CONTINUOUS ADAPTABILITY:
WEB-BASED RESIDENTIAL PARTICIPATORY DESIGN USING MODULAR PREFABRICATED CONSTRUCTION

HUIYAO HU¹, BUI DO PHUONG TUNG² and PATRICK JANSSEN³
¹,²,³National University of Singapore
¹huiyaohu@gmail.com, 0000-0001-8427-2676
²phuongtung1231992@yahoo.com, 0000-0003-3951-8192
³patrick@janssen.name, 0000-0002-2013-7122

Abstract. High-rise residences are typically very homogeneous and only allow for very limited variability in apartment configurations. Since the 1960s, practitioners and researchers have been exploring alternative visions of adaptable housing solutions that involve residents in the design process. Recent research has proposed digital platforms for residential participatory design. However, methods of modifying apartment configurations after building construction have not yet been developed in detail. This paper suggests a high-rise housing system that supports continuous adaptation and a web application that facilitates participatory design. The proposed construction system leverages on the prefabricated building modules and the open building concept to allow constant renewal of its non-structural building parts. This is complimented by a preliminary prototype of an online platform developed to streamline the design, negotiation and transaction of apartments by the homebuyers. The research conceptually investigates the potential of modern technology in redefining the role of architects and the relationship between residents and their buildings.

Keywords. Participatory Design; Mass Participation; Modularity; Prefabrication; Open Building; User-driven Design; Web Application; Self-renewal; SDG 11.

1. Introduction

Contemporary residential high-rises in Asia are often characterised by their homogeneity and repetition. They are designed through a top-down approach for inhabitants who are alienated in the process (Lee, 2003). Despite significant shifts in values and family compositions of the new generations in some now developed Asian nations, most dwellings still share the same legacy layouts, designed for ideal nuclear families with regular work life patterns, with the goal of tackling demographic challenges and housing shortage in the past (Nagore, 2014). The buildings are rebuilt around every 40 years, wasting embodied energy and producing large amounts of waste in the process (Heckmann, 2016).
Social and cultural changes have increased demand for new lifestyles such as co-living and working from home. As argued by Henri Lefebvre, space should not be a pre-existing and unchanging container which people fill up and move around it, but a product of human activities (Lefebvre, 1991). The old system of Fordism and static spaces have become incompatible with emerging understandings of a Post-Fordist world that is heterogeneous, pluralist, and ever-changing (Ma & van Ameijde, 2021). It is time for architects to start thinking about how to catalyse mass participation in the customisation of residential designs.

This research proposes a novel high-rise housing system, based on two core ideas developed in the 1960s: the open building concept and participatory design (Habranken 1962). It serves as a response to the United Nations' (UN) Sustainable Development Goals of making cities and human settlements inclusive, resilient and sustainable (United Nations, n.d.). The main novelty of the proposed system is the possibility for residents to continually change the spatial configuration of their apartments during the lifetime of the building, referred to in this research as ‘continuous adaptation’. In the proposed concept, such adaptations are made possible by new technical advancements in the domain of prefabricated modular design.

The open building concept suggests that there should be multiple layers of control in a collective housing building. Two key layers are the support layer and an infill layer. The support layer consists of the immovable, structural parts of the building, such as columns and beams, while the infill layer consists of the non-structural, replaceable parts of the building such as partition walls. The two layers can be treated as separate entities, with different life cycles (Brand, 1995). Together, they allow for a building design that is highly adaptable and optimised for participatory design whereby the professionals configure the support layer, and the residents can design the infill layer with some guidance.

Historically, several built residential projects have used participatory design approaches, where future residents are able to influence the design of their apartments. Three key projects were La MéMé, Ökohaus and Next 21. La MéMé, a medical faculty housing project by Lucien Kroll, was designed with inputs from the workshops conducted for students and school staff (Williams, 1979). Ökohaus, a project by Frei Otto, used the open building concept separating structure from infill, and allowed each family to plan their own infill apartment (Callahan, 2013). Next 21, a project by Yositika Utida, also used the open building concept and allowed 13 different architects to design the infill apartments. In this case, all designs followed a set of common rules and materials, resulting in a more unified appearance (Kim, Brouwer & Kearney, 1993). In all three cases, participatory design approaches resulted in residents having significant influences over the design process. However, a key limitation of these examples is that most designs are defined pre-construction. During the lifetime of the buildings, it would be difficult for later residents to change the spatial configuration of their apartments, due to various constructional limitations and constraints.

The idea of continuous adaptation has been a core concept of various post-war movements, including both Archigram and the Metabolist Movement. An iconic example of a built project that incorporated the concept of continuous adaptation was The Nakagin Capsule Tower. The design was based on a series of capsules that could be plugged into (and out of) the vertical core of the building. However, in practice, the
CONTINUOUS ADAPTABILITY: WEB-BASED RESIDENTIAL PARTICIPATORY DESIGN USING MODULAR PREFABRICATED CONSTRUCTION

capsules were never replaced because removing any one capsule requires all the capsules above to also be temporarily removed (Maeda & Yoshida 2021).

More recently, researchers have proposed various digital platforms for mass-participatory design that will allow apartment designs to be adapted to the specific requirements of the residents. Chien & Shih (2000) describe an application developed to help the designers manage buyers’ selection of finishes and interior layouts. Lee & Li (2007) explored a 3D Layout generator that creates interior designs based on questionnaires answered by the buyers. Lo, Schnabel & Moleta (2017) suggested the need to gamify the design platform and provide opportunities for negotiations between users in a participatory design project. Ma and van Ameijde (2021) proposed a Hybrid Structural System that generates customised housing floor plan layouts based on inputs collected from the house buyers.

While the proposed platforms highlight the potential of digital platforms to streamline participatory residential design, two key issues are identified. First, the platforms do not allow residents to directly create their own designs. Instead, they process residents’ opinions in the form of questionnaires. Second, the platforms all focus on design adaptability before construction starts. The idea of continuous adaptability during the lifetime of the building is not developed in detail.

In this research, a novel high-rise housing system is proposed that supports both continuous adaptation and participatory design. To enable continuous adaptation, an innovative modular prefabrication system is proposed that allows infill structures to be modified while the building is in operation. The participatory design process takes place on a prototype web application that allows residents to design the spatial configuration of their apartments.

Section 2 gives an overview of the proposed construction system. Section 3 describes a prototype of the web application for residents to create apartment configurations. Finally, Section 4 draws conclusions and discusses future research directions.

2. Modular Construction System

The proposed construction system implements the open building concept using two key material systems: reinforced concrete for the support and prefabricated modules for the infill. The concrete structure will have a long lifespan while the prefabricated modules have a short lifespan. The prefabricated modules are Structurally Insulated Panels (SIPs), which are light-weight, energy efficient and environmentally friendly. The construction system is defined within an orthogonal 3D grid to facilitate effective and efficient production and assembly of building modules.

The support consists of the load-bearing reinforced concrete structure, which includes the basement retaining walls, shear wall around vertical cores, horizontal corridor slabs on each level, and a 3D frame of columns and beams, as illustrated in Figure 1. The building cores include the staircases, passenger lifts as well as freight elevators that are large enough for transporting SIP panels.
Apartments are the infill, created by inserting prefabricated modules within the columns and beams of the 3D frame. The modules are used to create the complete enclosure of the apartment, including floors, walls, and roofs. They are mechanically connected to the frame, to facilitate the physical installation or removal of the panels. Throughout the life span of the building, residents can reconfigure their apartments by replacing the prefabricated modules.

2.1. SUPPORT

A typical building typology is envisaged, as shown in Figure 2. On all floors, a central corridor runs down the length of the building, acting as a street in the sky. On either side of the corridor, the concrete frame extends two bays deep. Each bay is 7m deep, 3.5m wide and 3.5m high. The 3.5m width means that SIP floor modules can easily span the distance without requiring any additional structural support.
The vertical cores connect the floors and create lateral structural stability. Apartments can then be created on either side of the corridors, with their entrance always directly accessible from the corridors. The corridors are laid with integrated services containing the mechanical, electrical and firefighting systems for the apartments. Heating and air-conditioning are centralised, resulting in improved efficiency and minimising noise disturbances.

The building cores includes the fire-escape staircases, passenger lifts as well as freight elevators. The basement serves as the temporary storage space for the prefabricated modules, which are delivered from the factory to the building in trucks before they are carried up the building in the freight elevator with minimal disruption to the other residents. The central corridors and freight elevator are sized to allow the delivery of modules to and from each apartment.

The overall form of the buildings can be computationally generated or manually tweaked to take various shapes, depending on the site constraints, as shown in Figure 3. The porosity of the building would be maintained by limiting apartments to filling up to a maximum of 70% of the frame. The void spaces can then be used as terraces and outdoor spaces and can also improve ventilation and daylight penetration.

2.2. INFILL

SIPs are chosen as the predominant infill material of walls, floors and ceilings for their environmental-friendliness, ease of installation and affordability. They are prefabricated construction elements that can be mass-produced in a factory and subsequently jointed on site using mechanical connections. They can be made from scrap wood, hence making them even more eco-friendly than timber.

The SIPs and other infill components such as windows and doors make up the prefabricated infill modules for the apartments, as illustrated in Figure 4. Residents will be provided with a catalogue of prefabricated modules to choose from when creating their apartments. The mass production of these modules allows the ease of configuration and replacement.
The prefabricated modules are secured in position by mechanical connections to the concrete columns or beams in a frame. The installation of the modules is done by professional renovation teams. No exterior scaffolding is required. The process starts at the corridor, laying floor SIPs that then form a working surface. The mechanical, electrical, and plumbing systems run under raised floors in each apartment and connect to the corridor, as shown in Figure 5.
3. Prototype Web Application

The proposed housing system is supported by a web application for residents to purchase or sell infill space, as well as to configure apartments.

The web application allows residents to perform four main functions:

- **Space Transaction**: Buy and sell space in the grid, based on the financial market value of the space. Spaces can be put up for sale, and people can bid for the space.
- **Infill Configuration**: Design an apartment within the space that they own, by configuring infill modules from the catalogue.
- **Negotiations**: If a proposed design breaks any environmental rules, the resident can use the platform to negotiate with neighbours to try and reach a financial settlement.
- **Approval**: When the apartment configuration has been completed, the design can be submitted to the building committee for final approval.

The most challenging part is the second step, in which residents create spatial designs of the infill space on the web application. The residents are assumed to have no 3D design experiences. As such, the web application must be highly user-friendly.

For this reason, a gamified approach is proposed to make it easier for people to create a complex 3D model of their apartment. Game design elements, such as operation and interface commonly found in popular home design games, are implemented in the design of the platform. The aim of gamification is to allow the users to navigate and engage with the platform more intuitively (Deterding et al. 2011).

In order to test the feasibility of this approach, a prototype web application has been created. The web application facilitates the Space Transaction and Infill Configuration functions as described above.
3.1. USER INTERFACE

In the web application, users are first asked to select a set of eligible infill space units for which they want to configure an apartment. These units may either be owned by them or are for sale. The volume, costs and number of floors of the selected units are presented to the users to assist them in their decision making, as shown in Figure 6.

Figure 6. 3D viewport for users to select infill spaces to design or perform transactions upon

After completing their infill space selections, the users can access the 3D Workspace of the selected spaces to configure their apartment. As presented in Figure 7, users can customise the layout and appearance of the apartment spaces using a range of infill modules provided in the catalogue to the left of the webpage. The costs of the spaces and modules are tabulated on the right of the webpage to help the users keep track of their expenses. For users who find it challenging to design an apartment from scratch, they can kickstart the process using a template provided in the system before modifying it to their preferences.

Figure 7. 3D Workspace for residents to design their apartment using a catalogue of modules
CONTINUOUS ADAPTABILITY: WEB-BASED RESIDENTIAL PARTICIPATORY DESIGN USING MODULAR PREFABRICATED CONSTRUCTION

In the 3D Workspace, users can turn on the display of the neighbouring apartments in the settings. The ability to see the designs of neighbouring apartments is to allow users to review and negotiate any conflicts of interest that may arise.

3.2. USABILITY TESTING

In order to test the prototype web application, two user-studies have been conducted. The first group consisted of architecture students, while the second group consisted of citizens with no architectural training. In both cases, the users were asked to create apartment configurations that fulfilled specific requirements. The results show that in both cases, users were able to create apartment configurations with ease. However, certain configurations negatively impacted neighbouring apartments, such as infringing on privacy or blocking daylight access. Future prototypes and trials are needed to work out more robust rules that can prevent design flaws while maximising the users' liberty in customising apartments.

4. Discussion

Modern-day residents are diverse and are often very far from the idealised nuclear family. Given the shifts in values and family compositions, existing generic residential apartment layouts are outdated. The proposed approach aims to overcome this issue by imagining a novel type of residential building that allows both continuous adaptation and participatory design. It is enabled by the open building concept: the support being a concrete frame into which apartments are inserted as infills. Modifications of the infill panels are facilitated by a modular system of prefabricated panels. The web application is designed using a gamified approach, making it easy for non-designers to create 3D models of their apartments. It facilitated the ongoing participatory design that allows residents to buy and sell space, design apartment configurations, negotiate with neighbours, and finally get approval for their apartment.

The prototype web application demonstrates that the proposal is feasible although further development is required. Its usability tests confirmed that users, who may not have a design background, can successfully configure their apartments on the platform.

Under the proposed approach, the role of an architect focuses more on being a designer of spatial rules rather than the designer of a final spatial form. Future research will investigate how architects can more effectively use spatial rules and guidelines to coordinate the participatory design by residents.

The proposal challenges the concept of a building: it is no longer a static entity, but instead a dynamic process that will undergo continuous adaptation through participatory design. In many existing projects, the concept of adaptability ends up becoming purely symbolic due to various practical limitations. Learning from past built projects, this research proposes both a user-friendly web application and a modular prefabricated construction system that aims to make continuous adaptation through participatory design a viable reality. It is a work in progress towards achieving the UN Sustainable Development Goal 11 of participatory, integrated and sustainable housing.
Acknowledgements

We thank Dr Hossein Rezai-Jorabi (National University of Singapore) for reviewing and giving feedback on the structural design of the proposal.

References