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INDUSTRIAL AND ADAPTABLE COMPONENTS FOR BUILDING WASTE REDUCTION

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ABSTRACT
One of the main concerns of environmental sustainability is to reduce the depletion of valuable materials and natural resources. To do so, construction waste management needs to be considered in the early stages of building components design and preparation. Industrial, Flexible and Demountable building system (IFD) is attempting to create more adaptable buildings while managing its end-of-life more efficiently and focusing on the long-term performance of the structure and materials. This research focuses on the development of an IFD system for a two-story residential layout. In this regard, proposing a procedure to evaluate the conceptual prototype was the key concern. The procedure contains assessments according to IFD criteria and structural characteristics. ETABS software was applied for analyzing the stability and load bearing capacity of the structure. The assessments have testified to the flexibility and strength of the designed layout. Findings from this study have implications for future investigations on detail design and experimental analysis of the components.

***Keywords*:** Industrialization, Flexibility, Demountability, waste reduction, Terrace house layout

1. INTRODUCTION

Building construction process is a complex system that involves interactions between different parties (Egmond and Scheublin, 2005). In most of the developing countries insufficient cooperation between the parties have caused dysfunctional team works, and loss of opportunities for optimal use of resources as well as innovations in design and construction. Yet, Conventional ways of construction ignore the in-built capacity of the building for easy adaptation over time (Paduart et al., 2008, Razaz, 2010). Therefore, any change or renovation of the building will not be easily possible or result in significant cost during its life cycle. Industrial and flexible systems try to improve the construction in such a way that result in a faster, economic , higher quality and environmental friendly buildings in compare with traditional methods (Zegers and Herwijnen, 2004).

However, flexible and reusable construction system can only be attained if the design process considers the general construction system and construction detailing at the same time (Paduart et al., 2008). Therefore, attention has to be paid to the integration and technical requirements of the elements and the connections as well. This research project focuses on the development and analysis process of an IFD double-story housing layout. Firstly, design criteria for industrialization, durability, adaptability and dismantling in building construction, are discussed. These criteria have been applied during the design and assessment process in the next step. Furthermore, ETABS software has been applied to analyze the structural design of the building. The analysis methods have helped to draw the results and validation of the design and presenting suggestions for future studies.

2. INDUSTRIAL, FLEXIBLE AND DEMOUNTABLE SYSTEM

Different approaches for building design and construction have been applied to balance the efficient use of materials, changing user demands and increasing life cycle costs. Industrial, Flexible and Demountable systems (IFD) emphasis the easy change and adaptation of buildings while reducing resource depletion and construction costs (Ball, 2002, Bon and Hutchinson, 2000, Gallant and Blickle, 2005, Kohler and Hassler, 2002).

2.1. Industrial construction

CIB W24 has defined the industrialized building as a technology that modern systematized methods of design, production planning, control, and mechanized manufactures are applied (International Council for Research and Innovation in Building and Construction, Work group24). In fact, the industrial way of construction, develop building elements under controlled circumstances and in a repeatable process (Zegers and Herwijnen, 2004). In this case, the elements can be used in several buildings with different characteristics to reduce the cost of manpower and time consuming activities. The quality of the building parts will be controlled during the manufacturing and assembly process either in the factory or the building site.

2.2. Flexibility in Design

Change is an inevitable requirement during the life of the building, according to users' demand or for facilitating other functionalities or introduction of technologies and regulations (Slaughter, 2001a) (Brand, 1994, V.Greden, 2005). Therefore, it is necessary to prepare the building that would be able to change the layout and using materials to meet the new requirements. This trend is important because, focuses on the long-term performance of building structures and materials (Bullen, 2007, Gregory, 2004).

Since, flexibility results from the bilateral balance between durability and adaptability, design for flexibility should follow criteria for durable and adaptable design.

i. Design for durability

Durability is defined by the nature of the building's reaction to various conditions to which it is exposed over time. If the designed elements of the building are expected to have a long lifetime, they should be capable of tolerating coming changes (S.Macozoma, 2002). This ability will require a durable structure that allows for changes of finishes, secondary building elements and services (Sassi, 2000).

Design for durability will increase resource productivity by reusing material during renovation and, therefore, optimizing material application. It can reduce costs and negative impacts of the operation and maintenance of the building. However, the benefits of durability depend on the quality and lifetime of the building components. If the building becomes obsolete shortly after construction, the cost of increased efficiency will not be covered (S.Macozoma, 2002, Sassi, 2000).

In general, if the expected lifetime of the building is shorter than its elements or materials, design for recycling should be considered. Although recycling is commonly associated with material issues, it can also be used in the design process (Razaz, 2010). Design for adaptability, is an important criterion for recycling (Dorsthorst and Kowalczyk, 2002).

ii. Design for adaptability

Adaptability is defined by the versatility of a building when encountering internal expected variations or environmental uncertainties. Adaptability is important for buildings that have longer lives than their current functions. Accordingly, design for adaptability is meant to improve the ability of a building to change and fulfil different functions during its lifetime (Dorsthorst and Kowalczyk, 2002).

2.3. Demountability and material reuse

In current construction, components and structures are not designed to be separated or applied in new buildings. This has resulted in non-recyclable building materials as the major part of waste. Furthermore, big amounts of the recycled materials are limited to low quality use or even land fill (Durmisevic, 2006). New design approaches are trying to simplify dismantling of high-value materials for reuse and recycle and improving the waste issues (Chini, 2002). Demount-ability enables the building parts with various life spans to be separated with little damage to other building parts and suited to be reused or recycled. Indeed, design for dismantling encourages the application of recyclable materials as well as simplifying the separation of materials before or after demolition (Dorsthorst and Kowalczyk, 2002). Therefore, it will extend the life of the building as a whole.

3. PROTOTYPE HOUSE DESIGN

Terrace houses are a ubiquitous form of residential building. According to the changes in the people's way of life and the high cost of accommodation, the rate of changes for reuse and adaptation to this type of buildings are excessive. However, little changes have been made in their design properties for the last 25 years and inflexibility of the spaces, and inappropriate renovations have resulted in social and environmental issues (Hashim et al., 2009).

The prototype unit of study consists of a double story terrace house. A structural system based on precast columns with concrete stabilizing walls is chosen, built upon an in-situ constructed basement. One of the positive effects of such a system is the flexibility it generates. In the case when bearing concrete outer walls are used; the location of openings such as windows or doors must be carefully calculated for each element. In fact, a system with precast columns gives the designer a larger freedom to place openings in the outer walls, since only the columns are taking the vertical loads. It also gives a larger ability to change the location of openings in the facade after building's completion. Meanwhile, the panels between the columns can be replaced while the building is still in use.

The interior architectural design attempts to create configuration that encourages the possibility of future adaptations for the spaces use (Figure 1). Consequently, the unusable or single function spaces like circulation and fixed elements have been minimized. The plans, section, and elevation have been framed from a modular grid which based on the available standard sizes (Ministry of Housing and Local Government Malaysia, 2009). The grids will allow simply reducing or expanding the design based on the site restrictions. The main walls in front and rear facade have been considered as non-load bearing and the main requirement for the interlocking panels are the stability and transferring the weight load to the beams and columns. Partition walls were considered as, 600mm × *400mm × 100mm*, concrete panels. The panel dimensions followed modular design rules, which require the horizontal controlling dimension of 3M or 300mm, and vertical dimension to be 1M or 100mm. Accordingly, other spaces in the house are also in conformity with modular dimensions, therefore, encourage the application of other modularly coordinated components such as doors and windows. The typical room height of 2800mm has been adopted; thus, the application of half or broken block for fitting into the space won't be required. Besides the proposed panels other elements' characteristics are selected according to the standards available in 'Modular Design Guide' and components available in IBS catalogue booklet (Ministry of Housing and Local Government Malaysia, 2009).

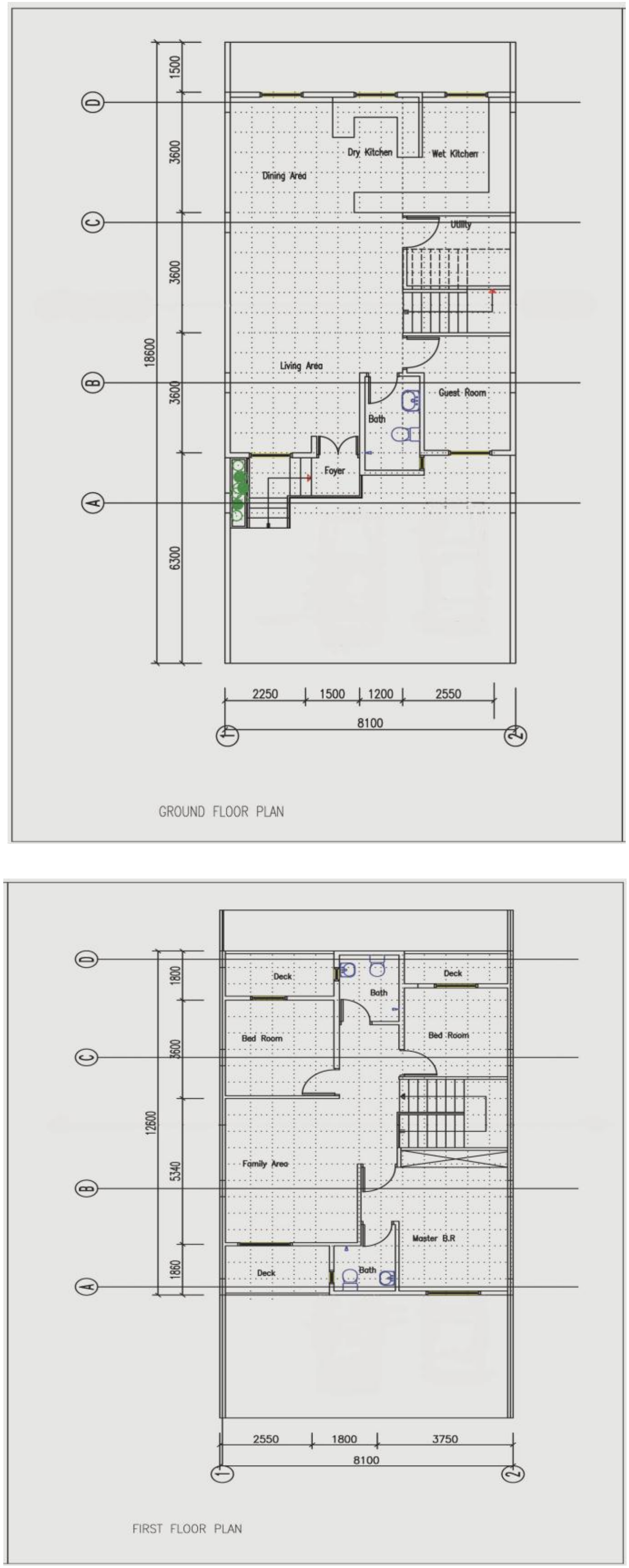

Figure 1 Prototype terrace house, design concept plans

4. ASSESMENT PROCESS

Assessment of flexibility is a difficult process as a result of few intentional flexible designs in existing modern buildings (Davison et al., 2006). For the purpose of this study theoretical and simulation processes have been applied for evaluating the design.

4.1. Theoretical assessment

Various design characteristics have been suggested by researchers for industrial, flexible and demountable building construction (Gassel, 2003, Holtz, 2006, Zegers and Herwijnen, 2004). Three main categories of these criteria have been considered for evaluation of the proposed design. The key design parameters are presented in Tables 1-3.

Table 1 Industrialization criteria for design

Criteria	Source	Design features
Standardized parts	W.Hurely, 2002; Morgan and Stevenson, 2005	All the layout subparts that are manufactured in series
Modular system	(Crowther, 2005, Geraedts, 2001, S.Macozoma, 2002)	All the dimensions are according to Modular system coordination
Reduce number of parts	(Mark Webster et al., 2005) (Guy, 2002)	Consist of small number of parts
Simple assembly protocol	(Geraedts, 2001, Vakili-Ardebili and Boussabine, 2006)	The parts can be assembled on site by means of simples actions and lightweight equipments
Reduce waste	(Durmisevic, 2006);(Chini, 2002)	Produces little waste during manufacturing and assembly on site
Changeable	(Keymer, 2000, Mark Webster et al., 2005); Charytonowicz 2007; Sassi 2008)	Standard components can be changed during the service life

Table 2 Adaptability and durability criteria

Criteria	Source	Design features
Freedom of design	(Chini, 2002)	Small and changeable parts provide free and adaptable design
Adaptable during assembly	(Keymer, 2000); Guy 2002	Is not depending on a strict assembly planning
Independence of disciplines	Geraedts 2001; Mark Webster et al., 2005	Installation process, bearing structure, outer shell, and interior finishing can be performed independently but combined at the end
Changing of layout	Mark Webster, Gumpertz et al. 2005	Possibility of changing the layout with little disturbance to other parts of the building

Layout freedom	(Chini, 2002)	Open and free interior spaces for future adaptation
Adjustability of building parts	(Chini, 2002); Morgan and Stevenson 2005)	• Bearing structure: prefab elements have limited adjustability • Installation : dry connections make the installation practically adjustable • Outer shell : light panels with dry connections • Interior finishing : modular design and adjustable

Table 3 demountability criteria

Criteria	Source	Design features
Reuse from other buildings	(Crowther, 2005); (Slaughter, 2001b)	The prefab components can be used from other buildings without alteration
Dry connections	(S.Macozoma, 2002); (Geraedts, 2001); (Sassi, 2008) (Guy, 2002)	Application of dry connections for joining the panels, column, roof, and floor
Demounting of parts	(Crowther, 2005) (Slaughter, 2001b) (Geraedts, 2001) (Fletcher et al., 2000)	Can be demounted with little disturbance to the other parts
Demounting without waste	(Crowther, 2005) (Slaughter, 2001b)	Demounting will not cause waste production
Reuse of materials	(Morgan and Stevenson, 2005, S.Macozoma, 2002, Sassi, 2008, Thormark, 2001, Vakili-Ardebili and Boussabine, 2006)	Elements' materials can be used as new raw materials
Reuse of building parts	(Keymer, 2000); Mark Webster, Gumpertz et al. 2005;(Charytonowicz, 2007); Sassi 2008)	One building component can be reuse in the other buildings

4.2. Simulation

A simulation analysis was applied to assess the house layout design. ETABS2000 Extended 3D Analysis of Building Systems (Version 9.0.4) has been used to analysis the structural design of the building. ETABS is well known structural software utilizes Finite Element Method for analysis of the common structural systems. It is equipped with steel and concrete design modules, which were used for design of main load carrying elements. Graphical representation of model and loading is also provided (Ghoulbzouri et al., 2009). It is used in our analysis for its relative ease of use, detailed documentation, flexibility and vastness of capabilities.

a. Applied Codes

For concrete structure and foundation design UBC97 has been employed.

b. Loading

The applied loads have been calculated for two-story residential building. The loads have been determined according to project specification for dead, live and earthquake loads.

The load combinations for the three main loads, Dead Load (DL), Live Load (LL), and Earthquake Load (EQ) at X and Y directions, have been determined as bellow:

- 1.4DL
- 1.4DL +1.7 LL
- 1.32 DL + 1.1 EQX + 0.55 LL
- 1.32 DL - 1.1 EQX + 0.55 LL
- 1.32 DL + 1.1 EQY + 0.55 LL
- 1.32 DL - 1.1 EQY + 0.55 LL
- 0.99 DL + 1.1 EQX
- 0.99 DL + 1.1 EQX
- 0.99 DL + 1.1 EQY
- 0.99 DL - 1.1 EQY

The graphical representations of the model are shown in the following Figures 2-3.

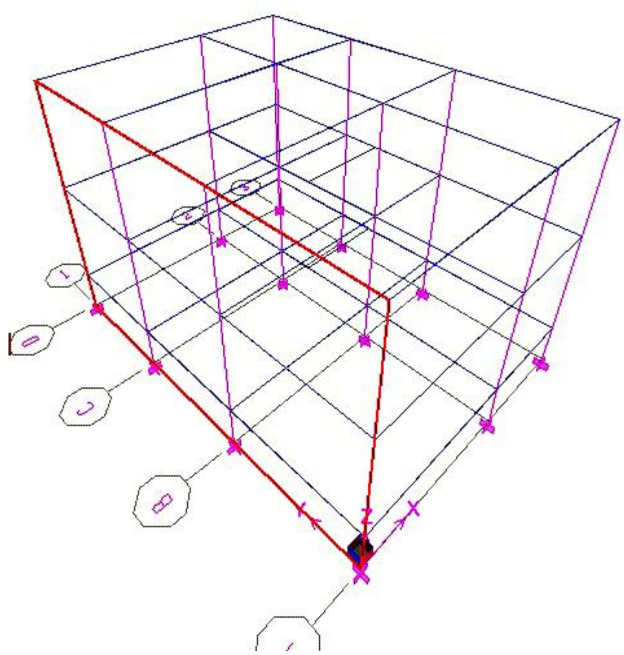

Figure 2 General 3D view of the model

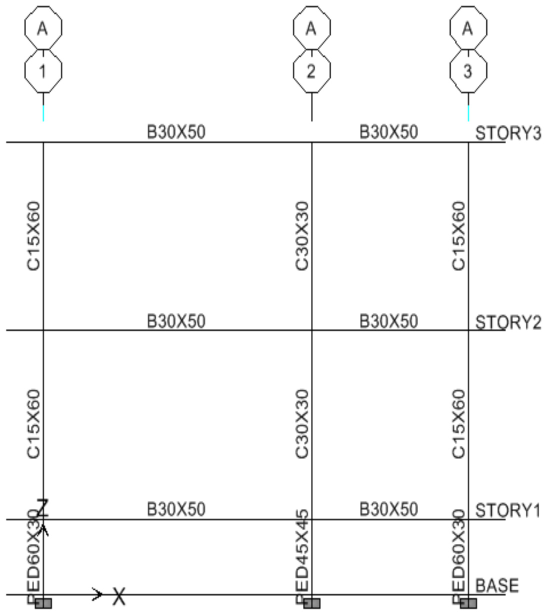

Figure 3 Framing view axis A-A

5. RESULTS AND DISCUSSION

The concrete structure has been analyzed with ETABS2000 Ver. 9.0.4. The interior forces between elements were according to kgf/cm units. The controls of vertical and horizontal replacements of beams and columns have been checked. Results from Column P-M-M Interaction Ratios shows that the ratios of existing loads to the capacity of the columns are less than 1.0 in all the stories. It means that the assigned prefabricated columns and beams have the capacity to tolerate the existing loads. Furthermore, (6/5) Beam/Column Capacity Ratios, shows that the ratio of beams' capacity to columns' capacity is less than 1.0 in all stories. This is a specific criterion for frame structures that needs to be always less than 1.0 (Figure 4).

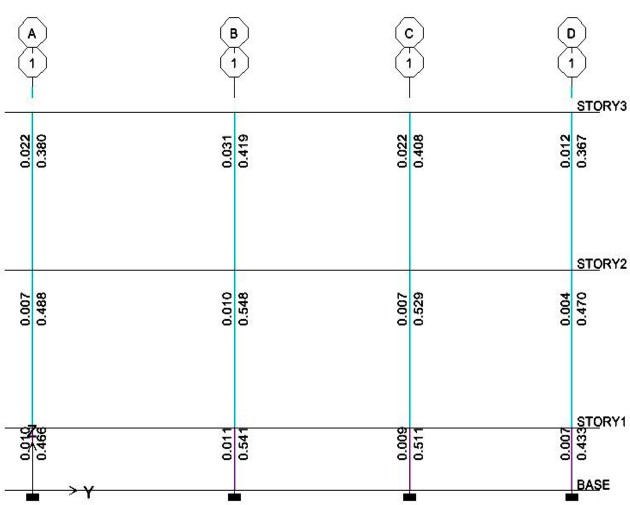

Figure 4 (6/5) Beam/Column Capacity Ratios

6. FUTURE DESIGN AND CONFIGURATION

Design and configuration of the panel system play a key role in the whole concept. The interlocking mechanism for ease of assembly and disassembly is the main concern. The efficiency of the detail design and interlocking method will be analysed through an experimental procedure in the next step of the study. The following features are sought to be included in panel-blocks design and development: (i) Designing the interlocking structure in an efficient manner that would withstand the loads from different directions, (ii) Following modular coordination system, (iii) Applying simple shapes for production and assembly of the panels, (iv) Conducting dry and fast construction with minimum in-situ casting to make the process more environmentally friendly

7. CONCLUSIONS

Considering the useful life of a building project in the primary design stages will result in reducing the waste through material recycling or component reuse. In fact, according to each project lifecycle, suitable design criteria should be employed. This paper presents a process for development and evaluation of IFD building components. The evaluation consists of two steps, theoretical analysis according to IFD criteria, as well as simulation analysis for the structural performance. The main considered features of the design were to; fulfill industrialization, durability, adaptability and dismantling. Application of these assessments has testified to the flexibility and strength of the designed layout. The offered design still needs further development and the detailing principles on the interlocking mechanism of the panels, which will be set up in the next steps of the study.

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