Adaptable Housing of Precast Panel System in Malaysia

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Abstract

The paper identifies the potential solutions to deliver quality housing for the Malaysian as well as to solve and ever harmonizing the architectural design with the innovation of precast panel system in construction. The adaptability is the design which allows for any additions or changes in order to make it more flexible. This will ease for any renovation or extension that currently limited in housing using Industrialized Building System (IBS). A case study including questionnaires survey of housing using IBS was carried and the finding shows that there are two innovations in the project which are the Plug & Play and Support & Infill. As a conclusion, the application of IBS will facilitate users to renovate or extent his or her building to suit their needs thus allows flexibility in architecture.

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Keywords: Industrialized Building System (IBS); precast wall panel; adaptability; plug and play

1. Introduction

Precast concrete has been used as cladding on buildings since the 1920s and has become increasingly popular since the 1950s. Recently the range of products has broadened as manufacturers have incorporated new design aesthetics of the variety of shapes and finishes. Year round construction is possible with panels that are quickly erected at the site, providing the opportunity to rapidly enclose a building and speed up construction. This can be very beneficial since the building industry in Malaysia is growing towards industrialization in construction by implementing Industrialized Building System (IBS).
However, the gap still exists between manufacturing industry and construction industry – buildings are still being produced in conventional ways. To understand the relationship between manufacturing and construction, the parameters for joint design and product selection (Foley, 2002; and Tan, 2006) need to be studied. The joint of plug-in concept for the prefabricated component need to meet the design standard (Zulkefle, 2007) for IBS to be green (Al-Waer et al, 2008; and Tam 2007). Thus, a logical rule-based geometry that describes the connections between elements (Mac Gairbheith, 2009) is need to look carefully on what aspect of IBS could be contributed to the development of Open Building System for housing in Malaysia.

Therefore, the purpose of the study is to empirically and systematically investigate the effectiveness of Open Building System and how the results for adaptable housing in terms of socio-economic (user’s satisfaction) and cultural (design and construction). The study aims to explore the process of manufacturing and installation of IBS precast components for housing. In addition, the study tends to identify the level of satisfaction of users, and to develop a model of Open Building System for adaptable housing of precast panel system in Malaysia.

2. Adaptability in Housing Using Precast Concrete Wall Panel

The advancement of technology has touched every part of our lives over the last century – including construction industry. A conventional construction is the result of many factors which can be technological, social or financial, and this gap still exists between manufacturing and construction industries in Malaysia. However, construction industries practically continue to produce residential buildings in conventional ways. The world has currently been alarmed with the issue of environment and sustainability, and indeed the construction industry has constantly been worried by the increasing cost of building maintenance and lifecycle issues. Therefore, in the last decade, IBS was promoted to enhance the importance of prefabrication technology rather than conventional method in construction.

Historically, frames and infilling became the most universally accepted principle of British residential buildings’ construction in the early 1950s. The architects and engineers adopted the box frame method (consist of large precast concrete panel wall and slab) for construction of houses (Glendinning & Muthesius, 2000). Therefore the load bearing large-panel precast concrete construction residential buildings was introduced in England in 1956.

In order to maximize volume production, the ‘Modulor’ system has proponents of an open system approach in the interchangeability of parts throughout the construction industry of Europe in the 1960s (Glendinning & Muthesius, 2000 and Abel 2004). Modular Building System consists of modular parts at different hierarchical levels that can be joined together according to the connection rules to form a functional whole. The modular is an intermediate stage towards an eventual evolvement of open system which allows for easy adaptation of prefabricated components to any layout and their interchangeability within the building.

Kendall (2005) reported that France began their prefabricated building through George Maurios who adopted Open Building System in 1975. Earlier, the applications of renovation using Open Building System have been developed such as ENTRA and MOBIT. Since the early 1970s, the Finnish BES system for housing widely used a basic design unit and a multi-module of 12M. It employed slabs, walls, bathroom, staircase and several components of standard dimension. According to Kieran & Timberlake (2004) and Zulkefle (2007), the adaptable prefabricated bathrooms with easy access for services systems have been develop and fully utilized in Japan and Europe. In addition, complete single-sourced Infill Systems are used widely in Finland. The advantages of open industrialization are not only implicit in greater efficiency and economy for the production of a building but also accomplished by other important aspects such as sustainability.
Construction industry in Malaysia began in the early days of Federation of Malaya in 1948, together with the formation of the various states in the country. The construction of the Malay traditional house mainly relies on its strength of a complex jointing system made rigid by the use of timber wedges (Wan Hashimah, 2005). According to Rodd (2003), timber that is relatively light-weight has always been at what might be regarded as the cutting edge of the building technology of the era. However, Kamaluddin (2009) claimed that concrete is the material of choice for housing in Malaysia by a significant margin.

In 1960s, mass production of housing using precast concrete is not new to the Malaysian construction industry. The Danish Larsen-Neilson System were constructed in Pekeliling Flats in 1966 and French Estiot System were used in Riffle Range Road Flats in 1967. In 1978, 1,200 units of houses was built in Penang using British Precast System and in 1980, 2,800 units of houses was constructed using Hazama Gumi System from Japan. However, the adoptions are limited only for proprietary and stand-alone systems (closed system) rather than Open Building Systems.

Following these pilot projects, Modular Coordination (MC) measurement. From 1981-1993, precast concrete technology from the Praton Haus International, Germany were given numerous housing projects to be constructed in Shah Alam, Selangor. PKNS Praton Haus Berhad was formed in 1981 as a housing provider for Perbadanan Kemajuan Negeri Selangor (Mohd Sufian, 2009). There are two (2) types of construction systems which have been introduced which is large panel systems and skeleton systems. Connections in such system of reinforced concrete structure are potentially the most critical part of the IBS components (Tan, 2006). Joint are required for durability, fire-proofing and water-proofing for architectural performance, strength, rigidity, and ductility for mechanical efficiency and the ease of handling and clearance for expansion as well as contraction. Constructively, it is the main factor in controlling the performance of IBS residential building. In addition, it is equally important that the detail design attributed must be able to be constructed. The purpose of connections is to maintain the integrity of the structure under the applied load. According to Elliott (2003), the definition of a connection is the action of forces (tension, shear, and compression) and/or moment (bending and torsion) through an assembly comprising one (or more) interfaces. The design of connection is therefore a function of both the structural elements and of the joints between them.

Essiz and Koman (2006) in their study found that design demands (artistic and technical) increase with each further step towards industrialization. The combination of sociological and ecological standards together with functional and aesthetic designs could utilize the full advantage of industrialization without creating lifeless buildings and environment. Erman (2002) claimed that aesthetic considerations became an inseparable part of the joint without putting its primary function aside. On the other hand, the mechanical fasteners that have been developed as a substitute for intricate interlocking joints played the major role for industrialization, mechanization and mass production. Feasibility of demountable joints can be improved with the advance working tools. The highly developed electronic working tools enable the prefabrication of intricate interlocking joint (Erman, 2002). Therefore, the concept of adaptability and flexibility for homes could be realized.

Adaptability in general is the ability of individual modifications to suit new conditions. The ability to adapt to changing needs by changing internal walls and installation inside a dwelling unit while maintaining a constant area may be described as internal variability. Practically, adaptability covers all internal changes, including changes of character in both the availability of space and the structure of space, subdivision, and the combination of spaces. A basic interpretation of adaptability is the refitting of a physical environment as the result of a new circumstance. Friedman (2002) defined adaptability for homes as “providing occupants with forms and means that facilitate a fit between their space needs and the constraints of their homes either before or after occupancy”. However, homes in Malaysia have followed another path. It has always been conceived as something necessarily static and safe. What happened to the sustainability and “machine à habiter” that Le Corbusier proposed at the beginning of the 20th century?
The organized and accessible systems such as IBS-Housing will no longer be useful except for the lowest commodity products for which competition is weak or nonexistent, or for which there is a public monopoly (Kendall, 2005). Therefore, the standard plug and play joint and connection are vital in prefabricated component of IBS to avoid monopoly of IBS component in Malaysia construction industry. The concept of plug and play of joint and connection are ease for construction and enhancing the ability to effectively access, repair, and modify over the lifecycle of the house. Similarly, the design of IBS-Housing and its systems such as the interior space can be reconfigured in a relatively straightforward manner as occupant living requirements change over time. Thus, the concept of adaptability and flexibility strongly overlaps in this matter. And while these concepts are being discussed, in practice they are very much related and a single design approach or technology may support both simultaneously. In fact, the ultimate goal of the IBS-Housing research is to develop solutions that satisfy both of these principles.

According to Abu Hammad et al (2008), research and project experience shows significant savings can be made when applying this approach. The potential to develop 3D volumetric IBS-Housing in Malaysia needs combination of innovative design and construction methods. It is important for an industry that is constantly alarmed by the increasing cost of building maintenance and lifecycle issues (CIDB, 2009). Hence, it is very significant to select the appropriate building systems, components, and materials that require minimum maintenance (Chew & Das, 2008) to form the prefabricated IBS-Housing.

Durability is a key point to prevent the deterioration of structures and members of buildings over time and to maintain the safety, comfort and health of the users. According to Asiah et al (2009), most of the users in Malaysia are fairly satisfied with their house finishing, such as noise transmission from outside into the room, and the defect of building component. Crack remains the highest case of defect recorded for the houses in Malaysia, especially for single and double storey terrace housing. As for these cases, maintenance of external wall tiles is needed once every 20 – 30 years, simply in terms of masonry joint repair. In addition, most Malaysians prefer to improve their house by doing renovation and extension. Therefore, the plug and play precast panel for external walls will enhance the durability and waterproofing properties. The plug and play panel could be fixed manually in place to maintain constant performance quality as well as ease for maintenance and renovation. Since the precast panels have a fine surface irregularity in order to maintain the high hydrophilic properties, they remain clean for a long period. Unlike painted external walls and siding board external walls, this may considerably reduce the amount of maintenance work, such as waterproofing and repainting, which may be required.

3. Methodology

The methodology for data collection used in this research is case study including questionnaire survey. Stake (2000) described three types of case studies that were used for this research as follows:

- Intrinsic: Explores a particular case to gain a better understanding of it
- Instrumental: A particular case is examined to provide information or insight on issues or the refinement of theory.
- Collective: A number of cases are studied jointly in order to inquire into the phenomena, population, or general condition.

The questionnaires were distributed to the tenants of teachers’ quarters in the urban, suburban and rural area of Selangor and Perak. The teacher’s quarters which were constructed during 1998 to 2002 remain as the biggest housing in Malaysia constructed using IBS. The research examined the needs and satisfaction of residents for every internal space of the quarters such as the living area, dining area, kitchen, bedroom, and bathroom.

Interviews were conducted with the Project Manager from the Developer’s side and the other was with the Project Manager from the Main Contractor’s side; both of which were in charge of local projects.
involving the use of IBS construction. The key questions regarding IBS precast components that were asked in the interviews are as follows:

- **Programming**: Clear directives from the developer on decision of whether to adopt IBS precast components should be decided at early stage of the project.
- **Adaptability**: Control of the programme and project reliability.
- **Buildability**: Capacity and capability for hoisting and assembling IBS precast components during construction.
- **Quality Control**: Mass production and mass customization of IBS precast components.
- **Plug & Play**: Maximum efficiency and fewer mistakes on erection of IBS precast components.
- **Modular Coordination**: Application of adaptability, modularity and buildability according to the Malaysian Standards.

A major methodological contribution of the study is the case study for design with adaptability for IBS-housing. The observation has been validated through content analysis, and criterion validated through the pictures and drawings, where the relationships with other variables in the theoretical model were tested with significant relationships. Based on the validated observation, it was believe that crucial Moreover, the items in the instrument have shown a high level of reliability since the study offers a logical bounding of the case which promoting Open Building System.

### 4. User’s Satisfaction of Internal Spaces in Teacher’s Quarters

The project was known as Privatization Project for the development and construction of teachers’ quarters for Ministry of Education, Malaysia. The project was launched in 1998 and consists of 10,000 units of apartments on 107 sites for teachers’ quarters throughout Malaysia. Each apartment unit has 3 bedrooms, 2 bathrooms, a living room, a dining room, and a balcony.

The Kendall’s coefficient of concordance ($W$) was computed to measure the level of consensus among tenants for the factors proposed. The Kendall’s coefficient of concordance and $p$-value for scored ranking were 0.233 and 0.000 respectively. Since the $p$-value was less than 0.05, the study was found to be statistically significant and consistent as shows in Table 1 as follows:

Table 1. Test Statistics

<table>
<thead>
<tr>
<th>N</th>
<th>Kendall’s W</th>
<th>Chi-Square</th>
<th>df</th>
<th>Asymp. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>233</td>
<td>0.233</td>
<td>217.226</td>
<td>4</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The correlational analysis was performed between adaptability and the other five variables: living area, dining area, kitchen, bedroom, and bathroom. Based on the correlational analysis, all five variables were significantly and positively correlated with adaptability. The highest Pearson correlation value was 0.254 for bedroom, while the lowest Pearson correlation value was 0.205 for bathroom. However, based on the finding in Kendall’s coefficient of concordance, the orders of importance for the five spaces in the house are kitchen, dining area, bathroom, bedroom, and living area, as shows in Table 2 as follows:

Table 2. Analysis between adaptability and the other five variables.

<table>
<thead>
<tr>
<th></th>
<th>Living</th>
<th>Dining</th>
<th>Kitchen</th>
<th>Bedroom</th>
<th>Bathroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kendall's Coefficient of Concordance (Mean Rank)</td>
<td>3.87</td>
<td>2.82</td>
<td>1.94</td>
<td>3.25</td>
<td>3.11</td>
</tr>
<tr>
<td>Pearson Correlation Analysis</td>
<td>0.209</td>
<td>0.222</td>
<td>0.230</td>
<td>0.254</td>
<td>0.205</td>
</tr>
</tbody>
</table>
In addition, the Kruskal Wallis tests were conducted to test differences of mean ranking of items related to adaptability as shows in Table 3 as follows:

Table 3. Mean ranks and statistics for Kruskal Wallis tests

<table>
<thead>
<tr>
<th>Activities</th>
<th>Asymp. Sig.</th>
<th>Age of Respondent</th>
<th>Location of House</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>21 to 30 N=46</td>
<td>31 to 40 N=116</td>
</tr>
<tr>
<td>Daily family activities</td>
<td>0.005</td>
<td>124.07</td>
<td>123.67</td>
</tr>
<tr>
<td>Teaching, learning and studying</td>
<td>0.016</td>
<td>122.78</td>
<td>126.35</td>
</tr>
<tr>
<td>Family gathering</td>
<td>0.004</td>
<td>130.53</td>
<td>124.51</td>
</tr>
<tr>
<td>Social meeting</td>
<td>0.031</td>
<td>119.82</td>
<td>126.06</td>
</tr>
<tr>
<td>Society Meeting</td>
<td>0.453</td>
<td>115.89</td>
<td>121.12</td>
</tr>
<tr>
<td>Family ceremony</td>
<td>0.127</td>
<td>115.41</td>
<td>125.79</td>
</tr>
<tr>
<td>Family celebration</td>
<td>0.257</td>
<td>110.55</td>
<td>125.27</td>
</tr>
<tr>
<td>Open house</td>
<td>0.058</td>
<td>106.73</td>
<td>123.58</td>
</tr>
<tr>
<td>Discussion and consultation</td>
<td>0.444</td>
<td>124.64</td>
<td>113.63</td>
</tr>
<tr>
<td>Exhibition</td>
<td>0.459</td>
<td>125.58</td>
<td>112.32</td>
</tr>
</tbody>
</table>

Based on the results shown in Table 3, out of the ten attributes of adaptability, four items are shown to have significant difference in mean ranking of Age of Respondent based on its p-values being less than 0.05. The difference in ranking of certain attribute of adaptability is highest for tenants with aged from 21 to 30 for the family activities (breakfast, lunch, dinner, etc), and family gathering (interaction between non-neighbour), while tenants in age from 31 to 40 years old for the activity of teaching, learning and studying (preparing lesson plan), and social meeting (interaction between neighbour) in their house.

Out of the ten attributes of adaptability, only one item is shown to have significant difference in mean ranking based on zone. The mean ranks are 116.50 for urban, 97.47 for semi-urban, and 146.56 for rural. This implies that the biggest impact for teaching, learning and studying activities in the house is from quarters located at rural area.

5. Precast Structural Insulated Wall Panel in Malaysia

Precast Structural Insulated Panel (SIP) walls provide an economical solution when compared to the conventional column/beam/infill wall system. The primary advantages are speed of construction and elimination of wet trades. To minimize the requirement to lap vertical bars, the walls are recommended to be designed as plain concrete members in accordance with MS1313 and MS1064.

The Permanent Concrete Formwork (PCF) double walls system provides innovation through re-engineering in SIP walls. The wall is a combination of prefabrication and conventional in-situ construction. In essence, the PCF system is a semi-prefabrication system which provides the benefits of a precast system while maintaining the flexibility and integrity of the conventional system. This concept is made feasible through a systems approach driven by sophisticated CAD/CAMS applications of advanced technology. In planning and incorporating as much of the building scope of works during manufacture, a faster construction period is achieved as several activities and requirements will be eliminated or reduced.
in scope. Quality of finish is enhanced through quality control and assurance at the state of the art of manufacturing facility.

The PCF double walls system is an alternative method for wall construction. It could be used as both a load bearing and non-load bearing wall. Double walls are made from two half slabs elements formed into a sandwich-type wall panel with a void in between. Half slabs are 50mm thick precast reinforced concrete form elements to be utilized as permanent structural concrete formwork for cast in-situ final concrete. The concrete used conforms to the requirement to the concrete grade as per original engineers’ design.

The structural steel requirement for the tensile and shear reinforcements consists of lattice girders and longitudinal and transverse steel bars which are incorporated in the precast planks during production. As highlighted by Elliot (1996), lattice girders are provided in order to:

- ensure mechanical bond between precast and in-situ concrete,
- provide the precast plank with vertical stiffness in a temporary condition,
- contribute to the flexural reinforcement, and
- help during lifting of precast panels.

These prefabricated walls will be transformed into a solid reinforced concrete wall once installed on site and the void is filled with concrete.

The most important performance mission of precast SIP wall panels is to keep rain and other weather elements from penetrating the building. The design and execution of these joints is therefore of the utmost importance and must be accomplished in a rational and economical manner. A key advantage of precast concrete over other exterior precast SIP wall systems is its relative impermeability – water does not penetrate precast concrete.

5.1. Typical Dry Joint Design

Typical precast SIP wall panel joints are 15 mm to 20 mm wide on the exterior and 13 mm on the interior. The typical joint between precast SIP wall panels has a single line of sealant for weatherproofing and a closed-cell insulating backer rod to set the depth and shape of the sealant. Exterior sealant selection should be based on the ability to maintain elastic properties, weather performance and resistance to harmful UV rays.

Equal in importance to the width of the sealant joint is the depth. For joints designed with 13 mm to 25 mm width, the depth should be equalled to one half of the widths. In plan view, the shape of the sealant should concave, similar to an hourglass. The backer rod provides the interior concave shape; the sealant applicator provides the tooled concave shape at the exterior. It is essential to avoid depths too shallow or too deep to prevent premature debonding of the sealant to the concrete surfaces.

5.2. Wet Vertical Joints

The vertical and horizontal wet joints form a structure with a high quality and great tolerance and so quality is controlled by the system not by the engineer. What distinguishes this system is the use of the vertical joints which helps a lot with the building’s quality. It has many types that differ based upon its functions. The method of constructing them is a great advantage of the system which contributes to the speed of works execution. The thickening of edge of the precast SIP wall panel allows for a reasonable size of vertical recess to be formed as follows:

- The construction joint of oval shape cavity for two adjoining panels.
- Panel and column are assembled together and provide a space of tolerance for easy installation.

This large cavity can be filled with chipping concrete well vibrated to form a strong wet joint. This wet joint also acts as a cast-in-situ stiffener (once a vertical steel bar has been inserted and concrete has
been poured into the core) and bonds the panel to the column. As such, it can prevent the ingress of water effectively. This joint is able to transfer lateral load by shear action of the concrete infill to the adjacent columns. This can be further improved by adding non-shrinkage cement-plaster to finish the construction joint of all external walls. There are seven types of wet vertical joints as part of the O-Stable Panel System which was patented by Baktian Sdn. Bhd. The joints are shown in Fig 1 as follows:

![Isometric View of Standard Detail of Wet Vertical Joints](image)

Fig. 1. Isometric View of Standard Detail of Wet Vertical Joints. Source: Baktian Sdn. Bhd. (2011)

All precast panel walls of O-Stable Panel System were designed as a braced slender plain wall. The in-situ floor slab and columns between these walls act as a diaphragm in both direction and thus this combination will behave like a rigid concrete box. The bottom connection of the wall is categorized as pinned joint while the top connection is fixed. At typical units with precast walls as structural members, all provision for ties are met and these joints are mainly transmitting compression load. Progressive collapses are also taken into consideration.

5.3. Embedded Services

A variation of prefabricated wiring chases is to go one step further and actually install wiring in the wall panels in a factory setting. This requires more rigorous planning on the part of the builder and electrician, but offers benefits such as a well organized electrical layout and reduced on-site installation time. One detail that arises with pre-wired wall panels is connecting the wiring in adjacent wall panels as they are set on-site. One approach to making these connections in the field is the use of modular electric connectors.

Plumbing installation is also incorporated into the precast SIP panel walls and the location and type of fixing must be confirmed first before walls are concreted. More stringent checks and coordination is needed at factories because hacking of precast walls on site is not advisable. Close attention must be put into sanitary and cold water services as these require openings both on slab and precast walls and may
require structural reinforcements. Coordination work also must be done with site personels and consultants with regards to fixing of doors to services room as required by building authorities.

In the case of infill units, it is unlikely to be acceptable to provide a new full wall panel system, since usable areas will be sacrificed. In this research project, the infill panel is recommended to be modified as shown in Fig 2 as follows.

![Fig. 2. Pre-Programmed Structural Separation Element as a part of Infill Unit; Source: O-Stable Panel System (2011) and Gijsbers (2006)](image)

### 6. The Contribution of IBS in Development of Open Building System

The analysis of interview and observation from case studies were performed between Open Building System and the other six (6) variables: programming, adaptability, buildability, quality control, plug & play, and Modular Coordination. Based on the content analysis, all six variables were significantly and positively correlated with Open Building System.

The highest priority is adaptability, while the lowest is Modular Coordination. In this study, most of the owners and tenants prefer their houses to be designed with adaptability, while contractor and designer of the house prefer the buildable precast components. The level of adaptability for the IBS-housing in this study were ranked as high for bungalow houses, medium for apartments, and low for quarters.

The main contribution of this study is a model for Open Building System which is shown in Fig 3. The model takes into consideration all the major findings from the qualitative analysis. The model also ranked variables and its related items from highest to lowest as well as maximum to minimum impact respectively.

As Malaysian households prefer to be different from their neighbours and have varieties in their needs through time, the housing system should provide adaptability for served areas whereas the serving areas, catering to more basic human needs, can display similar features from one dwelling unit to another. As IBS technology is mostly factory-related, the precast components reach for the best for plug & play concept of IBS-housing in Malaysia.

An optimal solution is offered by a hybrid approach; concentrating on the serving areas in compact factory-made 3D modules called Service Cores. On site, the Cores are positioned perpendicularly to the
façade, while locally built floors and exterior walls span longitudinally between them to generate the served areas. The Service Core is to housing as what the engine is to the body of an automobile, or to the fuselage of an airplane.

The Service Core approach that is considered as a Plug & Play concept fully meets the sustainability agenda when mechanical (dry) joints are used in order to permit reconfigurations without any demolition. Therefore, the served areas generated between the cores are functionally adaptable, open to a diversity of scenarios and accommodating either loft or partitioned arrangements.

The construction of the served areas, and its adaptability to suit changing needs, is a simple activity which deserves to be done locally, both for economical and cultural reasons. The exterior wall panels are plug and play tiles or curtain walls connected to the Cores; they constitute an open sub-system in terms of materials and forms, and they can play a determinant role in responding to the local culture and harmonizing with the Malaysia Standard.
Adaptability
1) Size of kitchen
2) Size of dining area
3) Finishing of bathroom
4) Size of bedroom
5) Finishing of living area
6) Arrangement of spaces

Buildability
1) Design for simple assembly
2) Encourage standardization/repetition
3) Design for IBS or modularization
4) Analyze accessibility of the jobsite
5) Design for the skills available
6) Consider suitability of design materials

Quality Control
1) Factory standard
2) Improves the worker’s efficiency
3) Less impact to the environment
4) Enhance housekeeping and site tidiness
5) Cleaner and safer site conditions
6) Generally inflexible for changes

Plug & Play
1) Disconnectable
2) Standardized connections
3) Size, shape and position tolerances
4) Individual removable
5) Direct usable
6) Support and infill

Programming
1) Present and future users
2) Functional analyses
3) Norms and characteristic values
4) Evaluative study
5) Statistical prognoses
6) Components and elements

Modular Coordination
1) Precast wall panel
2) Precast slab
3) Door and window
4) Precast column
5) Precast beam
6) Joint and connections

Fig. 3. Open Building System Model
7. The Development of Design with Adaptability for IBS-Housing in Malaysia

This study indicated that the size and arrangement of spaces as well as their finishing were basically the highest possible adaptability level. At the moment, the building industry is not organized to provide adaptability for housing, especially for terrace and bungalow houses. The industry should take advantage from the current technology of IBS towards adaptability in order to achieve the ultimate objective for the creation of effective and innovative products for housing.

The requirement for building adaptability is becoming increasingly relevant from both commercial and sustainability perspectives. It may also be more amenable to incremental growth and thus to the introduction of innovative technologies and policies. As a matter of policy, whilst adaptability needs further emphasis as an important component in the IBS-housing developmental effort, the flexibility of building should also be given greater emphasis (Habraken, 2005). According to Habraken (1998), the building is usually divided into support and infill with regard to flexibility. The infill undergoes changes when flexibility is applied. However, daily building practices reveal that the applied solutions have not been satisfactory until today. The application of changes to products and product platforms based on user requirements is a common practice.

Housing policy for IBS-housing is based on the tacit assumption that new residential dwellings must be of a high architectural quality and of a high standard with respect to building technology and that they ought to manifest themselves in a contemporary idiom. Additional, new dwellings ought to be designed with some kind of experimentation in mind, taking a point of departure in the surroundings’ urban character and potentials.

These aims pose great demands – and not only in the architectural trade. The demands are imposed on the entire construction branch, on the authorities and on the users, who exert their influence on the market as a consequence of supply and demand. Results of the case studies cover the several aspects as follows:

- Socio-economic and cultural aspects – contractor;
- Technical aspects – designers and contractor; and
- Systematic aspects – policy maker, contractor, and designers.

8. Recommendation

It is apparent that technology of IBS has a major impact on design and construction of housing in Malaysia. Some policy improvement plans for revitalizing adaptable housing emerged from this study. The policy is described base on the following aspect:

8.1. Socio-Economic and Cultural Aspects

As this is a new concept and approach, the government’s active support and publicity were chosen as the most important factors for the success in the industry. It was agreed that consumer attitude toward the concept of adaptable housing urgently needed to be changed to accommodate them. It was viewed that systematic research and Malaysian mentality should be sufficiently considered through short and long-term roadmaps for adaptable housing, and that improvement was needed in the consciousness of residents through education regarding the maintenance, management, and adaptability. It was also viewed that architectural programming for adaptable housing is needed in preparation of standardized design plans, as well as developing IBS, economic support, and an accurate demand appraisal.

8.2 Technical Aspect
The development of technologies and structures for adaptable housing is being proposed. A few potential lightweight wall structures and ceiling materials with plug-in assembling concept should be further researched. Such would be supported by the technological development of IBS and introduction of new support and infill appropriate for adaptable housing, such as development and distribution of structural forms, and R&D of various interior finishing methods and designs.

8.3 Systematic Aspect

From the perspective of laws and policies, IBS can accommodate new technologies, together with the preparation of Open Building System that urgently needed. Experts and stakeholders must work to ease the construction industry in implementing Open Building System in housing through which the regulations should be eased as follows:

- The easing of approval of housing development from the local authority.
- The easing of basic facilities allotment as a solution to the step-wise application of design standards for Open Building System that considers remodelling.
- The right of light for the application of green building certification.
- The control of maximum height and easing of housing act permits.
- The allotment for special repairs and reserve for residential repairs.

The application plan is also proposing a step-by-step application that is carried out at unit level, not radical applications. It was identified that, considering the construction of support and infill, each individual unit should separate their control of services system such as electrical, plumbing and water supply system. It also should be eased for inspection during maintenance and installation of parts for services system.

9. Conclusion

To make exchangeability and (multiple) reuse of building components achievable in practice and to allow adaptability of constructions through reconfiguration, design should focus on standardisation of form and dimension of the basic elements of construction systems on one hand, and on the use of building components composed by dry assembled compatible basic elements on the other hand. A new direction of architectural programming for adaptable housing of precast panel system should be developed further, based on the adaptability model in this research. This can allow designers to understand and meet design standard and user needs.

References


