Units” (Habraken 1976).

The “Support” would normally be limited to the structure, the collective circulations and the wet services main conduits. The building is completed with the “Detachable Units”, which include the external envelope panels, the partitions and the service & equipment sub-systems. These Units can be interchangeable, available at building products outlets and in most cases installed by the occupants themselves.

The “Detachable Units” are governed by the “Support”, which provides a series of served and serving zones together with intermediate margins that can be allocated to one or another zone. Strategic openings are available to accommodate growth or size reduction.

The SAR approach is now pursued by the “Open Building” movement, rallied under the Working Commission W-104 of the International Council for Research and Innovation in Building and Construction (CIB). The “Support” is called “Basic Building” by the CIB W-104 specialists (Kendall 2004) and most of the time they will include the external envelope within that designation, whereas the other “Detachable Units” are called “Infill”.

6 Applying the IFD approach to the Nine Types of Building Systems

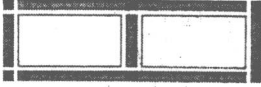


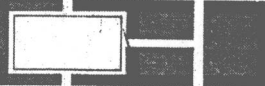
As buildings are site-related and as technology is normally factory-related, three basic building systems categories can be outlined. They are the basic colours (i.e. blue/red/yellow) from which the 9 types of building systems are generated (Richard 2005): the Site-Intensive KIT-OF-PARTS (A- Post & Beam, B- Slab & Column, C- Panels, D- Integrated Joint); the Factory-made 3D MODULE (E- Sectional Module, F- Box); the HYBRID (G- Load-Bearing Service Core, H- Megastructure, I- Site Mechanisation).

The following tables will describe how the 9 types of systems can be brought to be Industrialised, Flexible and Demountable (IFD). Each table will indicate the basic nature of each category and of each type within that category. For each type, the tables will summarize the specific INDUSTRIALISED strategies and technologies as well as the levels of FLEXIBILITY and DEMOUNTABILITY.

6.1 Site-Intensive KIT-OF-PARTS

In general, the Site-Intensive KIT-OF-PARTS with bolted dry joints offers appropriate ductility in earthquake situations and can serve low and mid-rise buildings, up to ± 20 stories. To reach the high-rise status, three options are available: additional bracing, use of mechanical formwork to cast in situ walls and/or floors in order to obtain a monolithic structure or adding a vertical circulation core cast in situ with sliding formwork (see 7.3-“I”).

Table 1 Applying the IFD approach to the Site-Intensive KIT-OF-PARTS

© Roger-Bruno Richard 2004		INDUSTRIALISED Strategies and Technologies	FLEXIBLE and DEMOUNTABLE Operations
I- Site-Intensive KIT-OF-PARTS ("Meccano")	All sub-systems are made at specialised plants and transported separately = important jointing operations at the site.	Distributing the tasks to a large number of available manufacturers = reduction of the initial capital investment	By definition, all the sub-systems can be relocated and demounted when dry joints are used.
 A- POST & BEAM	Skeleton requesting horizontal and vertical infill	The frame acts as a connector to the infill panels	Adaptability on three axes
 B- SLAB & COLUMN	Simplification through the introduction of a single horizontal element	Possible integration of the services within the structural slab	Adaptability on two axes
 C- PANELS	Load-bearing flat components providing a linear distribution of the loads	Usually integrating the soundproofing and fireproofing performances	Adaptability limited to the structural bay
 D- INTEGRATED JOINT	Monolithic component simplifying the connections by locating the joints outside the geometrical meeting point	Simple single axis interfacings and accelerated site assembly	Adaptability conditioned by the geometry of the structural sub-system

The NEXT-21 prototype in Osaka (Osaka Gas 2000), designed under the direction of Professor Yositika Utida, as well as the Nikkenkei Open Housing System (NOHS) prototype in Kugahara, designed by Dr Shin Okamoto, are two significant examples of IFD systems.



Figure 2 NEXT21 in Osaka

The components themselves can offer multiple choices, like the many modular holes present on a piece of the Meccano set. As demonstrated by projects like GenterStrasse (Kossak 1994) in Munich, designed by Otto Steidle, multiple-corbels columns can be combined with other off-the-shelf components to generate a full-fledge IFD system.

The Descon system, developed under the leadership of William F. Dawson and only non-US winner of Operation Breakthrough, is a very clever Open System in precast concrete, innovating and generating variations within the realm of available technology. Descon was inviting local and regional manufacturers to bid on the basis of three documents: performance criteria, modular coordination rules and interfacing details. *“D/C has no manufacturing facilities for off-site production. All elements of the system are produced in existing local plants, as in the case of pre-stressed concrete, or in regional plants as in the case of bathrooms, kitchens, etc.”* (HUD 1973).

As the jointing of an Integrated Joint system is done away from the geometrical meeting point of the axes, only two parts are meeting each other at each joint. The best example of an Integrated Joint system would be Componoform (Componoform 2003): it is basically a joint-to-joint system, generating an open skeleton identical to the configuration of a Post & Beam system as far as the other sub-systems are concerned.