Open Building Solutions for Sustainable Renovation of Existing Apartment Buildings in Taiwan

Tu, Kung-Jen

1 National Taiwan University of Science and Technolgy, Taipei, Taiwan

Abstract: The objectives of this study are to present the concepts and techniques of the developed 'Integrated Open Building Remodeling System (IOBRS)' which adopts 'open building concepts' and is to be applied to the sustainable renovations of existing apartment buildings. The IOBRS is further implemented in an apartment unit to demonstrate how the system can flexibly respond to multiple possible remodeling needs during a family’s life cycle. The IOBRS consists of three subsystems: the demountable partition subsystem, the floor subsystem and the trenched floor to be employed in the dry zones as well as the pre-wall installation subsystem in the wet zones of an apartment unit. When applied in the renovation of an existing apartment building, the IOBRS is expected to offer (1) spatial flexibility to cope with occupants’ changing needs over time; (2) improved maintainability to facilitate maintenance of pipes and wires; and thus to result in sustainable renovation of existing apartment buildings.

Keywords: support, infill, pipe distribution, interior system, systems integration

Introduction

‘Apartment building’ has been the major type of habitat in metropolitan areas in Taiwan, and 50% of them are more than 30 years old now [1]. Certain conventional construction practices in apartment buildings have affected the spatial functionality and maintainability of apartment units required in order for the building to meet households’ changing needs and to sustain over its life span. For example, main pipes in bathrooms are typically placed within enclosed vertical shafts, and branch pipes and wires buried within columns, walls and slabs (Figure 1a, 1b), making it difficult to maintain, repair or renew pipes and wires [2]. In addition, conventional brick partitions have made it difficult to reconfigure interior layout of apartment units, and generated large amount of construction waste and noise during renovation (Figure 1c). As a result, it is common for individual households to customize and renovate their units by adding external pipes and wires on building façade haphazardly, resulting in chaotic building appearance (Figure 1d, 1e). The average life span of domestic residential buildings is only 30-year in Taiwan [3], meaning that most of the existing apartment buildings are old and deteriorating, and will soon be demolished if no appropriate renovation systems are developed to extend their life spans.

To resolve the above problems, this study applied ‘open building’ concepts and techniques to develop the ‘Integrated Open Building Renovation System (IOBRS)’ to be adopted when renovating existing apartment buildings to improve their flexibility, maintainability, and sustainability.
The ‘open building’ concept

‘Open building’ is a design concept and approach aiming to deliver buildings with maximal capacity for accommodating the diverse needs of different householders over time. To achieve such goals, Habraken [4], the pioneer of open building theory, proposed that the following building delivery process and supply chain model are established:

1. The making of a building is divided into two stages: the ‘support’ of a building (base building elements with longer lives and remain unchanged, such as structure, envelope, etc.) and the ‘infill’ (fit-out elements with shorter lives and change more often, such as partitions, floors, equipment, service pipelines, cabinets, etc.).
2. The ‘support’ of a building is designed to form a flexible and open architecture to accommodate diverse ‘infill’ parts. Systematic design methods, such as the SAR method devised by Habraken [4], may be applied in the design of the ‘support’.
3. An ‘infill’ industry is formed to supply diverse ‘infill’ systems and parts that are highly integrated or interconnected, and can be independently installed or upgraded within an open architecture (support) for each householder.

‘Open building’ has been implemented worldwide in the making of new residential open buildings [5]. For the majority of existing apartment buildings in Taiwan, the concept of ‘open building’ was not implemented, and the ‘support’ of these buildings were not designed to be as open and flexible as expected. To make existing apartment buildings more sustainable and long-lasting, this study focused on developing an open interior ‘infill’ system and components to be implemented in housing renovation.
Integrated Open Building Remodeling System (IOBRS)

By adopting ‘open building’ concepts, the ‘Integrated Open Building Remodeling System’ (IOBRS) was developed to be a universal solution to meet the housing renovation needs of any householder in any phase of building life in any type of apartment product. The IOBRS intends to achieve maximum ceiling height and spatial flexibility, minimum material consumption and construction waste, and integration for wire and pipe management in each remodeling project. The developed IOBRS consists of four major elements (Figure 2):

1. Coordination system: A 30cm grid line system is used within an apartment unit to coordinate the construction dimensions of all subsystem components and existing building structure.

2. Floor subsystem (Figure 2a): A composite subsystem (10cm thick), consisting of wood flooring, cement board, concrete blocks, softwood bed, and waterproof membrane (under wet spaces), is laid over conventional concrete slab.

3. Trenched floor (Figure 2b): A linear cavity space, enclosed by thin metal plates and covered by finish wood flooring, configured around the perimeter of the unit for distributing wires (power, cable, network) and plumbing pipelines.

4. Partition subsystem (Figure 2a): A demountable composite subsystem (10cm thick: 45cm or 90cm wide panel unit; 210~ 300cm tall), consisting of light gauge steel C-channel, calcium silicate board, and fiberglass. Within an apartment unit, the place where a partition intersects a trenched floor, the pipes and wires will rise into the bottom of partition and are redistributed through panel units to certain equipment or outlets.

A full scale mockup was built to show the construction details of the floor subsystem (including trenched floor) and partition subsystem above the slab and those of regular ceiling subsystem and lighting fixtures below the slab in a dry space and a wet space (Figure 2c, 2d).

In the design phase of an apartment remodeling project adopting the developed IOBRS, the original partitions within the unit are first removed to uncover the bare ‘support’ of the unit; then the trenched floor is laid out along the perimeter of the unit; and finally the interior layout is reconfigured based on occupants’ needs (Figure 3). In the construction phase, the supplier will take orders of all the required sub-system components from the owner. The frames of modular panels (light gauge steel C-channel of each panel) with different widths and heights will be prefabricated and assembled in factory with one side covered with calcium silicate board and the other side left open. The ordered open panels and all other components will then be shipped and assembled on site according to the interior layout scheme. Conduits for power, communication, and plumbing are distributed from the trenched floor through the open panels to certain equipment and outlets in each room. Finally, the open panels are filled with fiberglass, and the open side covered up by calcium silicate board.

Table 1 reveals the differences between the IOBRS and the conventional construction system widely adopted in housing remodeling in Taiwan. Essentially, the conventional construction system is regarded as ‘wet, enclosed and inaccessible’ construction, and is less flexible to
meet occupants’ changing needs and is difficult to maintain. Whereas, the IOBRS is regarded as ‘dry, modular, demountable and accessible’ construction, and offers high level of spatial flexibility to cope with diverse customers’ needs over time, as well as maintainability.

Figure 2. The ‘integrated open building remodeling system’: system components and applications.

(a) Trenched floor placed along the perimeter of the unit  (b) The resulting interior layout (standard 3BR unit)

Figure 3. An example of adopting the IOBRS in an apartment remodeling project.
Table 1. Comparing the IOBRS against the conventional system widely adopted in housing remodelling.

<table>
<thead>
<tr>
<th></th>
<th>Floor</th>
<th>Partition</th>
<th>Ceiling</th>
<th>Bathroom/Plumbing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Tiles/stones on</td>
<td>Brick wall</td>
<td>Suspended plywood</td>
<td>Embedded in brick wall or concrete slab</td>
</tr>
<tr>
<td>system</td>
<td>concrete slab</td>
<td></td>
<td>ceiling</td>
<td></td>
</tr>
<tr>
<td>IOBRS</td>
<td>Concrete block,</td>
<td>Demountable framed</td>
<td>Suspended grid ceiling</td>
<td>Distributed in accessible enclosed pre-wall</td>
</tr>
<tr>
<td></td>
<td>trenched floor</td>
<td>panel</td>
<td></td>
<td>cavity</td>
</tr>
</tbody>
</table>

Housing remodeling simulation and life cycle cost analysis

The developed IOBRS was further applied in a realistic apartment unit to simulate a series of possible housing remodelings during a family's life cycle and to analyze the resulting life cycle cost of the IOBRS applications. The research subject is a 85m² apartment unit with a standard three bedroom configuration (original floor plan shown in Figure 4).

The IOBRS was implemented in the apartment unit to configure four interior layouts reflecting possible spatial needs at four different stages during a family's life cycle:

1. **Stage-1 Young couple**: the unit was reconfigured to form a residential portion (one bedroom, bathroom, kitchen) and a studio portion for a young couple to live and work.
2. **Stage-2 Two-generation family**: the unit was reconfigured to provide standard three bedrooms plus a study room setting to meet the requirements of a two-generation family.
3. **Stage-3 Three-generation family**: the unit was reconfigured to provide standard three bedrooms setting to meet the requirements of a three-generation family.
4. **Stage-4 Empty nest**: the unit was reconfigured to provide four bedrooms for rent once the couple has entered its 'empty nest' stage and moved to another place.

Figure 4. Four interior layouts were configured with the IOBRS to simulate the housing remodelings to meet the spatial needs at four different stages during a family's life cycle.
In addition, life cycle cost analyses were conducted to estimate the remodeling cost of each of the four reconfigurations applying the developed IOBRS as well as the widely adopted conventional construction practice and system respectively (Figure 5). The remodeling cost of each reconfiguration includes the following items:

1. the cost to demolish and remove the non-reusable infill parts (finish floor, partition, ceiling) to disclose the bare support;
2. the cost to repair the finish floor and to redistribute the wires and pipelines;
3. the cost to construct the partitions;
4. the cost to construct the ceilings.

As Figure 5 shows, the costs of housing remodelings adopting the ‘conventional construction system’ at four stages over a family’s life cycle remain relatively steady, ranging from 250K to 280K NTD. On the other hand, the remodeling cost adopting the IOBRS for the first time (Stage-1: 398K NTD) is higher than those at subsequent stages which are relatively stable (Stage-2--4: 170K~190K NTD).

Compared with the widely adopted conventional system, the IOBRS remodeling cost is 50.8% higher at Stage 1, mainly because of higher first cost associated with IOBRS’s floor subsystem (Figure 5). Nevertheless, the IOBRS remodeling costs are 24.1~35.7% lower at Stage-2--4 than their conventional system counterparts, mainly because of IOBRS’s lower demolition and partition costs (Figure 5) resulting from the 'reusability' of the subsystems.

The total accumulated life cycle cost of four-stage remodelings is $1,066,603 for the conventional system, and $940,930 for the IOBRS (12% less than the conventional system). The IOBRS’s accumulated life cycle cost becomes lower in the Stage-3 remodeling. The more often an unit is remodeled during its life cycle, the more cost advantages the IOBRS has.

Figure 5. Life cycle cost analysis of the construction cost of each remodeling associated with the developed IOBRS and the conventional system (remodeling cost in New Taiwan Dollar).
Conclusions
The ‘open building’ concepts were adopted to develop the ‘Integrated Open Building Remodeling System (IOBRS)’ to be applied in the sustainable renovation of existing apartment buildings in Taiwan. The developed IOBRS consists of three major subsystems: floor subsystem, trenched floor subsystem, and the demountable partition subsystem. The developed IOBRS was further applied in a $85m^2$ apartment unit to simulate how the system can flexibility respond to four-stage housing remodelings during a family’s life cycle. Finally, the resulting life cycle costs of four-stage housing remodeling adopting the IOBRS are compared against those of the conventional system. It’s found that the first cost of IOBRS is 50% higher than the conventional system; however, its accumulated life cycle cost becomes lower in the third remodeling (payback time), and its total life cycle cost of four-stage remodelings is 12% less than that of the conventional system. In conclusion, when applied in the renovation of an existing apartment building, the IOBRS is expected to offer (1) spatial flexibility to cope with occupants’ changing needs over time; (2) improved maintainability to facilitate maintenance of pipes and wires; and thus to result in sustainable renovation of existing apartment buildings.

References