A HOME DESIGN SYSTEM BASED ON COMPONENT REUSABILITY

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Abstract. This paper proposes a computer-aided design system for modular houses, focusing on component reusability. By resolving user-designed house layout into its component elements, and producing lists of reusable elements and those necessary to purchase, the system assists users in need of making design changes in their modular house. The application of the strategies described here may reduce human efforts in complicated process of re-arranging components according to new layout design and help to increase the reuse of module components in practice.

Keywords. Modular house; component reusability; home remodelling; user participation; computer-aided design system.

1. Motivation

In architectural field, sustainability issues that aim to save resources, reduce waste, and provide high quality living environment at the same time have recently become the centre of public attention. Unfortunately, however, demand for high quality of housing inevitably leads to frequent house renewal that involves layout adjustments to properly respond to the various and changing needs of the tenants (Kumagai 2002), which makes high quality of house performance and resource saving difficult to coexist. As an effort to avoid the conflict, there have been many studies on new structure systems and functions of the residential building with both durability and adaptability, and Open Building System is one of them. Distinction between structure parts that we refer to as ‘support’ and changeable building parts called ‘infill’ provides customisable non-structural part of building based on residents’ lifestyle and makes replacement of materials possible. (Kendall and Teicher 2000) Not only
has the advent of Open Building System lengthened life span of buildings, but it has also introduced Modular Construction, a promising way of providing the customisable infill. A large portion of research has discussed that the use of modular construction provides many significant advantages, including: 1) saving on overall project schedules, 2) improvement of quality, 3) increased onsite safety, 4) the reduced need for skilled workers on site, and 5) a decrease in the negative environmental impact caused by construction (Lu and Korman 2010). Moving in direction of modular construction, housing module components have been developed by diverse companies and research institutes including PANeKYO, NEXT21, Daiken Corporation, and Korea Institute of Construction Technology (Lee and Kim 2010). Although non-structural and changeable space of residential building and module components to fill it meet the physical qualifications for flexibility in housing, user-participatory design changes are not very common. This paper defines the absence of a tool that supports pre-project planning and component coordination as reason why residents in modular houses have difficulty in participation, and believes that aid of computational tool is helpful to overcome the challenge.

The purpose of this study is to investigate the possibilities of user-initiative design change in modular houses and to improve computer-aided design system for modular residential buildings. In this paper, framework of the system is presented with necessary functional specification and illustrated with a case study using housing components by Korea Institute of Construction Technology as an example. This system could be used by expert or by non-expert, but in both cases, it may reduce human efforts in complicated process of rearranging components according to new layout design and help to increase the use of module components in practice.

2. Background

Excess of the house supply ratio has brought about a transition from a supplier-oriented environment to a customer-oriented one in housing market in many countries of Asia including Korea, Japan, and Taiwan. Additionally, since customers became to consider their various needs and the quality of housing more important than they had done, house customisation is inevitable to meet the various needs and to ensure competitiveness in the customer-oriented housing market (Shin et al. 2008).

Renovation to make houses customised to residents now accounts for more than half of the construction market in many developed nations. To improve the capacity of residential buildings to adapt to changes in space, the responsiveness of buildings to end users should be improved, while at the same time increasing efficiency, sustainability, and capacity for change (Kendall and
Eric von Hippel explains that user participation in design is desirable to manufacturers as well as residents, pointing out that “a variety of manufacturers have found it profitable to shift the tasks of custom product design to their customers along with the appropriate toolkits for innovation” (von Hippel 2005).

Infill components of residential building could be a significant constituent of the toolkit for user-driven house customisation. The infill components employed in this paper is *Movable Lightweight Partition Components* developed by Korea Institute of Construction Technology. It is mainly comprised of panel type wall components, storage type wall components, door components, and accessory components, having features as described in Figure 1.

![Figure 1. Overview of movable lightweight partition wall components (KICT 2007).](image)

Coordinating and locating components before fabrication has always being one of the most challenging tasks encountered in modular construction process (Tatum and Korman 2000, Korman 2001, Lu and Korman 2010). That is because historically a specified model for plan design and fabrication with module components did not exist. Situation gets more challenging in renovation of modular houses and even more when an end-user tries to drive the process. That is, despite of development of infill components and interface, residents in need of home renovation with components currently have little information available on how to rearrange and fabricate the components based on the design changes, which component can be reused for their new house layout, and how to minimise additional purchase of components.
One of the most convincing reasons for the difficulty is that few studies have been done on a means of supporting modular construction in early stage of design. When users, therefore, want to remodel their home built with module components and to have it fabricated, they experience the major limitation of current computer-aided design tools, which results in frequent interruption in remodelling process because of lack of information about reusable components. In order to make improvement, required features of 3D architectural design tools for modular construction needs to be completely redefined, and the tools should be improved with due regard to component reusability.

3. Approach

This study proposes a different approach to build user-centric environment for design and fabrication of house with module components. While the current web-based solutions in practice such as Autodesk Homestyler and Sweet Home 3D provide only visualisation function to support communication on design idea, the proposed method in this study defines the absence of a single, specialised platform that provides fabrication information extracted from design model as the reason why users have difficulty in making design change in their home built with module components. Particularly, this research focused on help to reuse module component in design changes. We developed a system that helps to componentise apartment unit layout into housing module components to give component documentation and quantity take-off based on component reusability to residents interactively based on the design changes that they make.

The methodology comprised the following four phases: preprocess, componentisation, component specification, and quantity takeoff phases, which correspond to Sections 4.2.1 through 4.2.4 of this paper. The flow diagram of the proposed method is represented in Figure 3. A detailed description of the procedures involved in each methodological phase is provided from Section 4.2.1 to 4.2.4. Electrical wiring and piping system is not within the scope of this research.
4. System design

4.1. SOFTWARE ENVIRONMENT

In this paper, *Sweet Home 3D*, an open-source free interior design application with 2D and 3D preview was used as a parent system. *Sweet Home 3D* enables users to easily draw their housing layout, which allows them to make the changes in design and to have it visualised with ease. It is written in Java and offers the ability to extend the functionalities of this application (Chong et al. 2009).

In this paper, we used this software with the rules to componentise home design layouts based on the components in hand. This rule-based housing design system offers the users a promising application for housing remodelling because it allows times and efforts to be saved from calculating the required components based on reuse.
4.2. SYSTEM DESIGN

![System Architecture Diagram]

*Figure 4. System architecture.*

4.2.1. Preprocess

In this phase, information given in schematic layout is collected and refined into the required format for the following phases. This phase is comprised of three sequential steps.

*Step 1: Extracting Component Information*  
The first step of preprocess phase is to extract component information. Every component has name, location and dimension attribute. In particular, each wall component has its own values for identity number, location of both ending points, and the distance between the two points. The ending points are measured at the centre line of the interior walls, while those of any panel type walls which encounter exterior wall, columns, doors or storage are measured at the dividing line.

*Step 2: Correcting Wall Type*  
Once component information is extracted, some of wall components which adjoin a storage component undergo change in its value. This step is necessary because storage components serve as a kind of wall component in the actual construction stage, while end-users of the system put storage components to the schematic layout as furniture. That is, panel-type wall component is not necessary in where it adjoins storage component.

*Step 3: Getting Wall Dimensions Refined*  
This step decides whether the dimension of the components is inside dimension, and if not, changes it into inside dimension. When one of the ending points of a component is the same as one of another, it needs to be refined in the required format, inside dimension, for the next phase. As the ending points are measured at the centre line of the interior walls, half of the thickness of the wall should be subtracted from the original distance to get inside dimension.
4.2.2. Componentisation

The Componentisation phase divides the drawn walls in line into wall components based on the type of combination among walls such as I, L, T, and cross type. This phase is comprised of two sequential steps.

**Step 1: Determining Joint**  This step determines the type of combination of each wall among I, L, T, and cross type, and adds the joint information to the dimension value. I type wall does not meet other interior walls and it is determined when it does not share either ending point with other walls; L type wall meets another wall, and it can be decided when two walls share one ending point; T type wall meets other two walls, and it is determined when the three walls share one ending point; cross type wall meets other three walls, and it is determined when the four walls share one ending point.

**Step 2: Panelising**  Panelising divides the walls drawn in line by the user into panel type wall components. The standard size of the module used in this study is 300 mm, 600 mm, and 900 mm. As walls are not always divisible by modules, irregular panel which is as long as the remainder could be required. The goal of this step is to minimise the amount of irregular panels while panelising the walls. Irregular panel size ranges from 100 mm to 400 mm.

4.2.3. Component specification

The component specification phase determines what accessory components are necessary in order to fabricate the design in practice. This phase is important because the 3D models made by the user is originally do not have any information about fabrication such as what else components are needed to combine the wall modules.

4.2.4. Quantity takeoff based on component reusability

The quantity takeoff phase decides whether the user can reuse components currently in hand for the required components to fabricate the new design. This phase refers to user component database and makes a list of reusable components and need-to-purchase components. Once the list is completed, the system prices the components and prints the result.

After the four phases of the system, the information extracted from the schematic layout finally results in the useful information, the list of the required components for the layout. The list is printed, being categorised into reusable one and need-to-purchase one.
4.3. USE SCENARIO

A user has a house built of module wall partition components developed by Korea Institute of Construction Technology. The user wants to make changes in the current layout of the house and remodel it. The user uses the system proposed in this study to visualise his or her new design idea and get information on how the modules should be fabricated, what else modules he or she need to buy.

![Interface of the proposed system.](image)

4.4. CASE STUDY

The two layouts of one house renewal case were designed based on a single story unit in Figure 6.

![Physical constraints.](image)

All outer walls are 300 mm thick and the physical constraints include configuration of outer walls and location of columns, the front door, and windows. The
location of two bathrooms was fixed in this study because bathroom system is out of the scope of this study.

Figure 7 shows the two plans and the corresponding 3D digital models. One is the pre-remodelling plan and the other is the post-remodelling plan. For example, the layout on the left column of Figure 7 is changed to the other as a result of unit remodelling.

![Figure 7. The initial layout and the one after remodelling.](image)

### TABLE 1. Required components.

<table>
<thead>
<tr>
<th>Type of Components</th>
<th>Size (mm) W, H, D</th>
<th>Reuse Amount</th>
<th>Purchase Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Partition Wall</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular</td>
<td>300 × 2400 × 100</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>600 × 2400 × 100</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>900 × 2400 × 100</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Irregular</td>
<td>100 × 2400 × 100</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Storage Type</td>
<td>600 × 2400 × 600</td>
<td>4/0</td>
<td>0/1</td>
</tr>
<tr>
<td></td>
<td>900 × 2400 × 600</td>
<td>8/0</td>
<td>0/3</td>
</tr>
<tr>
<td><strong>Door System</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessory (Lumber)</td>
<td>Rectangular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corner</td>
<td>20 × 20 × 20</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Door</td>
<td>900 × 2100 × 100</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Panel</td>
<td>900 × 300 × 100</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Balcony</td>
<td>2000 × 2400 × 100</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1 presents the results of operation of the system about the case, showing the bill of materials for the remodelling cases, categorising them into two groups, namely Reuse and Purchase. According to the result of quantity takeoff based on the material reusability, the user needs to purchase the components on the first column from right side of Table 1, and the other required components can be reused among ones that the user already have.
5. Discussion

The application of the strategies described here may reduce human efforts in complicated process of re-arranging components according to new layout design and help to increase the use of module components in practice.

One of the best contributions of this study is to define the functional specification of digital design system especially for modular construction. As the existing systems focus on wet construction and offers helpful functions usually for it, digital design system framework for modular construction has not existed, nor does the definition of required functions exist. In the future, extended study dealing with location-based quantities and movement of electric wiring and wet place would make the system more useful.

References