PARTICIPATORY HOUSING: DISCRETE DESIGN AND CONSTRUCTION SYSTEMS FOR HIGH-RISE HOUSING IN HONG KONG

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Abstract. There has been a recent increase in the exploration of mereological systems, speculating on how digital design, assembly and reconfiguration of ”digital materials” (Gershenfeld, 2015) enables digitally informed physical worlds that change over time. Besides opportunities for construction and design automation, there is a potential to reimagine how multiple stakeholders can participate in the computational decision-making process, using the benefits of the ”mass customization of logistics” (Retsin, 2019). This paper presents a research-by-design project that applies a digital and discrete material system to high-rise housing in Hong Kong. The project has developed an integrated approach to design, construction, and inhabitation, using a system of ”discrete parts” which can be assembled in various apartment configurations, to incorporate varying occupant’s requirements and facilitate negotiations and changes over time.

Keywords. Participatory Design; Generative Design; Adaptable Architecture; High-rise Housing.

1. Introduction

High-rise housing in Hong Kong is highly standardized, to optimise design and construction costs. As the layout of an apartment defines the social relations and possible patterns of user behaviour (Hanson, 1998; Hillier, 1996), the over-optimisation of floorplans limits the freedom of choice of activities and discriminates against people with non-standard lifestyle requirements. Previous studies into the evolution of building typologies in Hong Kong public housing (Kitahara & Shinohara, 2014; Deng, Chan, & Poon, 2016) show that while the quality and environmental aspects of housing projects have improved, the amount of space and layout has not changed over the years. While new estates since 2004 adopt a ‘non-standard’ planning approach, the apartment layouts are in fact based on a standardised catalogue that offer no alternatives to the strategic arrangement of rooms. To optimise space, living rooms double up as circulation spaces to access bedrooms located at the perimeter, resulting in a high degree of unavoidable social interaction between household members.

This study employs a topological approach to the planning of apartment layouts, proposing different configurations of room locations and connections

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to offer different possibilities for social networking. We argue that this is an appropriate and necessary evolution in design thinking about housing, in a time when society is no longer characterised by standard nuclear families and regular work/live patterns. New technologies and cultural changes have increased demand for new forms of co-living and working from home, requiring new types of apartment layouts for a wide range of lifestyles.

Following the introduction of analytical descriptions for social structures in architecture by Hillier & Hanson (1984), ‘’space syntax‘’ methodologies have been widely adopted by researchers worldwide. The logic of defining spatial hierarchies and relationships has also been developed as a design methodology (Al-Jokhadar, 2017; Nourian, 2017), using generative computational methods to create apartment layouts based on network configurations. Layouts can be arranged in ways that enable more independent activities for different household members, or to offer them more freedom in choosing when or how to engage in social interactions.

Our study employs a configuration based design methodology (Fig. 1), generating apartment floor plans based on residents’ desired lifestyles. It explores possibilities for the introduction of mass-customised apartments, as we assume that many different households would have different requirements. As personal living requirements are open to change, and buildings will see different people move in and out over time, we also explore strategies for making layouts adaptable, using a building system that allows for the easy reconfiguration of apartment structures.

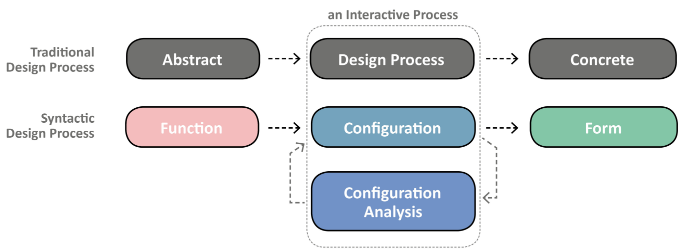

Figure 1. Configuration-based design processes (based on Nourian, 2017).

2. Generative Floor Plan Layout Design

For this research-by-design project, a unit layout configuration script was created to generate room clusters and relationships, based on a circle packing system and real-time physics simulation following on from Nourian (2017). The Rhino/Grasshopper plugin ‘’Wallacei‘’ (Makki, Showkatbakhsh and Song, 2019) was used to enable a multi-objective optimisation process, evaluating complex and contradictory requirements such shared circulation, building structure, daylight access and views.

As inputs to the script, end-user defined parameters are used including the number of required rooms, their function and size, and the desired connectivity between them. The inputs are translated into an automatically generated spring model that creates a closest packing solution by translating desired connectivity into higher spring stiffness parameters. Reverse relationships (maximising distance between rooms) can also be applied. The circle packing solution is translated into an orthogonal floor plan by using a standardised grid system relating to furniture element dimensions and building components (Fig. 2).

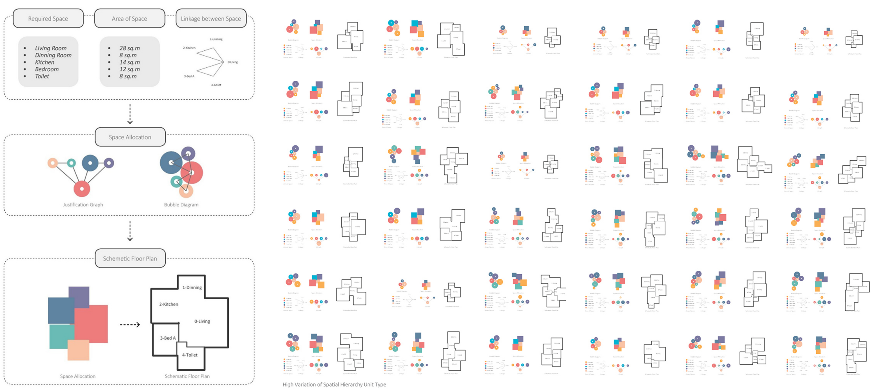

Figure 2. Design mechanism for generative apartment layouts.

The computational workflow was further developed to negotiate between several units on one floor, incorporating shared unit boundaries and their connection to vertical circulation. To test a hypothetical scenario with different apartments having to configure around a shared core, four different types of households requirements were used and a number of optimisation criteria were introduced to generate the collective floor plan layout. The four main fitness objectives used were daylight access, views, floor plate geometry complexity, and internal circulation. These objectives are analysed when floor plate geometries are generated using an expanded version of the circle packing method describes above, highlighting how some objectives may align in certain solutions while others are contradictory. Maximising views from all rooms, for instance, creates a more irregular floor plan outline, while optimising geometry complexity (which indicates construction costs) results in a more compact and simple outline. The nature of the multi-objective optimisation process is that several optimal solutions are presented to the stakeholders, giving insight in the consequences of prioritising certain parameters and allowing the users to make an informed decision in negotiation with each other (Fig. 3).

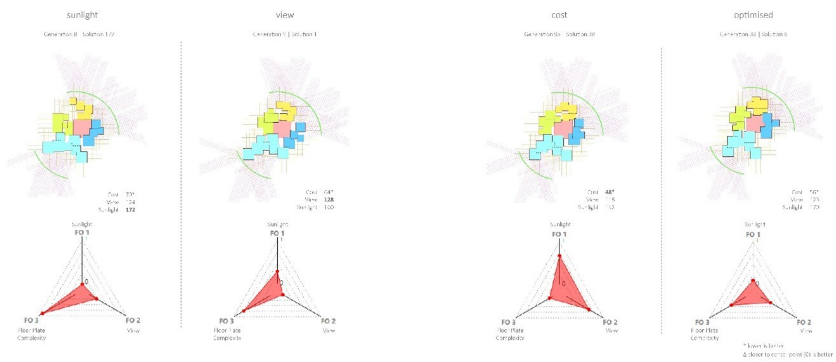

Figure 3. Layout optimisation based on daylight, views, complexity and circulation.

3. Optimisation Criteria for Multi-apartment Floor Plans

The generative algorithm incorporates minimum requirements for daylight access, to ensure that all rooms have access to light and ventilation in accordance with Hong Kong's planning standards and guidelines. In addition to measuring daylight access into all rooms, the algorithm incorporates a minimum distance of ten metres to another parallel façade element, to avoid privacy issues between neighbouring apartments. This distance could be adjusted by the residents, to fit different sites or cultural requirements.

To maximise views, which contributes to quality of living and to the value of the apartments in Hong Kong's high-density urban environment, sight-lines at 40-degree view angles (left and right) are projected from a row of points on the outer facades, checking for intersections with other parts of the floorplan geometry. A hypothetical context was added to test how layouts can be optimised in relation to attractive views in the surroundings, or to avoid view obstructions from adjacent buildings.

As construction cost is one of the major pressures on the design of housing projects in Hong Kong, the methodology used in this study incorporates several measures to rationalise the complexity of the generative solutions and improve their affordability. A key aspect is the integration of the characteristics of a modular construction system, assuming an assembly process of industrially prefabricated spatial units. The modular grid sizes for this system are optimised so that a large amount of different apartment configurations can be achieved with a small set of different modules. Using a process of 'snapping' to this construction grid, the algorithm can prevent non-standard modules and count the number of components needed to enclose the desired area of apartment floor space. The ratio between these values indicates the construction efficiency, while further data regarding the costs of different types of modules could be added, to give more specific feedback to the users. At the overall floor plate level, the script aims to reduce the total complexity of the floor plate geometry to reduce cost, assembly time and improve environmental performance.

Using the genetic algorithm functions in the multi-objective optimisation process, a large number of shape variations (phenotypes) are generated based on the same topological relationships (genotypes). All solutions are evaluated against the above fitness criteria and new generations of solutions are created by adding mutations to the best performing phenotypes of each generation. The desired number of rooms and their connections are achieved in all solutions, while presenting different options to the users that represent a different balance between views, daylight access and floorplan compactness. For the purpose of illustrating the potential outcomes of the generative design method, a series of 'non-standard' household and lifestyle scenarios was entered into the workflow, and the resulting apartment layouts and their spatial qualities were visualised (Fig. 5).

Figure 4. Iterative snapshots of floorplan layouts based on optimisation towards daylight and views, in relation to surrounding buildings.

Figure 5. Diverse life style requirements resulting in non-standard apartment configurations.

4. Integration Between Digital Participatory Design and Construction Systems

In parallel and in dialogue with the development of the generative design process for spatial layout solutions, a materialisation system was developed based on the premise of a fully prefabricated system of modular building elements. Following the desire to develop an adaptable apartment configuration system that would be open to changes in users, or user requirements over time, an interchangeable set of elements was developed based on the idea of ‘’discrete materials‘‘ (Retsin, 2016). The discretised parts were developed by adapting existing modular elements used in Hong Kong’s public housing.

Since the first prefabricated systems developed in the 1930’s and 40’s by Wachsmann, Gropius and others, factory made elements have evolved from panel systems to volumetric systems, known as PPVC (Prefabricated Prefinished Volumetric Construction) or MIC (Modular Integrated Construction). These systems use cost-effective, high-quality elements to enable rapid assembly on site. Recent systems also integrate various services and finishes, further reducing the needs for specialist trades and processes on site.

The concept of digital materials as introduced by Gerschenfeld, Sanchez (2014) and Retsin, offers a new perspective on the integration between digital design and construction systems, using generative computational processes to optimise physical structures that have the same organisational logic as their digital counterparts. Discrete assemblies of elements can be tested and evaluated by designers and stakeholders alike in a collaborative process, before deciding which version would be materialised. Example projects by Retsin and others explore universal elements that avoid a classification between structural and non-structural, taking advantage of the multiple combinatory possibilities of the pieces to create flexible compositions of prefabricated elements (Retsin, 2017).

Dry connections that are reversible extend the lifespan of the elements, connecting the materials systems to a philosophy of reusable and adaptable products, reducing environmental impact and use of natural resources.

The discrete materials systems in their pure form result in redundancies and inefficiencies when dealing with structural performance requirements at larger scales, which is contradicting with current practice in Hong Kong's high-rise tower construction, where separate building systems are highly specialised and optimised. Therefore for our study, we have focused on a composite system that combines a non-flexible internal tower structure and a reconfigurable ''discrete'' apartment construction system. This is similar to current practices in Hong Kong housing construction where in-situ cast concrete cores are supplemented by prefabricated elements that form partitions, stairs, bathrooms, and facades (HKHA, 2011).

5. Discrete Material Systems in Highrise Construction

Following the aim of providing a reconfigurable construction system that allows for participatory housing design, the building is divided into three systems which are designed according their different levels of adaptability. The permanent vertical structure combines a circulation core and moment frame to provide structural stability to the entire tower, as well as a framework against which to connect the housing modules (Fig. 6).

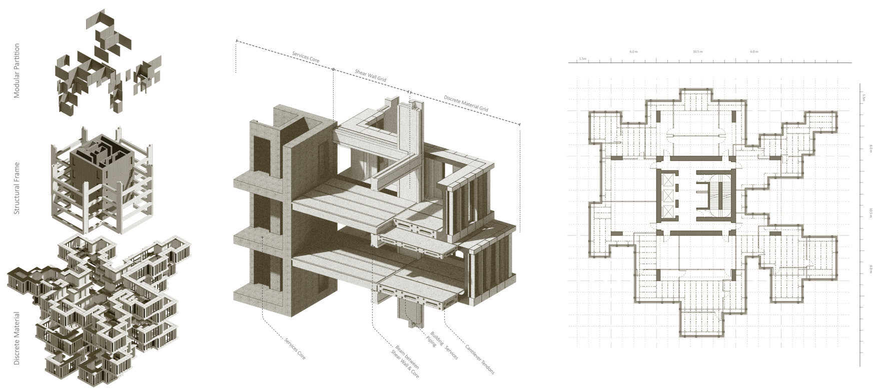

Figure 6. Combined system of permanent tower structure and adaptable apartment configurations.

The second system consists of the ''discrete'' spatial modules that form floor slabs and outer façade elements of the apartments, using a limited family of types with modularised dimensions. As individual apartments should be able to be reconfigured without affecting neighbouring units in all directions, apartments are cantilevered from the internal structure using post-tensioning cable systems. The steel framed modules would be designed to have efficient weight to strength ratios and have interlocking connection joints to create watertight enclosures. The third system consists of the internal partitions, which are light steel infill panels that are easily reconfigurable by the users. The different systems have different rates of change: apartments could be expected to be altered once every 3-10 years while interiors might be changed more frequently.

While some international research on discrete material systems speculates on the automation of construction and adaptation using robotics, this study assumed a near-future scenario where the changes in apartment configurations could be implemented using conventional contractor services and equipment. The key innovative aspect around the system is the control and negotiation around customised housing configurations as part of a participatory and collaborative community process, facilitated through a user-friendly mobile application. The role of the architect is expanded towards the design of these processes, including guidelines and mentorship to assist residents with their decision making. The algorithms tested in this study could be further developed to provide a comprehensive forecasting service on the consequences of residents proposals, running background performance calculations while visualising the desired or even better solutions, to create better living environments for all members of the community.

6. Conclusions

This research has explored the conceptual possibilities of introducing a customisable and adaptable construction system into the highly constrained practice of high-rise housing design. Through the development of a case study tower design, and a number of prototypical assemblies, several potential configuration states have been illustrated, describing an ever-changing and user-driven housing community. The use of multi-objective optimisation processes and computational performance analysis could help to facilitate the ‘’democratic‘’ process of finding a balance between the desires of individuals and the interests of the collective, through their ability to indicate opportunities and help mediate conflicts of interest through a data-driven design approach.

The study aims to demonstrate the potential of architectural systems and processes that don’t produce housing that is conceived as finished when construction has completed, but instead construct open-ended systems that evolve with the changing living requirements of their inhabitants. The continuous collection of performance and user data throughout the life of the community, can provide feedback for continuous updating and improving the physical environment. This interactive process establishes a new definition of participatory and bottom-up design. The digital model of the building is more than a duplicate version of physical tower, as it serves as a virtual testing, visualisation and negotiation platform for residents. The resulting interactions blur the boundaries between digital and physical systems, not only supporting the construction of customised housing, but also to document and communicate the benefits and balance between different spatial, environmental and building performance criteria. Most importantly, this interactive process facilitates informed collaborative participation and negotiation assisted by the power of computation.

Future research could be used to further developed the technical aspects of implementing the conceptual notions around ''digital material'' systems towards the complex typology of high-rise housing in Hong Kong. As housing is one of the most significant factors in the experience of urban living, more effort should be devoted to innovation, using a more critical and user-centric approach to ensure that designs are fit for purpose. As design and construction processes are already becoming increasingly digitised, it is time to futher explore the value and capacity of digital systems to actively respond to the demands of residents, contributing to a better quality of life and help to promote a sense of belonging. While this approach is capable of disrupting the doctrine of standardisation and repetition in housing in Hong Kong, it may also offer opportunities to rethink scenarios of inhabitation in many other types of buildings and locations across the world.

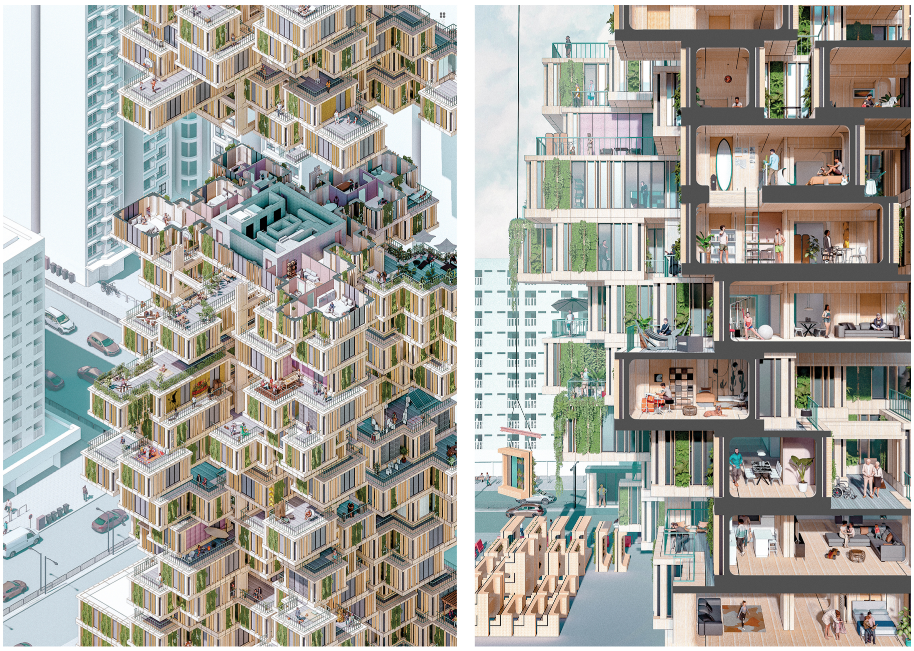

Figure 7. Diverse living configurations within participatory housing.

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