“IFD” SYSTEMS = OPEN BUILDING “PLUS”

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ABSTRACT

The Open Building approach should benefit more from the actual strategies and technologies offered by an INDUSTRIALISED system, since it is aiming at offering adaptability to the large majority of people. Such a large market justifies the investment in a process capable, in return, of simplifying production and reducing the cost while assuring better quality and precision. The precision achieved in factory production can generate components detailed for easy and fast installation: when dry joints are employed, an easy installation naturally implies an easy disassembly, leading to adaptability through space and time. A FLEXIBLE system can be readily available by grouping the usual sub-systems composing the Infill: personalized exterior wall panels, movable or demountable partitions / equipment and variable service distribution network. When the needs for change go beyond the realm of the Infill, the Support Structure should be served by a DEMOUNTABLE building system, allowing for an easy reconfiguration and/or relocation of the building and/or the reuse of its components for another building. Industrialised, Flexible and Demountable (IFD) systems are available in the three categories of building systems; they are offering complete adaptability through space and time without any demolition, as per the sustainability agenda.

Keywords: Adaptability, Building System, Industrialization, Flexibility, Disassembly.
INTRODUCTION

In the residential Open Building approach, the base building is a generic framework, called “Support Structure”, meeting the goals of a community of residents and usually resulting from their participation in the development process. “The Support is the permanent, shared part of the building which provides serviced space for occupancy...Which criteria any given Support will have to accommodate becomes a function of project economics, site conditions, the preference of various stakeholders and so on” (Kendall and Teicher, 2000). The Support is accommodating a series of “Infill” components selected by the individual occupants of a dwelling unit and adaptable to their specific needs through space and time.

As our societies face ever changing needs, the Support itself will eventually require some form of transformation of its own; probably sooner than later. Industrialised, Flexible and Demountable (IFD) building systems should then be available to generate affordable and interactive Support Structures: innovative models have to be developed, addressing market dynamism and client demands in a more effective way (Di Giulio et al, 2005).

INDUSTRIALISED BUILDING SYSTEM

Duality within housing

The Open Building approach has always considered industrialised production as the natural source of Infill components. But “Housing is a bulky consumer-oriented commodity; yet at the same time it embodies a jointly held social asset ... That housing has never achieved the straightforward match with consumer preferences achieved by other industrial products is partially a result of that duality” (Kendall and Teicher, 2000). As our societies are more and more experiencing Mass-Customization, that duality can perhaps operate differently; notably since the quality achieved by factory production can facilitate the jointing process.

Simplifying the production

Industrialisation is first and foremost a mathematical equation: a generic organisation will aim at a large market (quantity) to amortize the initial investment in a process capable, in return, of simplifying the production in order to offer an affordable and diversified product to the large majority of people (Richard, 2007).

The appropriate level of industrialisation is reached when an innovative technology is short-cutting the linear tasks of the traditional methods. In a single operation, for instance, the extrusion process generates the complex profile of a curtain wall frame. In a single operation, the extrusion process generates a pre-stressed hollow core concrete slab; thereby eliminating the setting and dismantling of formwork at the site, maximizing the compression features of concrete, minimizing the deadweight and reducing the construction wastes.

The immediate effect of simplifying the production is, by definition, a reduction of cost. But that is not the most important benefit. Factory production is generally capable of much more precision than traditional construction. To avoid spending the gains achieved at the plant, factory-made components or sub-systems have to be fast and easy to install at the site: when dry joints are employed, they are then fast and easy to disassemble.
Dry Joints

Dry joints are required to achieve full disassembly without destroying any significant part of the structural sub-system.

Dry joints exclude by definition any welding, bonding or cementing. Dry joint will be mainly mechanical: bolting, post-tensioning or locking. But a locking device requires a thorough quality control process, in order to make sure the slots are nested in the right place for good; that is perhaps the reason why they are rarely used.

Specificities of an industrialised building system

An industrialised building system is a set of parts where generic details are solved and made available before actual as well as different buildings are planned. In other words, the details and their rules are the same for a large quantity of buildings, but the planning of those buildings will vary.

Mass-customization and the Open Building approach

Industrialised building systems can offer individualised and personalized buildings by adopting the four “mass-customization” strategies enforced in most industries: 1- Flexibility of the Product, 2- Flexibility of the Tool, 3-Multipurpose Framework and 4- Combinability (Richard 2007-10).

The “Open Building” approach is already tuned to two of the four strategies: as mentioned above, the “Support Structure” is basically a “Multipurpose Framework” and the “Infill” is relying on “Flexibility of the Product” to operate changes notably with the partitions, the dwelling unit equipment (kitchen, bathroom, etc.) as well as with the facade panels. “Flexibility of the Tool” is the appropriate method to generate sub-variations whereas “Combinability” allows for multiple configurations out of a set of interchangeable components.

The sub-systems

Basically a building system is grouping the components required for each sub-system. Five sub-systems are usually recognized: Structure, Envelope, Partitions, Equipment and Services. Of course, some sub-systems may integrate more than one function. For instance a sandwich load-bearing wall will perform both as a structural component and as an envelope component; an interior load-bearing wall can also be a partition; a partition can accommodate the electrical/electronic wiring within the baseboard; a closet can also be used as a partition; a factory-made kitchen-bathroom 3D module can also contribute to the structure; etc.

FLEXIBLE SYSTEM

A flexible system will offer a coordinated set of components to serve the Infill. In a dwelling unit, for instance, the parents will want the bedroom of a young child close to their bedroom, but when that child becomes a teenager, an opposite layout is most likely desired by both parties. Various factory-made components are currently available:

- Demountable partitions, removable panels supported by notched studs;
- Partitions, responding only to a ceiling channel and dismantled in a single operation;
• Mobile 3D functional modules, like the individual booths in a landscaped office floor or the personal capsules on casters which can be moved freely in a “loft;”
• Raised floor allowing for the relocation of mechanical and electrical services;
• Interchangeable envelope panels revealing the personality of the occupant, etc.

The best example of flexibility is the NEXT21 building in Osaka, designed under the leadership of Professor Yositaka Utida and built by Osaka Gas Corporation (Osaka Gas, 2000). Each apartment is showing a different layout, governed by the specific needs of its occupants. Many layouts have been changed completely since the “initial” construction was completed, while maintaining 90% of the original components.

![Figure 1: NEXT21 Adaptable prototype in Osaka](image)

A simple raised floor technology accommodates the various layout changes: a filtered rod with a rubber pad at the bottom and an OSB square piece at the top is the basic component, completed by square under floor panels. The exterior façade components are composed of different glazing units completed by colourful stainless steel interchangeable horizontal laths.

A similar approach is now being implemented in Japan under the name of “Kodan Support & Infill" (KSI) in the many projects built by Urban Renaissance Agency (UR) and also in some major high rise condominium buildings built by private developers, including the recently completed Fukuoka Island Towers.

**DEMOUNTABLE SYSTEMS**

When the needs for change go beyond the realm of flexibility, the Support Structure should take advantage of a DEMOUNTABLE building system, allowing for an easy reconfiguration and/or relocation of the building and/or the reuse of its components for another building: without any demolition as per the sustainability agenda. Three categories of building systems can be outlined according to the distribution of the work between the plant and the site (Richard, 2007). Dry joints are available in each one of the three categories.
I- Site-Assembled Kit of Parts: All sub-systems are made at different plants and transported separately, which implies an important but fast & easy jointing operation at the site. The four types of systems (“A” to “D”) within that category are distinguished by the geometry of the structural sub-system.

<table>
<thead>
<tr>
<th></th>
<th>Skeleton requesting horizontal and vertical infill</th>
<th>Adaptability on three axes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A- POST &amp; BEAM</td>
<td>Simplification through the introduction of a single horizontal element</td>
<td>Adaptability on two axes</td>
</tr>
<tr>
<td>B- SLAB &amp; COLUMN</td>
<td>Load-bearing flat components distributing the loads and contributing to soundproofing</td>
<td>Adaptability within (or partially through) the structural bay</td>
</tr>
<tr>
<td>C- PANELS</td>
<td>Monolithic component locating the joint outside the geometrical meeting point</td>
<td>Adaptability conditioned by the geometry of the structural sub-system</td>
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**Table 1: The Site-Assembled Kit of Parts**

II- Factory-Made 3D Module: All spaces and all components of the building are entirely made, assembled and finished at the plant as 3D modules. The two types of systems (“E” and “F”) within that category are related to the fact that the building is either partially or totally formed by those modules.

<table>
<thead>
<tr>
<th></th>
<th>Small and easy to transport modules but incomplete, as they need major complement once at the site</th>
<th>The factory-made modules can be relocated, but not the site counterpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>E- SECTIONAL MODULE</td>
<td>Autonomous unit entirely completed at the plant</td>
<td>Variable clustering, but demountable only in low-rise configurations</td>
</tr>
</tbody>
</table>

**Table 2: The Factory-Made 3D Module**

III- Hybrid: Manufacturing at the plant the complex parts of the building and entrusting the site with the operations requiring heavy transportation. The three types of Hybrid systems (“G” to “I”) aim at benefiting from the advantages of the Kit-of-Parts while avoiding the limitations of the Factory-Made 3D Module.

<table>
<thead>
<tr>
<th></th>
<th>The “service” area (kitchen / W.C. / laundry / mechanical-electrical shaft / stairs / etc.) is built at the plant within a 3D module with structural capacity</th>
<th>The Core is a closed sub-system, but demountable, whereas the served areas are entirely available to open sub-systems</th>
</tr>
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<tbody>
<tr>
<td>G- LOAD-BEARING SERVICE CORE</td>
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<table>
<thead>
<tr>
<th><strong>H-MEGASTRUCTURE</strong></th>
<th>Framework to stack boxes in order to reach a high</th>
<th>The framework can allow different boxes, but complex jointing and redundant structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I-SITE-MECHANIZATION</strong></td>
<td>Bringing the factory and its tooling to the site as far as the structure is concerned</td>
<td>Restrictive adaptability, but most sub-systems besides the structure can be flexible and demountable</td>
</tr>
</tbody>
</table>

Table 3: The Hybrid

The Kit-of-Parts category is prolific in terms of adaptability, as many types of systems are more or less structural skeletons open to various “plug-in” components. The grouping of Factory-Made 3D Modules can adopt different geometries, but their feasibility is limited to low-rise constructions, to town-houses in the case of a residential system. As for the Hybrid, their duality does impose significant restrictions which are not necessary limits.

**DEMOUNTABLE SITE-ASSEMBLED KIT-OF-PARTS**

The Site-Intensive KIT-OF-PARTS involves a few simple factory-made components produced in large quantity and designed to be assembled at the site, which implies an elaborate series of jointing and connecting operations.

Bolted joints are the rule with both steel and wood frames. When fireproofing and soundproofing are prime criteria, precast concrete is prevailing since it can meet the criteria straight, without any additional covering or treatment: bolted steel connections are usual, but post-tensioning is an option.

**Bolted joints for Site-Assembled Kit-of-Parts**

Easy to dismantle bolted joints can be implemented for precast concrete components in any Site-Assembled Kit-of-Parts system. Anchored steel plates within a recessed pocket allow for the bolting process to take place. In order to facilitate the dismantling, the steel should be lubricated and an easy-to-break grouting applied to maintain the performances as well as to prevent rusting: the bolting will then be ready-to-undo with just a few hammer strokes. Perpendicular oval holes offer the proper tolerances.

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Figure 2: Steel angles connections with perpendicular oval holes
Post-tensioned joints for Site-Assembled Kit-of-Parts

Post-tensioned jointing is quite simple although sophisticated in its application, whereas the dismantling requires careful and progressive release with the help of temporary supports. The most practical approach is the Dywidag thread bar which can be staged floor by floor, using couplers and simple high strength nuts & washers to spread the tension.

Figure 3: Post-tensioned connection

Multi-options components

The "Meccano" kit is very often recognized as the iconic model of adaptability. Those pre-punched modular series of holes and their standard nuts & bolts allow for any type of configuration. Using the same components, the user will easily mount a simulation of the Eiffel Tower and/or the London Tower Bridge.

Otto Steidle applied that approach in his Munich Genterstrasse town housing project built in 1972 (Kossak, 1994). He introduced a continuous column with capitals available at each half-floor level, thereby allowing for split level floors as well as various (1, 1½ and 2 stories) ceiling heights.

Based on the same approach, an IFD system was proposed at the Université de Montréal to accommodate the ever changing contemporary university teaching and research spatial needs (Richard, 2008). Depending on the type of beam ("I", "L" or reversed "T"), a large spectrum of floor to ceiling heights can be generated.

Fig. 4: Multi-capital column of the IFD university building system developed in Montreal
DEMOUNTABLE FACTORY-MADE 3D MODULES

In the Factory-Made 3D Module category, one of the best combinations of adaptability and sustainability is offered by the small boxes of the Sekisui HEIM system (Richard and Noguchi, 2006). Due to the road transportation limitations in Japan, the units measures 5.614m X 2.464m, which means that a regular single family house would require 12 to 16 units. The units deploy a rigid framed-at-the-edges structure: a large room can be generated by grouping 2 or 3 boxes and partitions can be set anywhere within a single unit or between units. Multiple geometries are generated, as well as various interiors and façade treatments: actually, no two houses are similar.

At the site, the units are bolted corner to corner, which means that up to eight corners can get together when a unit is fully surrounded.

Sekisui Heim offers post-delivery services, allowing not only the possibility of adding units or renewing components, but also of dismantling the units to upgrade, recycle and even relocate the house, thereby accommodating the family scenario while achieving a full life-cycle operation.

DEMOUNTABLE HYBRID

The Hybrid category is aiming at “the best of both worlds”, manufacturing at the plant the complex parts of the building and entrusting to the site the operations requiring heavy transportation. That very broad goal becomes a limit as far as adaptability is concerned.

With the LOAD-BEARING SERVICE CORE, the “service” area is built at the plant within a module with structural capacity. Spanning between those “Service Core” modules,
large slabs are offering “served areas” open to different planning options (Richard, 2005).

As they are directly related to the Cores, those options are regulated by the system. Therefore, adaptability is quite large within the system, but the system is not adaptable to any type of planning.

![Figure 7: Richardesign Load-Bearing Service Core System](image)

The MEGASTRUCTURE is a kind of framework to stack boxes. It offers no adaptability other than the possibility of removing the boxes. But those boxes, which are structures by themselves, become live loads to the Mega-structure: that redundancy is the main reason explaining the few examples built and the fact that some tentative implementations went into bankruptcy.

As for SITE MECHANIZATION, bringing the factory and its tooling to the site to produce the structure, its results are equivalent to the cast-in-place supports as far as adaptability is concerned.

**CONCLUSION**

Properly applied and using a dry joint technology, Industrialised, Flexible and Demountable (IFD) building systems are offering adaptability without any demolition, directly in line with the sustainability agenda (Richard, 2006.10). Three conditions must be met:

- Aggregating the market to amortise a series of processes capable of simplifying production;
- Using the precision available with factory production to deliver high quality components fast and easy to assemble and disassemble at the site;
- Implementing the four “mass-customization” strategies in order to meet not only the needs for change but also the individual specificities of the occupants.
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