A Case for High-density Living,

A Study of Adaptable Prefabricated Construction

for High-rise Residential Buildings in Hong Kong

By

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A thesis submitted to
The Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Architecture
(Professional M. Arch)

School of Architecture
Carleton University
Ottawa, Ontario
January 2007

Abstract

This thesis argues that high-rise housing that offers its potential buyers a wide range of spatial configurations together with a design scheme that generates an interactive living environment is a better response to the demanding living conditions in Hong Kong. The research will be comprised of studies on demographic and economic factors that correspond to current living conditions in Hong Kong; the concept of adaptable prefabricated construction; the precedents of using prefabricated components with adaptable characteristics; and the integration of automobile and building assembly methodologies as a means to derive an advanced assembly construction system. In the design proposal, I will present the conceptual 'unibody modular' assembly system as an alternative adaptable prefabricated construction approach that is assembly-efficient while permitting diverse spatial configurations that depart from the design uniformity of high-rise residential buildings.

Acknowledgments

I wish to thank my parents and my brother, Sunny, for their supports and unconditional love over the course of my time at Carleton University. And special thanks to Kerry Kwan for the input of her time and ideas throughout the process of writing this thesis. At last, I wish to express my gratitude to my thesis advisor, Manuel Baez for his patience, constructive criticisms and guidance for the thesis.

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All images by author unless otherwise noted.

Chapter One

Introduction

This thesis will begin with an overview of commercialized perspectives toward high-rise residential development, and will analyze alternative construction methods that will resolve the demanding living conditions in Hong Kong. The thesis argues that the construction method of adaptable prefabrication together with the design scheme that generates an interactive environment for inhabitants is a better response to the demographic and economic factors governing housing in Hong Kong. Chapter Two will deal with the broader issues of residential developments in Hong Kong, such as the demographic factors that limit the amount of livable space per person, the shortage of green open space, the lack of interaction between households, and the economic factors that create the need for efficient building construction. In Chapter Three, the concept of adaptable prefabricated construction as an efficient assembly construction methodology will be studied in detail. This construction method creates design possibilities by incorporating building components that are adaptable to various functions. In Chapter Four, the efficiency of adaptable prefabricated construction will be illustrated with precedents that are based on innovative assembly systems and the adaptable design of prefabricated components. The precedents will be analyzed and will focus on the exploitation of the adaptabilities of prefabricated components that generate a wide range of spatial configurations. In addition, it will attempt to establish a relationship between the complexity of diverse modes of living and the economic necessities of prefabrication. In Chapter Five, the adaptability of the automobile's prefabricated 'unibody' assembly system will be studied in an attempt to integrate automobile assembly methodologies into housing prefabrication in order to generate a building system of adaptable prefabricated construction that has expanded design possibilities. In Chapter Six, the proposed site will be analyzed with its current site settings along with the prospective development adjacent to the site. In Chapter Seven, the design of a residential development will be proposed in an attempt to redefine the uniformity of Hong Kong's residential buildings by introducing a construction approach that integrates adaptable design possibilities while maintaining assembly-efficiency in building prefabrication.

Currently, the commercialized residential developments in Hong Kong have been guided by the simple motives of assembly-efficiency and fast paced construction. The assembly-efficiency of construction is based on conventional methods of constructing reinforced concrete structures with identical formwork for each building level and the use of prefabricated non-load bearing concrete walls. The result is a mass-production of dwelling units with homogenous spatial layouts, which cannot respond to the demands of diverse household compositions. In addition, the residential buildings have been fashioned with collective themes of 'fantasies' that have no inherent value, and may not cater to the preferences of individual households. The households are clustered within a series of identical residential towers that are grouped together on top of a podium in a landscaped open-air park setting with communal facilities. The developers have adopted this method as a means for providing ample clean air and sunlight, and have included the sharing of luxury facilities to facilitate social interaction. This is a marketing strategy to create a fanciful living atmosphere that appeals to the public; however, it is an avenue that allows interaction between residents only at the community level. The 'fanciful' residential buildings built with homogenous dwelling units lack the spatial flexibility to satisfy individual household needs and they also restrict interaction between occupants and neighbours at the community level. Generally, Hong Kong's recent residential design approach has neglected the consideration of individualized housing for diverse household compositions, and the ever-changing needs and interactions between households. The question is: can the gap between commercialized housing and individualized housing be closed? The issue that will be addressed throughout the thesis is the lack of diverse spatial layouts in the case of conventional uniform prefabricated building systems, notwithstanding the lack of interaction between households. A construction method that is an alternative to uniform homogenous dwelling units has to be considered. Will an application of adaptable prefabricated construction redefine the conventional perception of living in residential buildings in Hong Kong?

By understanding current construction methods and by integrating these methods into assembly methodologies from the automobile industry, the conceptual 'unibody modular' system, as envisioned, can become the preferred adaptable prefabricated construction methodology. The assembly system introduced in the thesis is expected to be assembly-efficient and would be design-variable as prefabricated components with adaptable characteristics are integrated. Given the adaptable characteristic of the 'unibody modular' assembly system, a wide range of spatial configurations could be generated to satisfy the various demands of households

In summary, the design proposal would modify uniform dwelling layouts under the proposed 'unibody modular' assembly system. In addition it will take into account the need for more open-green environment and interactive neighbourhoods. The proposed design would be comprised of diverse dwelling layouts using prefabricated components with adaptable characteristics for the construction of high-rise residential buildings. A semi-private space would be assigned for each dwelling and would be grouped together to provide the opportunity to improve interaction between households and neighbours. It is an attempt to provide a more physically and socially cohesive interactive environment at both the community and neighbourhood levels for high-rise residential developments that would blend in with the local context in Hong Kong.

Chapter Two

Residential Development in Hong Kong

2.1 Introduction

Residential developments in Hong Kong are dictated by demographic and economic factors. The demographic factors include a high-density population, a wide range of household compositions, and the need for housing units to cater to the growing population in Hong Kong. The economic factors include shortage of land space, the lack of open-green spaces, economic booms, and the desire for efficiency in building construction. With the interplay of these demographic and economic factors, the residential developments in Hong Kong have been based on the mass production of uniform prefabricated high-rise housing units with diminutive landscaped open spaces at the ground plane. The construction method of using repeated formwork to construct the reinforced concrete structures and the use of standardized prefab components for the high-rise residential buildings has earned a reputation for being assembly-efficient and time-saving.[1] However, the uniform housing design results in homogeneous dwelling layouts. It is appealing for developers to construct assembly-efficient uniform residential buildings, but it is less so for potential home buyers.

The production efficiency of this method appeals to developers attempting to answer the housing shortages resulting from economic booms and an ever-

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[1] Wong, Luke S.K., ed. Housing in Hong Kong: A Multi-Disciplinary Study. Hong Kong: Heinemann, 1978. P 91-106.

higher population growth.[2] However, the construction method has been criticized because dwellings are uniform and developers fail to consider or recognize the unique human and environmental factors that ought to be considered in the design of the buildings. This is re-iterated by Colin Davies who argues that most of the uniform prefabricated housing developments have lacked architectural perspective, i.e. the absence of architectural expression and the elimination of architectural principles. Davies believes that non-architectural prefabricated uniform residential building exists because architects and builders have two dissimilar perspectives. The two professional groups are educated differently and have different histories of building housing for residents. One group is financially motivated by profit and focuses on the efficiency of construction methods, while the other group is motivated by the concern for design that focuses on human needs and desires. These two groups of professionals work separately; however, they are dependent on each other. If they worked together, they could provide an economically sound and architecturally appropriate living environment.[3]

I concur with Colin Davies and state further that high-rise residential developments in Hong Kong today are too uniform and that the approach of simplified housing design is purely quantitative and lacks qualitative architectural concerns. The quantitative concerns simply deal with cost-efficiency and ease of

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[2] Gutierrez, Laurent, Ezio Manzini, and Valerie Portefaix. HK LAB. Hong Kong: Map Book, 2002. P 255.
[3] Davies, Colin. The Prefabricated Home. London: Reaktion Books, 2005. P 8.

construction, which are the two prime factors that have guided prefabrication as the mainstream construction solution for the current housing market in Hong Kong.[4] The qualitative concern that the preferences of individual households are not equal has been disregarded by the developers' housing approach. This chapter attempts to juxtapose the general notion of Colin Davies' argument, and my position on the uniform prefabricated high-rise developments in Hong Kong with respect to demographic and economic factors, and the absence of architectural inputs.

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[4] Wong, Luke S.K., ed. Housing in Hong Kong: A Multi-Disciplinary Study. Hong Kong: Heinemann, 1978. P 204-205.

2.2 Driving force of early prefabricated housing

In Hong Kong, economic upheavals have motivated building contractors to come up with new ways of thinking that generate new housing programs and experiments. An economic boom and social dynamics have created an acute housing shortage that requires a solution in the shortest possible time.[5] The economic boom has intensified the rural-urban drift and increased housing shortages. The result is a hyper-dense living situation. Developers have responded to this situation through the assembly-efficient prefabricated construction methodology.[6] The objective of which is improvement in production efficiency. For an example, in the early 1980s, the dominant massive prefabricated building blocks built in the To Ka Wan area, were the most significant hyper-dense residential development responding to the housing shortage in Hong Kong at that time (Fig. 1).

Fig. 1. Early prefabricated residential development, To Ka Wan, Hong Kong.

[5] Ibid. P 23-35.
[6] Ibid. P 93-100.

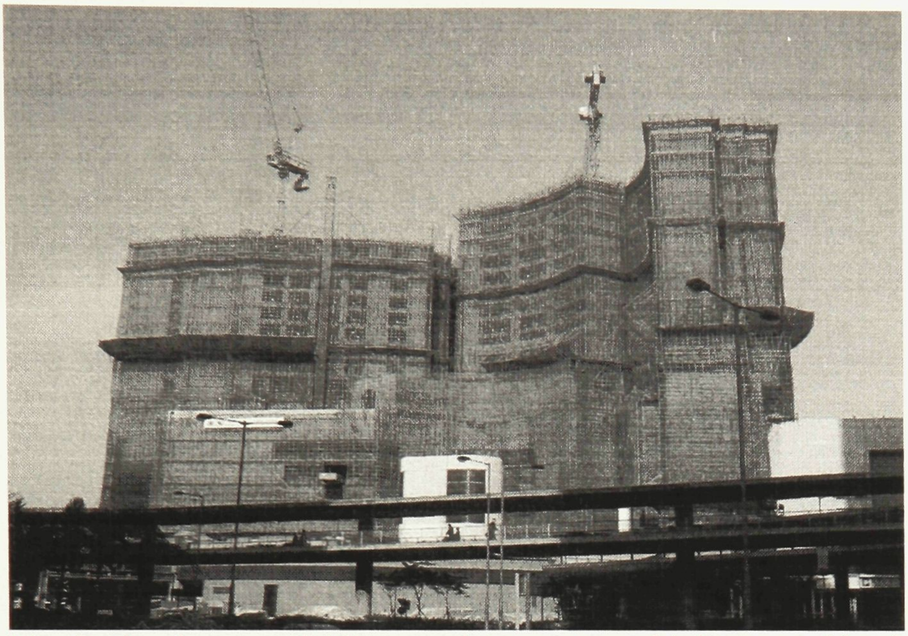

Fig. 2. Bamboo scaffolding used to construct high-rise residential buildings.

Developers at that time were not only inspired by new housing paradigms, but they were also mandated to deal with the mass-production of housing units from an entirely new perspective. The aim of these new housing paradigms was to devise an assembly-efficient construction system. The erection of prefabricated residential building blocks was based on conventional methods of constructing reinforced concrete structures with identical formwork for each level and the use of prefabricated non-load bearing concrete components. The entire building envelope was wrapped with inexpensive and reusable bamboo elements, the 'bamboo scaffolding' construction system, to allow the greatest mobility for workers during the construction stage (Fig. 2). The bamboo was used as a forming and constructive element allowing workers to ease the formworks into position and to access the outer surface of the building for touch-up works. Consequently, the 'bamboo scaffolding' system involved constructing and dismantling an additional structure surround the building envelope, and has been criticized for departing from the aims of fast-pace and assembly-efficiency.[7]

In addition, the prefabricated residential building blocks are built with homogeneous dwelling floor plans that are clustered together within the smallest amount of land. This method of clustering the buildings has been criticized for failing to incorporate green spaces in the living environment. So, a series of illegal discrete structures, commonly called 'metal cabins', were added by the occupants as additions to the dwelling spaces, as open-air balconies for planting, for relaxation, and for overlooking activities in the streets (Fig. 3 and 4).[8] Positively, these 'metal cabins' were used for a variety of purposes based on occupants' needs and desires. Negatively, they were constructed indiscreetly and without any concerns for possible damage to the overall structure of the façade wall. These metal cabins were not assembled by qualified contractors and were mainly built with exposed steel metal strips that could rust over time. Conceivably, the structurally unsafe 'metal cabins' could be a death trap or potential hazard for the occupants and residents who might be walking on the street. But in spite of these safety concerns, the 'metal cabins' demonstrated the demand for open-space in response to the compact living conditions in Hong Kong.

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[7] Walker, Anthony, and Stephen Rowlinson. The Building of Hong Kong: Contructing Hong Kong Through the Ages. Hong Kong: Hong Kong University Press, 1990. P 57-58.
[8] Woo, C. Wai. Hong Kong Style. 2nd ed. Hong Kong: CUP, 2005. P 109-110.

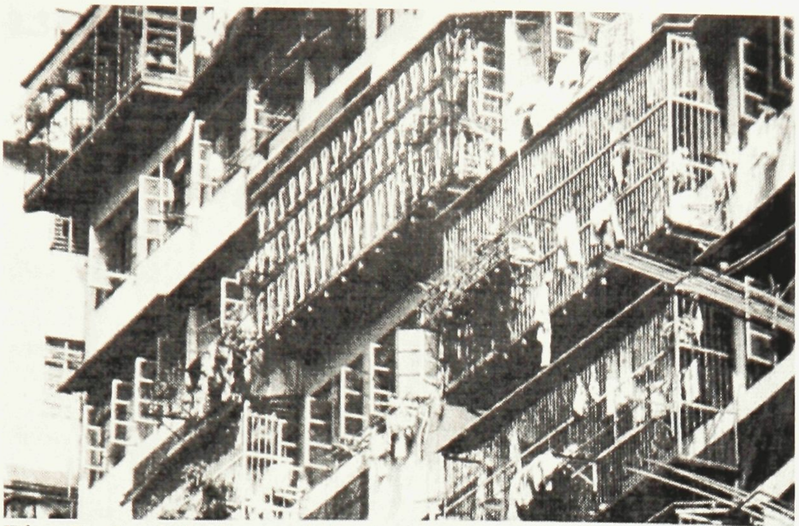

Fig. 3. Aerial view of the ‘metal cabins’.

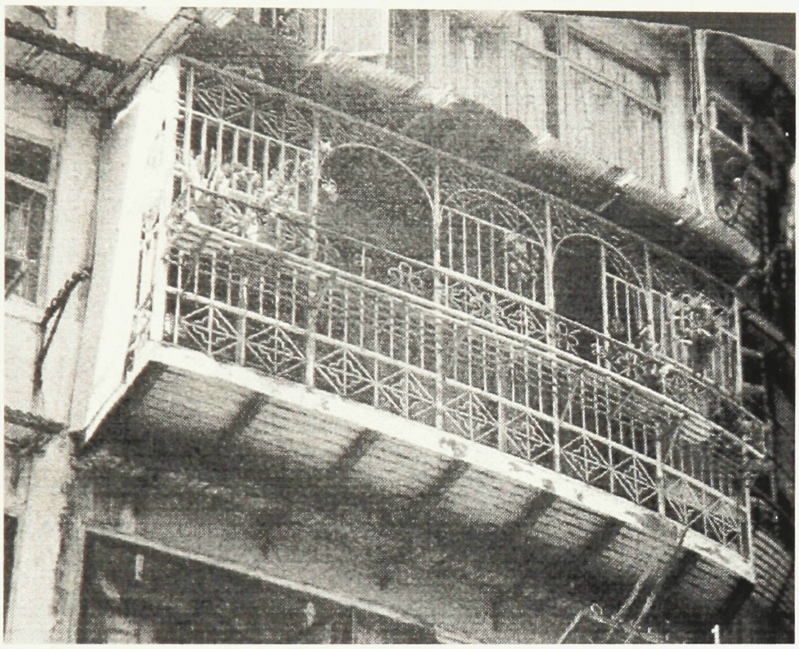

Fig. 4. A ‘metal cabin’ attached onto the prefabricated façade wall.

2.3 Pre-cast reinforced concrete construction

Since the early 1980s in Hong Kong, the economic factors of assembly-efficiency and mass-production have driven the developers to use the conventional pre-cast reinforced concrete construction method.[9] This method remains in use in today's housing construction. Current high-rise residential structures combine the use of pre-cast concrete formwork and prefabricated components such as reinforced concrete partition and façade panels. The layout of each level is formed by pouring concrete into the formwork, then each reinforced concrete floor plate is stacked vertically one on top of the other without variation in the design. Recently, the 'Jump Form' system has begun to compete with traditional 'bamboo scaffolding' construction system (Fig. 5 and 6). The 'Jump Form' system is a steel framed structure containing track rails and screw-operated jack rods that are positioned at the level of construction.[10] Then the pre-cast reinforced concrete components, such as the façade panels, are mounted onto the supporting joist frame articulated to the jack rods and can be easily positioned or removed by the track rails. It is a construction system of lifting and sliding the prefabricated components into positions efficiently using more machines than manpower. The entire steel framed structure of the 'Jump Form' system can lift itself up onto the next level by a jacking device after the construction works of a

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[9] Wong, Luke S.K., ed. Housing in Hong Kong: A Multi-Disciplinary Study. Hong Kong: Heinemann, 1978. P 91-93.
[10] Leung, Felix. 15 Most Outstanding Projects in Hong Kong. Ed. Stefan Hammond, Tim Youngs, and Carol Hui. Hong Kong: China Trend Building Press, 2005. P 162-165.

floor is complete. The system can thus save a lot of time and effort in the placement of the pre-cast concrete components and formworks.

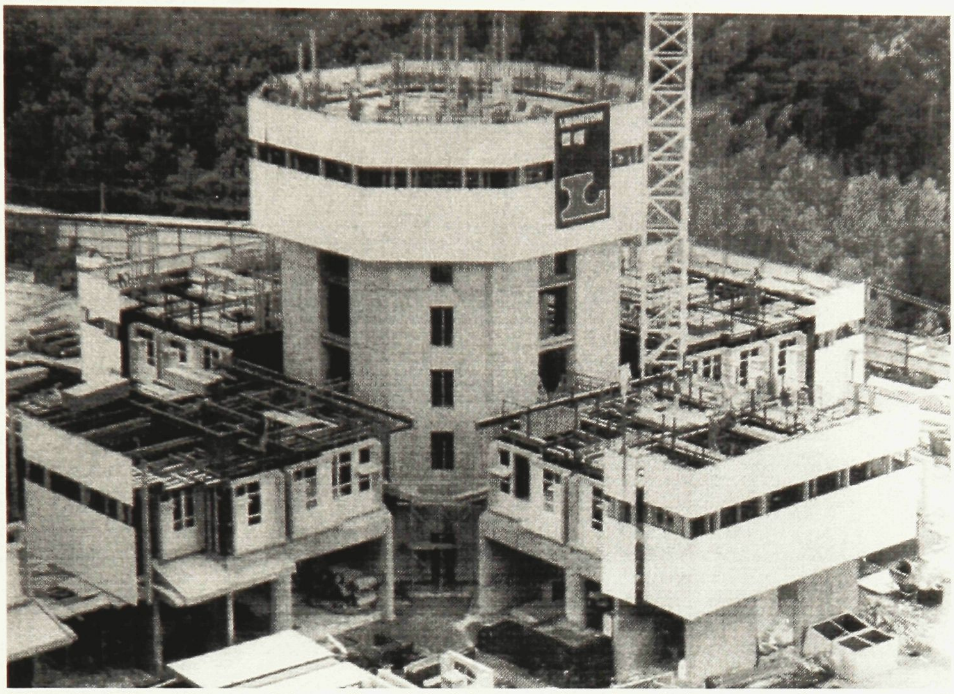

Fig. 5. The "Jump Form", a highly mechanized formwork system, Tseung Kwan O Area Phase 4, Hong Kong.

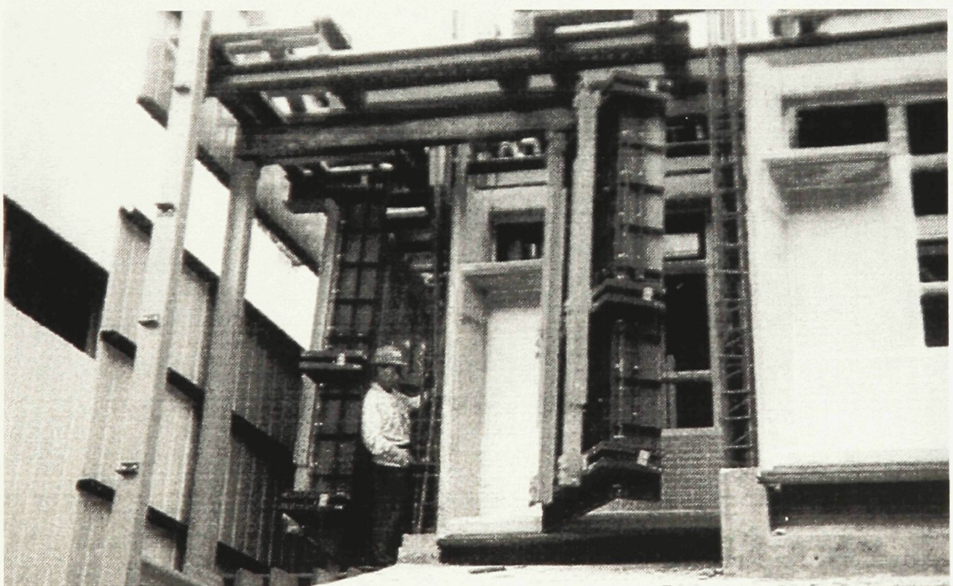

Fig. 6. The "Jump Form" assembly system shows that the track rail can enable the prefabricated panel to slide into position.

As a result, the developers construct buildings that are configured fundamentally the same. The developers claim that the pre-cast concrete panels can be easily assembled onto the reinforced concrete structures by workers with less construction failure and faster construction time as most of the prefabricated components can be assembled in a simple fail-safe procedure. The construction sequence is simple because most of the building components are prefabricated in the factory or on-site at ground level, and then hoisted into position by a crane on site. Applying prefabricated components in building construction is an attempt to maximize production efficiency. Overall, the consequence has been uniform models for prefabricated high-rise residential buildings where the priority is to expeditiously satisfy the developers' financial needs with maximum return on their investment.

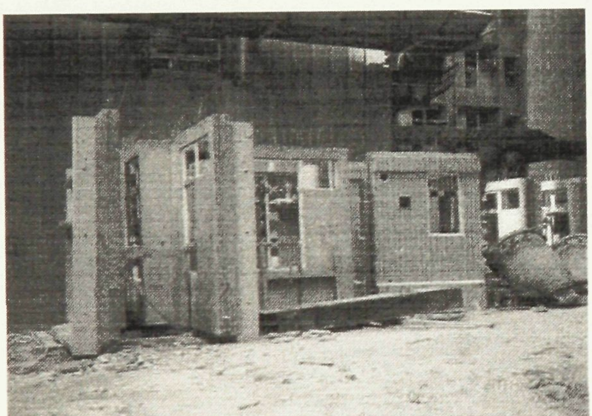

Fig. 7. Pre-cast reinforced prefabricated components- external wall (left).
Fig. 8. Prefabricated components- stairs (right).

2.4 Recent residential tower developments

As described before, the uniform prefabricated high-rise residential buildings began appearing in Hong Kong's urban landscape in the early 1980s. Since then, the method of construction has not changed, and developers still use reinforced concrete formwork construction systems with dimensionally standardized prefabricated non-load bearing panels. The result is a series of mass-produced uniform high-rise buildings that are executed in large-scale plans. However, recent private sector housing developers have realized that the market for uniform housing can not be successful unless there are additional features or offerings added to the housing package.[11]

As a result, private sector housing developers have included in their standardized housing proposals a range of 'fancy' decorated facilities to create a luxury image for the prospective clients (Fig. 9 and 10). Each residential development forms a group of towers built on top of a podium where a diverse range of functional activities and facilities is located (Fig. 11). The dwelling units or cells within each of the complexes are expected to be identical except for a few variations in the dimensions of the floor plans offered to prospective homeowners. The podium serves as a horizontal link between the clustered residential towers that are located on the same platform; it functions as the access point out of the cluster of towers; and it is the only place where residents can interact and

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[11] Woo, C. Wai. Hong Kong Style. 2nd ed. Hong Kong: CUP, 2005. P 22-25.

socialize with one another. The podium has been equipped with a variety of common services and facilities such as landscaped gardens, pools, shops, club houses and parking. Here the developers attempt to sell their version of "paradise" and to simulate "dreams" that they consider to be ideal for dwelling. The residential compound has become a theme park, where structures are embellished with decorative elements such as screens, walls, lights, mirrors, water fountains, and sounds. For example, the residential development named 'Caribbean Coast' has proposed an enormous swimming pool that is decorated with sand and watering features to mimic the atmosphere of Caribbean beaches (Fig. 12).[12] It is the swimming pool proposed on top of a podium that becomes the major selling point. This 'scenery' found in recent residential developments in Hong Kong has been described by Gutierrez and Portefaix as 'an expression of collective fantasy'; and that architecture is "[…] no longer the art of designing buildings, but rather it provides the means to support an exclusive concept."[13]

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[12] Gutierrez, Laurent, Ezio Manzini, and Valerie Portefaix. HK LAB. Hong Kong: Map Book, 2002. P 246.

[13] Gutierrez, Laurent, and Valerie Portefaix. Mapping Hong Kong. Ed. Anna Koor. Hong Kong: Map Book, 2000. P 75.

Fig. 9. An image shows the luxury of living created by the developers.

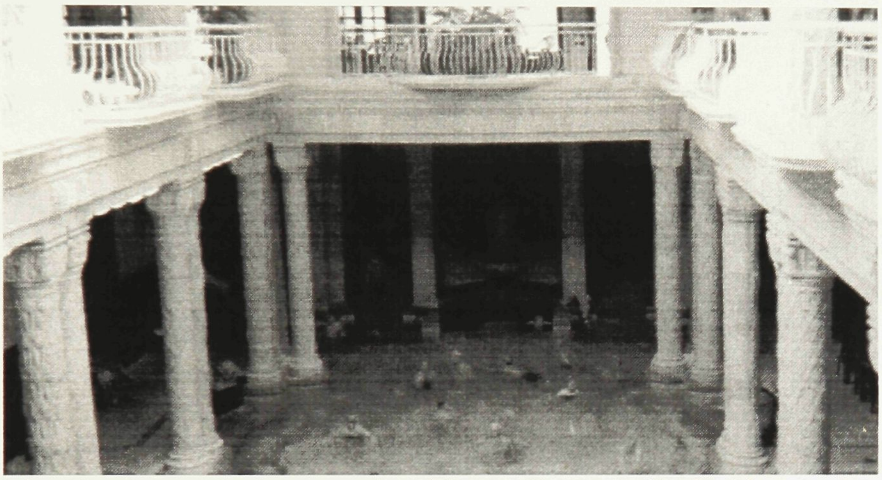

Fig.10. A pool decorated with replicated Corinthian columns to simulate the developers' version of 'paradise'.

The architectural features of residential developments in Hong Kong focus on decorative fantasies that represent both fashionable styles and images of luxury. Through clever packaging of expensive marketing and promotional messages, Hong Kong's housing developers have demonstrated their ingenuity by implementing their version of the ideal housing solution.

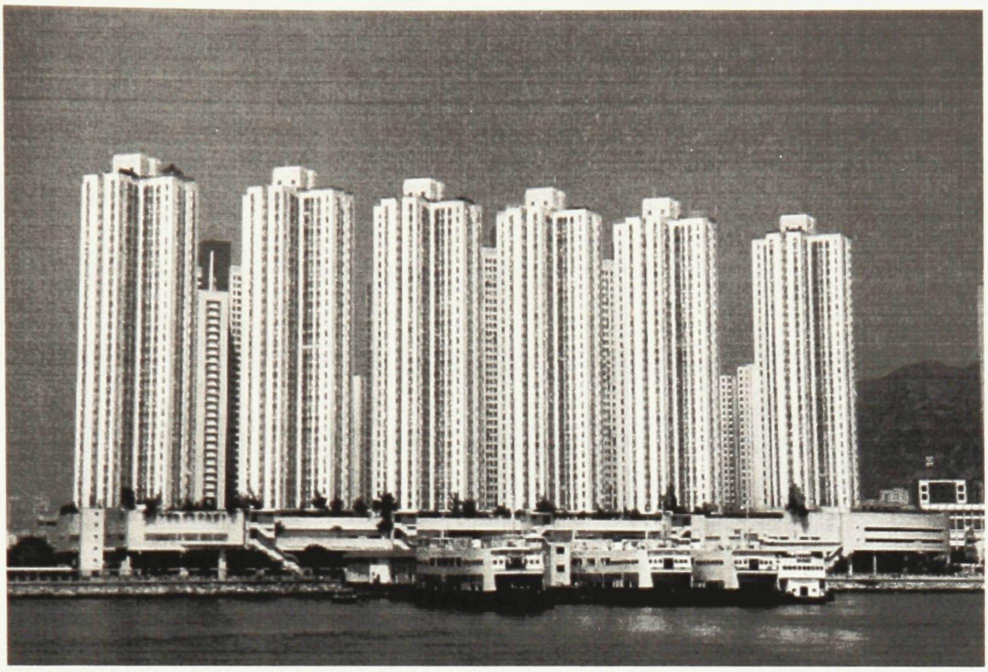

Fig. 11. A series of clustered uniform residential towers being built on top of a podium, Tuen Mun, Hong Kong.

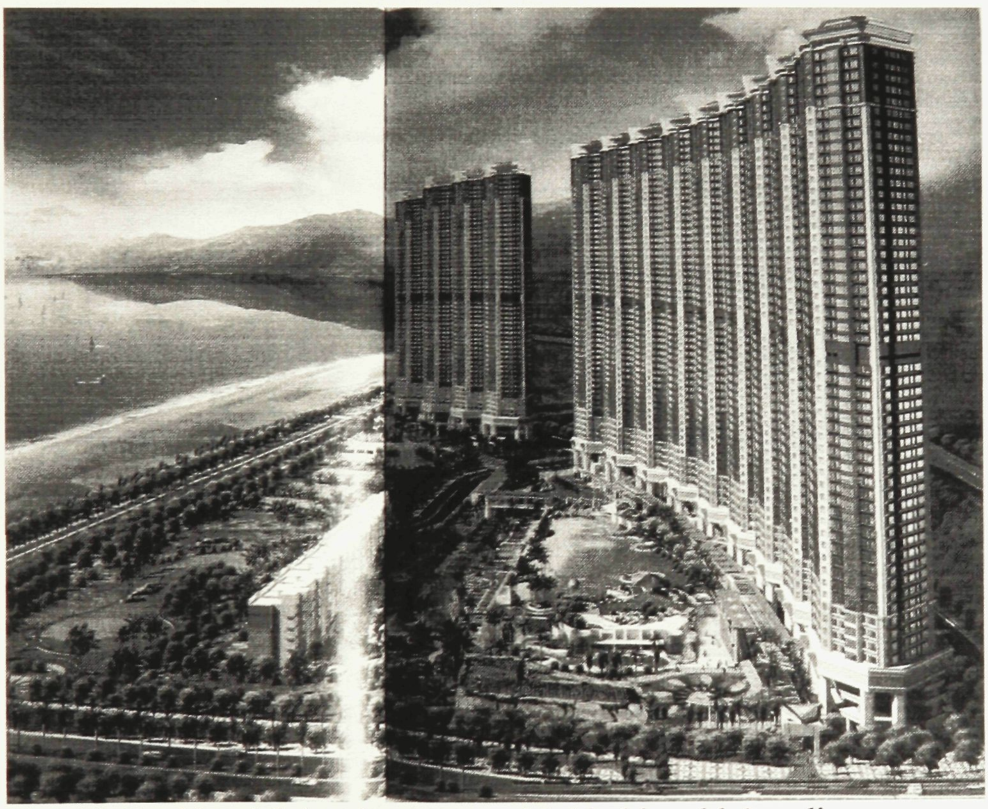

Fig. 12. Residential developments with 'fashionable' podium, a new residential development named 'Caribbean Coast', Tung Chung, Lantau Island, Hong Kong, 2000.

2.4.1 Constraints in unit dimension and spatial arrangement

The high population density and the high land cost of Hong Kong necessitate high-rise residential buildings. Studies of the large-scale podium design scheme in Hong Kong indicate that the amount of liveable space per occupant - more liveable floor area per building's footprint- and lower overall construction cost could be resolved by building taller residential towers. According to the book HK Lab, to compensate for these constraints, residential buildings must be built as high as permitted to provide a profitable return on the total cost of land, construction cost, and the expensive 'fancy' decorative facilities.[14] Meanwhile the use of homogeneous, regular and repeated floor plan designs in high-rise residential towers maximizes construction speed. The simplification and repetition of the gross floor plan design permits the supplementary use of prefabricated components as further cost and production efficiencies. The transition into constructing high-rise and uniform residential towers in Hong Kong is the local housing developers' attempt to minimize the cost of square footage of land by increasing liveable space in the vertical rather than the horizontal plane.

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[14] Gutierrez, Laurent, Ezio Manzini, and Valerie Portefaix. HK LAB. Hong Kong: Map Book, 2002. P 196-203.

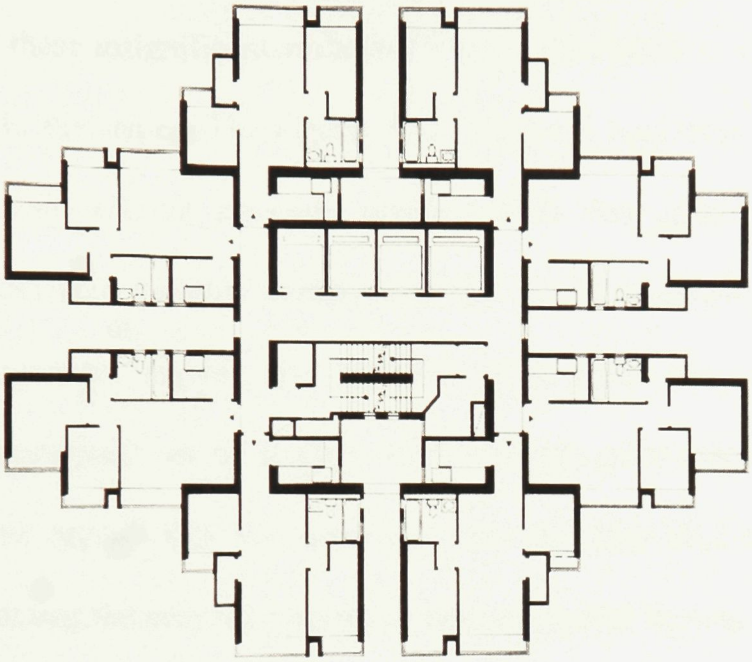

Fig. 13. A typical residential floor plan with 8 households' dwelling floor layout.

The current residential design approach in Hong Kong has an average of 40-50 storeys of eight repeated residential towers clustered together. These towers have a common floor plan design that groups 6-8 dwelling units per level around a central core.[15] A typical example is illustrated in (Fig. 13). The central core houses all the basic services and mechanical components for each level of the building. The units per level are replicated side by side, as a way of achieving higher assembly efficiency, lowering the cost and reducing the required construction time. A typical eight dwelling floor plan can only be configured with two different sets of dimensions and two types of spatial configurations per level. There can be a few design variations, such as the provision of special

[15] Ibid. P 220.

penthouse units at the top of buildings with either single or double storey. Aside from these insignificant variations, the overall spatial configurations of each level remain the same. The regular floor plans are beneficial only because they have the most efficient assembly process. Such floor plans are comprised of basic prefabricated building components that can be assembled in a short time. The homogenous, regular and repeated floor plans and uniform interior spatial configurations can be slightly varied through good interior design. However, it can be argued that this approach only provides decorative variations without addressing the primary concern of uniform spatial layouts.

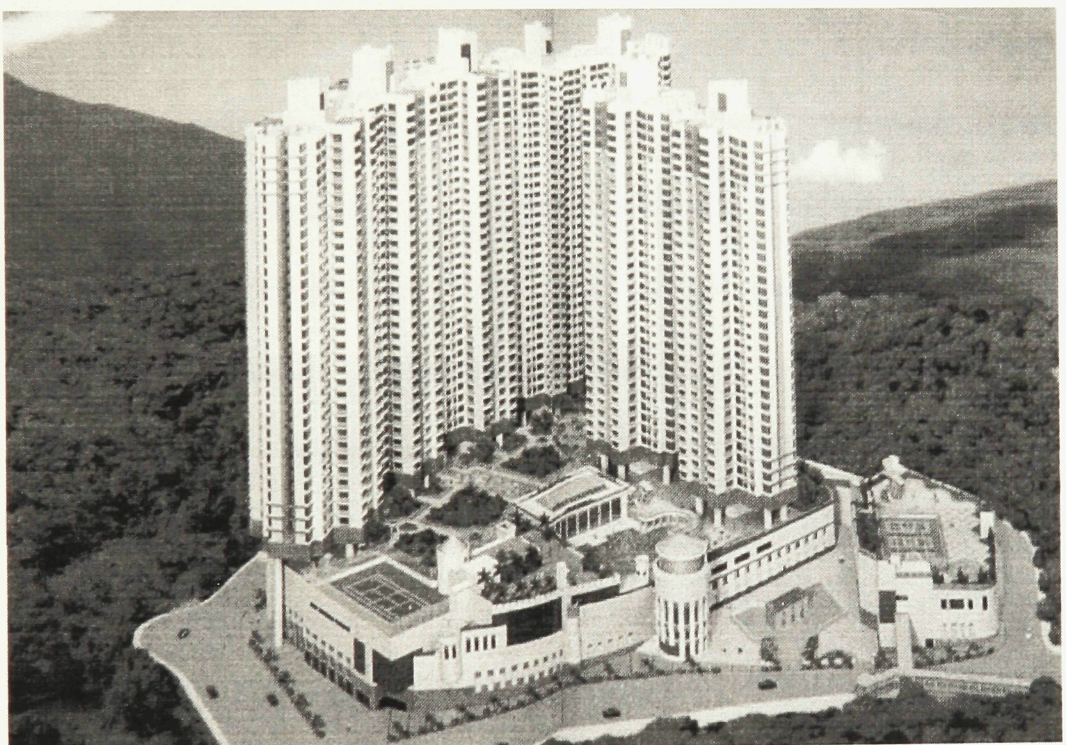

Fig. 14. Housing tower blocks proposed on top of a podium, Ma On Shan, Hong Kong.

Fig. 15. Uniformed residential buildings, a residential development named 'Hollywood Villa', Hong Kong.

Consequently, the homogeneous floor layout approach limits design variation, and creates a constrained living environment, namely, the limitation of household compositions; lack of privacy; lack of awareness of the relationship between the dwelling design and site context; and, restriction of households' interaction at the community level. The recent residential developments are enormous and are built as clusters of identical towers with matching floor plans on top of a podium (Fig. 14). The mirrored floor plans limit the dimension and variety of dwelling types per level, and prohibit the differentiation of household compositions within the residential developments (Fig. 15). Second, the residential towers are grouped closely together such that windows of contiguous units are orientated to face each other, diminishing the privacy of households in adjacent flats and within the flats themselves. Third, the replication of identical standardized openings for windows and balconies have ignored both the orientation and site context. The replicated dwellings have led to pervasive unawareness of the relationship between the design of the built form and the surrounding environment. Fourth, the communal spaces, such as elevators lobbies, and corridor walkways, are enclosed and are connected only through the compartmentalized staircases and elevators. These enclosed communal spaces offer their users a totally disjointed and disorienting experience, in contrast to providing some sense of spatial continuity. The homogenous floor plans have compartmentalized the communal spaces and dwelling units into zones of containment that are without any physical context; limit the variation of household compositions; limit interactions between neighbours, and lack a relationship to the surrounding environment. This is re-iterated by Ken Yeang who states that it is the repeated floor system which makes the current residential towers so spatially unsophisticated, isolated and internally unsatisfactory to the occupants.

> "What we have today in these tall buildings is an instant condition of spatial segregation. All their floor plates are spatially noncontiguous and are physically segmented off one from the other. Their spaces are no longer linked or interactive, but are isolated, homogeneous enclaves devoid of the diversity and richness of life that exists at the ground plane. This isolation exacerbates feelings of social alienation in its inhabitants. The desire for engineering expediency in the skyscraper's design and construction has undermined the potential for the diversity and richness of urban life in the building."[16] Ken Yeang

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[16] Yeang, Ken. Reinventing the Skyscraper: A Vertical Theory of Urban Design. Chichester: Wiley-Academy, 2002. P 59.

Further, I concur with the criticism by Ken Yeang in disputing the assertion that residential developers in Hong Kong have successfully answered the concerns of cost effective construction by designing homogenous floor plan layouts and high-rise built forms. However, the developers have overlooked the importance of human social values, and the diversity of distinctive households in their design plans. These oversights constrain socialization and interaction between households to the community level, on the platform of the podium only.

2.5 Proposal for adaptable prefabricated building design

The above analysis of recent uniform high-rise housing in Hong Kong has revealed that residential design schemes still have not met the diversified household preferences for housing. Their application of reinforced concrete construction using identical formwork has restricted builders in designing variable floor plan layouts for high-rise residential buildings. The philosopher Robert Kronenburg and the architect Kenneth Frampton, both have analyzed and searched for alternative construction methods in designing prefabricated buildings that respond to the ever-growing complexity of building design while maintaining assembly-efficient production. Kronenburg has suggested that prefabricated building components integrated with adaptable characteristics is a solution to obtaining diverse design possibilities and cost-efficient construction. He states that prefabricated components with design adaptability are not only a search for quantity, but also essentially a means for achieving finer quality of building.[17]

In addition, Frampton advocates that today's building industry transform building construction from "wet" techniques to "dry" techniques.[18] In other words, he suggests that every building component should be pre-manufactured at the factory and the components should be constructed as lightweight as possible for ease of transportation from the factory. As it is, reinforced concrete

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[17] Kronenburg, Robert. Spirit of the Machine: Technology as an Inspiration in Architectural Design. Chichester: Wiley-Academy, 2001. P 6.
[18] Frampton, Kenneth. Studies in Tectonic Culture: The Poetics of Construction in Nineteen and Twentieth Century Architecture. Cambridge, London: MIT Press, 1995. P 1-12.

construction is defined as a 'wet' assembly technique. The materials used in reinforced concrete construction are too heavy to transport. That limits the sizes of components to be fabricated in the factory, and requires on-site construction. Once building components used in 'wet' assembly techniques are bolted, hung, stacked, joined, or bonded together onto the reinforced concrete structural frame, the components become too heavy to be altered or re-formed to adapt to other spatial configurations. He has advocated the application of 'dry' assembly techniques of steel framing construction as an alternative, to maintain construction efficiency and to allow the lightweight characteristic of the building components in designing with adaptability to provide a wide range of spatial layouts.

2.5.1 Diamond Hill Village, Hong Kong

The Diamond Hill Village was one of the iconic examples that represented the success of Kronenburg's proposal of applying adaptable prefabricated components and Frampton's notion of 'dry' techniques to articulate the multiplicity and complexity of life in Hong Kong. The Diamond Hill Village was developed as a low-rise temporary shelter for low-income families in the 1960s. Each dwelling was a custom-built product and offered the minimum space necessary for everyday life. Individual dwelling was constructed by layering the galvanized metal sheets onto the custom-made metal skeleton structure with concrete foundation. Every household could adjust and alter the spatial layout of the dwelling because of the ease of handling the lightweight prefabricated materials, such as inexpensive galvanized metal sheets. The Village signified the richness of the living environment because each dwelling space was built according to household preferences. Evidently, the residents of Diamond Hill Village had employed both Kronenburg's and Frampton's design concepts to generate unique dwelling layouts. Aside from its unorganized developmental approach, insufficient for the

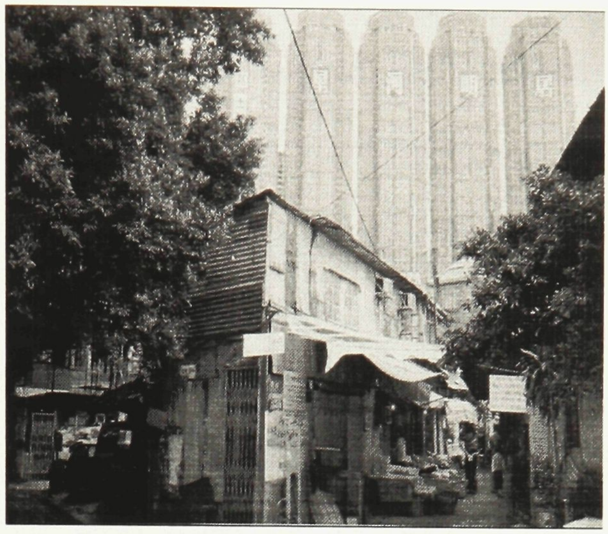

Fig. 16. A photo of Diamond Hill Village in contrast with the residential towers in the background, 1990.

low numbers of liveable spaces per square footage of land, and safety concerns, this dwelling design with the use of adaptable lightweight prefabricated components demonstrated that dwellings without any decorative fantasy elements could provide adequate living conditions. The outcome was the generation of highly adaptable prefabricated dwellings with diversified spatial configurations that were determined directly by each occupant's needs and preferences. Eventually, the Village was demolished in the early 1990s due to fire safety concerns and the shortage of land.[19]

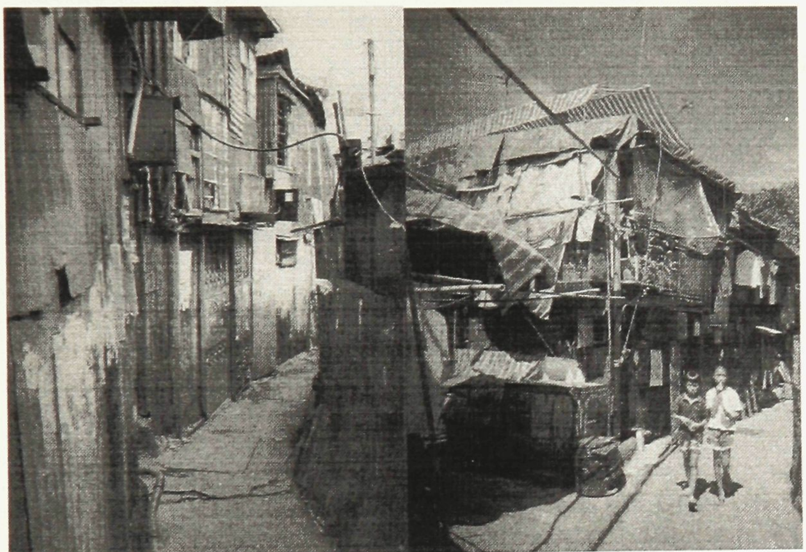

Fig. 17. Photos of Diamond Hill Village taken in late 1980s.

[19] Gutierrez, Laurent, and Valerie Portefaix. Mapping Hong Kong. Ed. Anna Koor. Hong Kong: Map Book, 2000. P 146.

2.6 Re-considering a new method for housing construction in Hong Kong

In summary, this chapter has discussed such limitations to housing construction as the demographic factors that limit the size of liveable space per person; the economic factors that related to the high cost of land; the design limitations of using reinforced concrete construction; and the unsophisticated homogeneous dwelling units that characterize high-rise residential buildings in Hong Kong. This list of limitations indicates a need for design adjustments or modifications. High-rise housing in Hong Kong needs to reconsider an alternative construction method of prefabrication that can provide diverse spatial layouts in order to meet the diversified household preferences; and, environmentally sensible dwelling units to improve the interactions between residents at the neighbourhood level. From my point of view, the integration of 'dry' construction techniques, and adaptability with lightweight prefabricated building components are appropriate construction solutions for housing in Hong Kong. It could be the design approach that accommodates the variation of household compositions without sacrificing the economic advantages of assembly-efficiency. This approach could create new architectural solutions that would avoid constructing uniform dwelling units and could encourage increased social interaction and enhanced living conditions.

Chapter Three

The Concept of Adaptable Prefabricated Construction

3.1 Introduction

> "We must not forget that individual needs and desires vary, and within the limits of social consensus man must be given choice. [...] Industrialized housing must therefore be designed for maximum utility, standardization, and interchangeability of the parts and maximum variability of the whole [...] in a hierarchical environmental-social-economic system."[20] Gilbert Herbert

Much like Gilbert Herbert's vision of a 'hierarchical environmental-social-economic system', the concept of adaptable prefabricated construction employs both the practical aspects of assembly-efficiency and the theoretical aspects of generating housing that is more responsive to household needs. These traits are neglected by housing developers and by the uniform building blueprints in Hong Kong. In terms of architectural concerns, adaptable prefabricated construction methods would be applied to fabricate dwelling units that are more responsive to individual preferences by delivering a wider range of spatial design configurations. Dwelling units would not need to appear identical to one another because of the success in arranging diverse spatial configurations and in maintaining assembly-efficient production. The mechanism for implementing both practical and theoretical concerns is by dimensionally standardizing the prefabricated building components and by integrating the adaptability of the components. It is envisioned that adaptable prefabricated construction would

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[20] Herbert, Gilbert. The Dream of the Factory-Made House: Walter Gropius and Konrad Wachsmann. Cambridge: MIT Press, 1984. P 63.

become the norm and that each dwelling would reflect a wide range of individual values and living standards, and would accommodate diverse household compositions.

This chapter examines the links between economic values and individual variations by first analyzing other architects' perspectives. They provide responsive design solutions based on the differentiation of individuals' preferences and assembly-efficient production. The chapter will also discuss relevant approaches to adaptable prefabricated construction that have been developed by the building industry. The foremost developed approaches include the 'standardization' of prefabricated components in order to advance construction efficiency and the 'adaptability' of prefabricated components to be assembled into a variety of building forms. With the inclusion of attributes such as 'adaptabilities' and 'standardization' of prefabricated components, adaptable prefabricated construction can accommodate the ever-changing household compositions and household needs without forfeiting the economic advantages of assembly-efficient production.

3.2 Architects' perspectives on adaptable prefabricated architecture

There are two principles that guide the fundamental avenues of adaptable prefabricated construction: dwelling that is responsive to individual preferences by designing the dwellings with diverse spatial configurations, and assembly-efficient building construction via the employment of prefabrication.

One of the principles is adaptable prefabricated construction that is responsive to individual needs. The architect, Herman Hertzberger, suggests that every household has his/her own predilections for comfort, familiar functions, and visual gratification as a way of characterizing his/her unique habitual way of recognizing living space. The individualized preferences acknowledge different standards of living and preferences for the form of space. Hertzberger advocates that prefabricated housing consider the differences in the occupants' needs and desires rather than their similarities by abandoning the collective interpretation of individual's preferences.[21]

> "We must abandon the collective interpretation of individual life patterns, [...] and allow the creation of a variety of spaces where the different functions are sublimated into archetypes which, by their overall suggestibility and their adaptability to any purpose and change of purpose, permit individual interpretations of the collective life pattern."[22]
> Herman Hertzberger

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[21] Eldonk, Jos Van. Flexible Fixation: The Paradox of Dutch Housing Architecture. Assen; Van Gorcum; Eindhoven: Eindhoven University of Technology, 1990. P 49-50.
[22] Ibid. P 49.

Furthermore, the architect, John Habraken, believes that the key factor in designing dwelling units is to put the occupants' needs at the centre of decision making, while providing construction convenience for housing developers by using a series of pre-defined spatial layouts.[23] He particularly emphasizes the importance of the occupants' participation in the design process. He calls this the 'support' and 'infill' principle.[24] It is a design process that integrates the quality of living needs, and the concerns of the diverse household compositions into the final production. The idea comprises pre-assigned choices for the occupants to select during the production process. Habraken implies that higher levels of participation from the occupants can enhance the integration of diverse individual preferences into the architectural form. This notion of the prominence of the

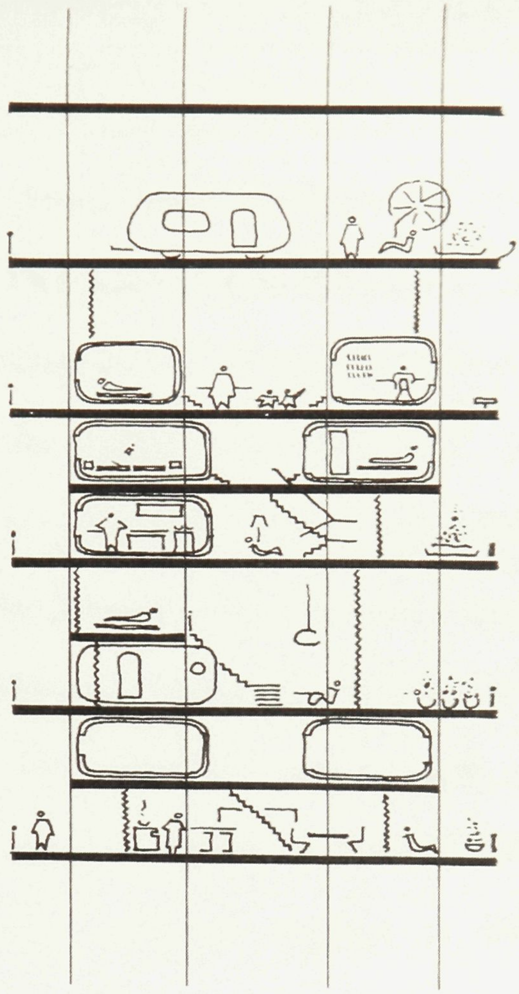

Fig. 18. Habraken described his 'infill' and 'support' principle through sketches.

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[23] Ibid. P 52-53.
[24] Bosma, Koos, Dorine van Hoogstraten, and Martijn Vos. Housing for the Millions: John Habraken and the SAR (1960-2000). Rotterdam: NAI, 2000. P 41.

occupants' participation can be advanced by providing a wide range of spatial configurations.

The other principle is to deliver diverse spatial configurations with an assembly-efficient production process. The author, Robert Kronenburg, states that assembly-efficient production is predicated on two contradicting criteria: the functionality and the mass-production of the prefabricated components.[25] This means directing the mass-production of components toward multi-purpose functionality. Providing many specifically designed components for a singular housing application is avoided if a prefabricated component is multi-functional. In addition, prefabricated components with multi-task capabilities not only facilitate assembly-efficiency, but also create a platform to generate diverse spatial layouts, which in turn can satisfy individual standards of utility, performance, aesthetics, and economic requirements. Kronenburg's viewpoint suggests that assembly-efficient production involves multiple functions as design criteria for prefabricated components.

The principles of adaptable prefabricated construction recognize individual needs and allows for the design of diverse spatial configurations to satisfy these needs. Also, these principles practice economy by introducing assembly-efficient production techniques into designing diverse spatial

[25] Kronenburg, Robert. Spirit of the Machine: Technology as an Inspiration in Architectural Design. Chichester: Wiley-Academy, 2001. P23.

configurations. For example, a group of architects called Archipel Designers, Eric Vreedenburgh, and Freek van Steyn, have proposed such a prefabricated dwelling design that uses adaptable prefabricated construction to meet individuals' preferences and assemble-efficiency. The proposed dwelling units would be composed of a standard prefabricated component integrating all the service elements, and components that could be positioned differently to form a range of spatial variations (Fig. 19). The design attempts to satisfy the variable desires, needs and living styles of occupants by providing pre-determined dwelling layouts from which occupants could select their preferences. The architect Le Corbusier, referred to the design movement of providing diverse dwelling characteristics and spatial configurations as 'character flexibility'.[26]

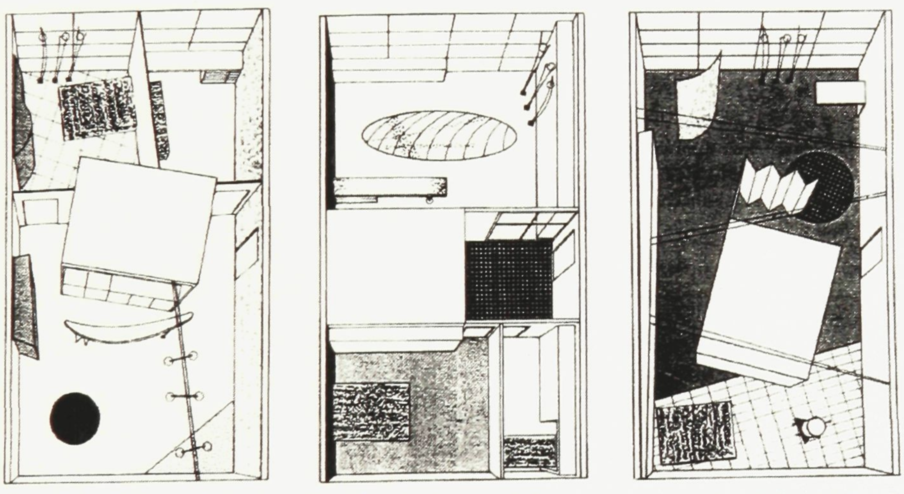

Fig. 19. Adaptable prefabricated dwelling layouts, Archipel Designers, 1984.

[26] Eldonk, Jos Van. Flexible Fixation: The Paradox of Dutch Housing Architecture. Assen; Van Gorcum; Eindhoven: Eindhoven University of Technology, 1990. P 65.

The use of adaptable prefabricated components ought to be the best solution for designing dwellings for diverse household compositions and varied individual needs. By exploring design solutions for prefabricated dwellings in high-rise residential buildings, we can investigate how adaptable prefabricated construction could facilitate not only the way in which diverse spatial configurations and assembly-efficient production impact the style of a building, but how they can be an architectural solution differing from the uniformed dwelling layouts resulting from the economic constraints in Hong Kong.

3.3 The design tendency for 'standardization' and 'adaptability' in prefabrication

The concept of adaptable prefabricated construction has implications that relate to building technology more so than to the marketing strategies that are prevalent in the building industries in Hong Kong. According to Le Corbusier, advanced building technologies can serve as catalysts for improving the quality of life by providing flexible spatial layouts with extensive possibilities as to the use and needs of occupants. He also recognized the economic value of assembly-efficient production and the simplification of the erection process. The mechanisms by which adaptable prefabricated construction could address these concerns and preferences, are 'standardization' and the integration of 'adaptability' into prefabricated components. By definition, 'standardization' is a means of manufacturing and mass-producing building components with an agreed norm of measurements, and 'adaptability' is a means of enhancing the multi-task ability of each prefabricated component in order to simplify the construction process. Both mechanisms can be developed with advanced building technologies to facilitate assembly-efficient production and provide diverse spatial configurations as part of the collective stimulus that would motivate residential building designs in Hong Kong to be less uniform.

3.3.1 Standardization

> "Standards are the products of logic, of analysis and painstaking study; they are evolved on the basis of a problem well stated. In the final analysis, however, a standard is established by experimentation."[27] Le Corbusier

The architect, Le Corbusier, believed that the standardization of components provided a clear organizing principle for building industries seeking an adequate solution to simplify the manufacturing process. The idea of standardization is to embody the prefabricated components with an agreed norm of measurements/ dimensions so that they can be mass-produced through the assembly-line process. Standardized prefabrication not only simplifies the manufacturing process, but also provides a framework for assembly-efficient production. The agreed norm of measurements/ dimensions is derived from two 'scales' of standardization approaches. The first and broader approach is the 'open building system', where the components are sub-assembled from many factories that are not dependent on a single production belt.[28] For example, components such as partition walls, stairs, windows, and doors produced by different manufacturers can be used for various building applications with matching standardized measurements. Currently, the 'open building system ' has been implemented by most industries because of its assembly-efficient principles of mass production of individual standardized building components. It provides

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[27] Le Corbusier. The Modulor: A Harmonious Measure to the Human Scale Universally Applicable to Architecture and Mechanics. Trans. Peter Francia, and Anna Bostock. London: Faber, 1951. P 33.

[28] Eldonk, Jos Van. Flexible Fixation: The Paradox of Dutch Housing Architecture. Assen; Van Gorcum; Eindhoven: Eindhoven University of Technology, 1990. P 41.

general guidelines and agreed upon principles that the building industry applies to develop simplified efficient building techniques.[29] The principle of the 'open building system' constrains overall building designs with established measurements of the prefabricated components rather than having the measurements determined by the building designs.

The second and narrower approach is the 'closed building system', that entails a series of standardized building components that are self-contained, purposely designed, calculated and made for an independent housing concept scheme.[30] The buildings are composed of standardized components built with measurements conforming to the singular design application. The building industry classifies the process as 'closed' because there is no exploitation of other measurements of existing industrial building components in the market.[31] Each standardized component is clearly defined in its own purpose and it acts as a part of a comprehensive entity. In other words, the 'closed building system' is a standardization process that produces prefabricated components with specifications according to the overall design plan in which greater design flexibility is created.

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[29] Proveniers, Ir. Adri, and Helga Fassbinder. New Wave in Building: A Flexible Way of Design, Construction, and Real Estate Management. Trans. [D.R. Welsh]. Assen; Netherlands; Eindhoven: Eindhoven University of Technology, 1992. P 11-14.
[30] Ibid. P 10.
[31] Herbert, Gilbert. The Dream of the Factory-Made House: Walter Gropius and Konrad Wachsmann. Cambridge: MIT Press, 1984. P 255.

3.3.2 Adaptability

As a consequence of the evolving standardization methodologies, building industries have to explore alternative assembly systems to advance the erection process and to discover possibilities to transform housing into more responsive architectural forms. The assembly systems are comprised of prefabricated components that adapt to interplay and interchange with one another in order to generate diverse design possibilities.[32] The objective is to design prefabricated components with multi-task purposes, for example diverse spatial layouts, without increasing the types of components that need to be constructed. The benefits of prefabricating components with adaptability derive from two main objectives: the improvement of the assembly process by assimilating the advantages of using minimum types of components; and, the desire of enhancing dwelling designs with greater spatial possibilities.

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[32] Pople, Nicolas. Experimental Houses. New York: Watson-Guptill, 2000. P 47.

3.4 The search for better housing construction methods

The fundamental goal of adaptable prefabricated construction for dwelling design is to offer buyers a wide range of spatial configurations, while maximizing to economic efficiency in construction. The integration of diverse occupant desires and household preferences into the design process is the solution that challenges the uniformity of building that has dominated Hong Kong's high-rise residential developments. It is important to note that the need for high-rise housing in Hong Kong will continue, and that the application of the latest adaptable prefabricated construction techniques will be applied in the search for architectural solutions that respond to the economic constraints and the ever-growing complexity of individual preferences.

Chapter Four

Adaptable Prefabricated Housing Precedents

4.1 Introduction

The history of the early nineteenth century, indicates that the building design and prefabrication industries began to work with each other.[33] The Crystal Palace, built in 1935 in Sydenham, England, is one of the most significant prefabrication achievements engendering a new perspective in architecture (Fig. 20 and 21). This new perspective fostered the use of prefabrication methods: generated interest in the use of available materials; and, promoted reformation of building structural systems that developed into traditions over time. Current cultural standards, acknowledgement of different modes of living, and interest in economical aesthetic designs have gradually modified these traditions. Consequently, both the innovative prefabricated and design systems have co-existed. Adaptable prefabricated construction is where the two systems have bonded and have defined a new architectural paradigm- resulting in an evolving system for creating prefabricated buildings and an enhancement in the living environment.

[33] Davies, Colin. The Prefabricated Home. London: Reaktion Books, 2005. P 9.

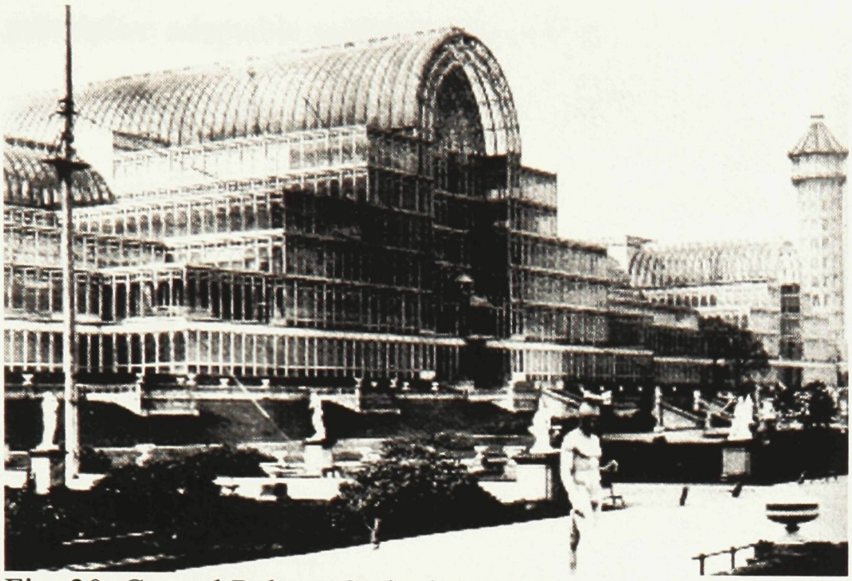
Fig. 20. Crystal Palace, Sydenham, 1935.


Fig. 21. Crystal Palace, Sydenham, a revision photo shown the transplanted structure.

This chapter will attempt to establish a direct relationship between the complexity of different modes of living and the economic necessities of prefabrication through the study of high-rise building precedents. All of the selected precedents that are in high-rise building form contain two basic principles: adaptable prefabrication technique and diverse spatial design schemes. Adaptable prefabrication techniques are proposed as an approach to generate greater design possibilities and assembly-efficient production. The scheme represents a formation of diverse spatial configurations that integrate the sensation of individualism and living styles. First, the precedents will be discussed in light of two well-developed construction assembly systems: the skeleton framing and the modular system. Second, the precedents will be analyzed regarding ease of transportation, flexibility of building forms, and the diversification of spatial configurations through the interplay of adaptable prefabricated components. The selected precedents will prove that the concept of adaptable prefabricated construction can 'assimilate' the advantages of technological developments while recognizing the ever-growing complexity of individual needs and desires for housing.

4.2 Architects with adaptable prefabricated construction

Since the early 19th century, adaptable prefabricated construction has been researched, explored and analyzed by many of the great masters of architecture. These architects have tried to generate new architectural forms employing advanced prefabrication technologies, and to educate the building industry regarding aesthetic appreciation.[34] Such architects as Le Corbusier, Richard Buckminister Fuller, and Moshe Safdie found that the housing market is inevitably influenced by the economic need for assembly-efficient production.[35] Each of these architects has his own enthusiastic manner of generating an innovative solution that addresses different modes of living and includes design features addressing individual needs. On the one hand, both Le Corbusier and Moshe Safdie have suggested that the prototypes of adaptable prefabricated housing should be aesthetically designed and should be considered with diverse modes of living in mind. Their housing designs have taken advantage of adaptable prefabricated construction techniques without sacrificing the desires for individuality. On the other hand, several architects such as Buckminister Fuller and Herbert Ohl are interested in deeper commitments to structural systems by experimenting with high-tech materials and building forms. Others, including the Archigram group experimented with modular forms called ‘capsule architecture’. These architects focused on the assembly flexibility of prefabricated components through their interchangeability and ability to generate diverse spatial

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[34] Ibid. P 9.
[35] Ibid. P 11-13.

configurations. The precedents set by these architects suggest that adaptable prefabricated construction can be enhanced through the integration of technological resourcefulness. This has dominated the future of mass-produced housing.

4.3 Le Corbusier-- Skeletal Framing System: Unité d'Habitation de Marseilles

In 1914, the architect Le Corbusier designed the skeletal structural system called 'Dom-ino'. 'Dom-ino' applied adaptable prefabricated construction methods which Le Corbusier eventually incorporated into the Unité d'Habitation de Marseilles. The basic 'Dom-ino' concept is based on what he called the 'five points of architecture' in the design of habitable environments. His 'five points of architecture' insist that the fundamental characteristics of a dwelling should be formed with five basic design criteria: the free columns (*piloti*); the free floor plan (*plan libre*); the free façade; the glazings that are structurally independent of the skeletal framework; and the roof garden. The term 'free' signifies a structural mechanism that adheres to the logic of design flexibility by providing a wide-open floor slab layout. He advocated that a building comprised of these five design elements has the design competence to generate variable spatial layouts and production efficiency.[36]

[36] Pople, Nicolas. Experimental Houses. New York: Watson-Guptill, 2000. P 15.

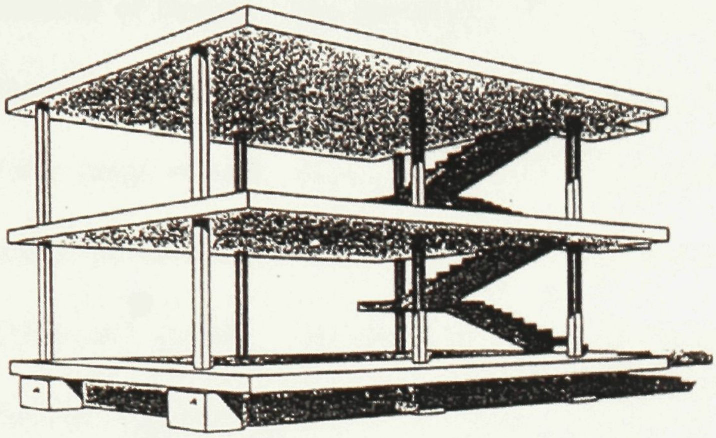

Fig. 22. Dom-ino prefabrication principle, the support structure, 1914.

The basic principle of the 'Dom-ino' system is to transfer and concentrate all loads onto 'free' standing columns and eliminated the need for load-bearing walls.[37] Since the floor slabs are supported by the use of slender columns, the plane of the floor slabs is wide-open, and thus allows flexible spatial design possibilities. Also, there is no necessity for prefabricated components to be structurally dependent on one another.[38] The wide open platform of the structure can be filled-in with a series of assembly-efficient, mass-produced, standardized, and prefabricated components such as partitions, doors, and windows, manufactured by an 'open building system'. The skeletal framing system is the method of choice for high-rise buildings in today's construction practice. Many builders prefer this assembly system because it has been researched and exploited by the building industry and manufacturers. The skeletal framing scheme of the 'Dom-ino' system has proven that the wide-open platform structure permits more

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[37] Eldonk, Jos Van. Flexible Fixation: The Paradox of Dutch Housing Architecture. Assen; Van Gorcum; Eindhoven: Eindhoven University of Technology, 1990. P 19-21.
[38] Ruegg, Arthur. Le Corbusier: Paris-Chandigarh. Basel; Berlin; Boston: Birkhauser, 2000. P 26.

freedom of design. The advantage of a skeletal framing system is that it is an assembly system that uses formwork to pre-cast concrete forms, allowing for a wider range of built shapes and spatial design possibilities. Such allowance for design possibilities indicates both the functional and aesthetic flexibility of the 'Dom-ino' system. The disadvantage of the skeletal framing system is that it involves a greater number of building components that need to be assembled on site. As such, it requires a longer time for the erection process in comparison to the modular assembly system. It is the diverse design possibilities offered through the wide-open floor slabs that have guided the 'Dom-ino' system as exemplified by Corbusier's Unité d'Habitation de Marseilles (1947), one of the earliest applications of building prefabrication in high-rise housing (Fig. 24).

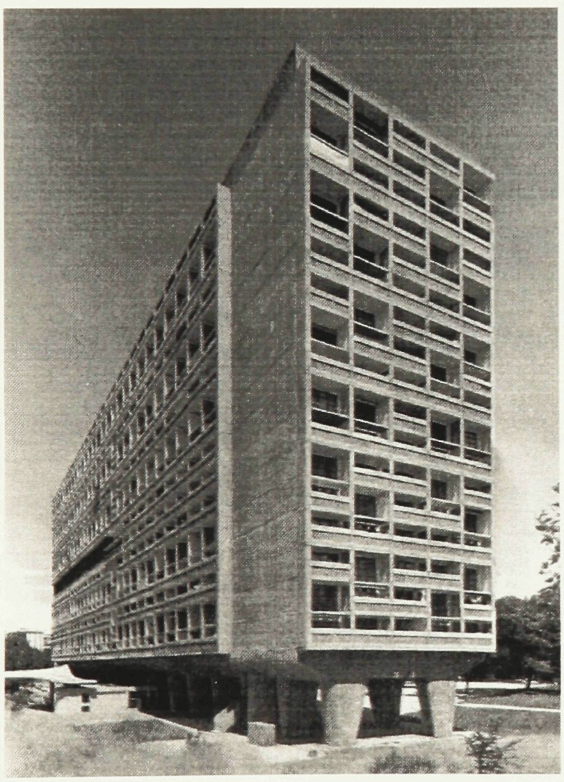

Fig. 23. Perspective view of Unité d'Habitation de Marseilles, Marseilles, France, 1947.

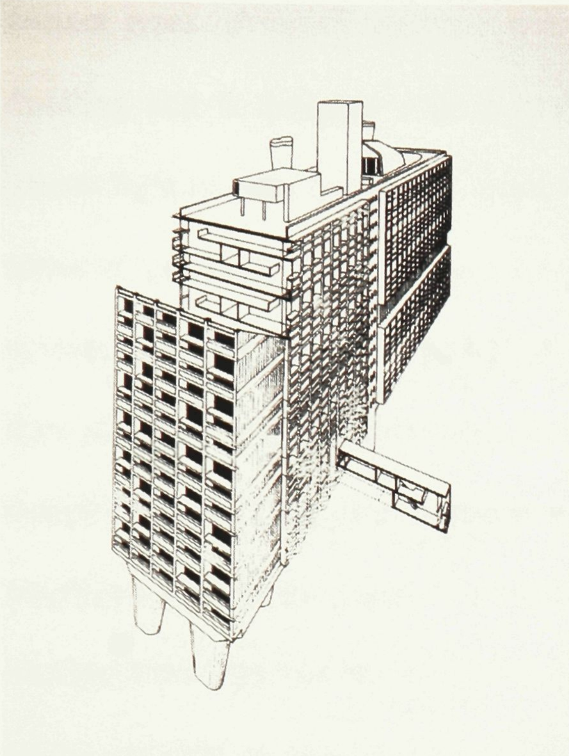

Fig. 24. Cut-away perspective showing dwelling units interlocking over the internal corridor.

The 'Unité d'Habitation de Marseilles' was constructed in Marseilles, France in 1947 (Fig. 23). Le Corbusier transposed his focus on individual houses to that of a high-rise building. The construction of the 'Unité' was highly rational at the time because it did not depend on individual craftsmanship, but on repeated casting of concrete slabs from construction molds. He employed different combinations of standardized prefabricated components to be assembled onto a massive 'Dom-ino' support structure. The series of wide-open slabs formed together in various dimensions allowed for two and three storeys single dwelling units (Fig. 24 & 27). The 'Unité' in Marseilles houses 337 dwelling units with 23 distinct types of spatial configurations within the 17 storeys building.[39] Each dwelling unit is designed with a double-height living room space that allows natural light to enter by a large window (Fig. 25). The facade is interrupted by a series of 'plot holes' where large-scale glazing is positioned away from the façade to form a private balcony, he called a '*brise-soleil*' wall. The '*brise-soleil*' façade does not only serve for views onto the outside surroundings, but it also uses the design freedom of the open platform structure to control the amount of light that penetrates the interior space. It is employed as a screening device that prevents sunlight from entering the living room directly during the summer months, but allows sunlight to penetrate the entire dwelling unit during the winter seasons (Fig. 28).[40]

It can be argued that Le Corbusier positioned the window away from the façade wall to allow for optimal use of the 'sunlight' effect as a device to direct the occupants' attention to the interior space of their dwelling units. The program-spaces are carefully laid out and harmonized with one another. The service facilities such as kitchen and bathrooms are located away from the façade wall. Other spaces include a bedroom that could be modified into a study room located on the second floor, with a balcony overlooking the living room. The master bedroom of a duplex unit is situated on the top floor above the adjacent

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[39] Frampton, Kenneth. Le Corbusier. London: Thames & Hudson, 2001. P 157.
[40] Besset, Maurice. Le Corbusier: To Live with the Light. Trans. Robin Kemball. New York: Skira; Rizzoli, 1987. P 163.

dwelling unit (Fig. 25, 26 & 27). The intention is to allow some of the dwelling units to have views on both sides (the mountains to the east and the sea to the west). In addition, the double-level living room allows for a fluidity of interactions in both vertical and horizontal directions. The wide-open platform structure means that the 'Unité' can be adapted to the specific requirements of diverse household preferences that include options of single occupant apartments, childless couples and homes for families with up to ten members.[41]

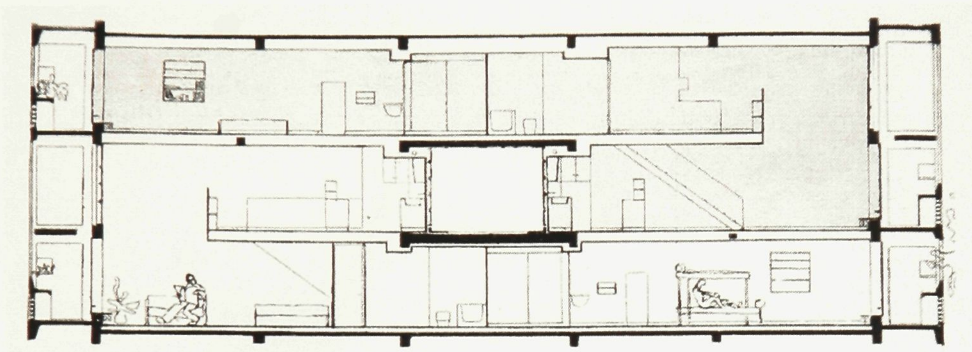

Fig. 25. Cross section- Two two-storeys flat interlock in such a way that a double-height living room is formed.

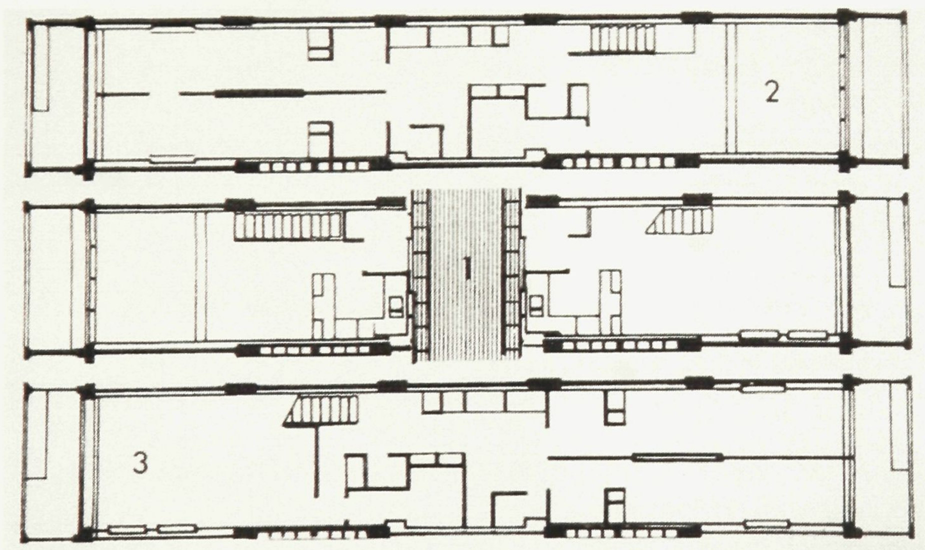

Fig. 26. Floor plans of a typical crossover duplex unit.

[41] Frampton, Kenneth. Le Corbusier. London: Thames & Hudson, 2001. P 157.

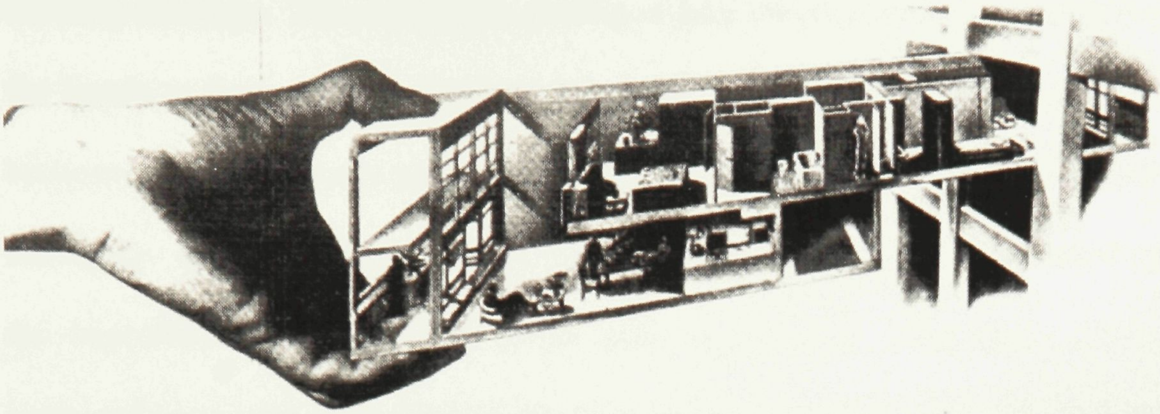

Fig. 27. A standardized duplex unit inserted onto the 'Dom-ino' structure, showing the double height and well lit living space.

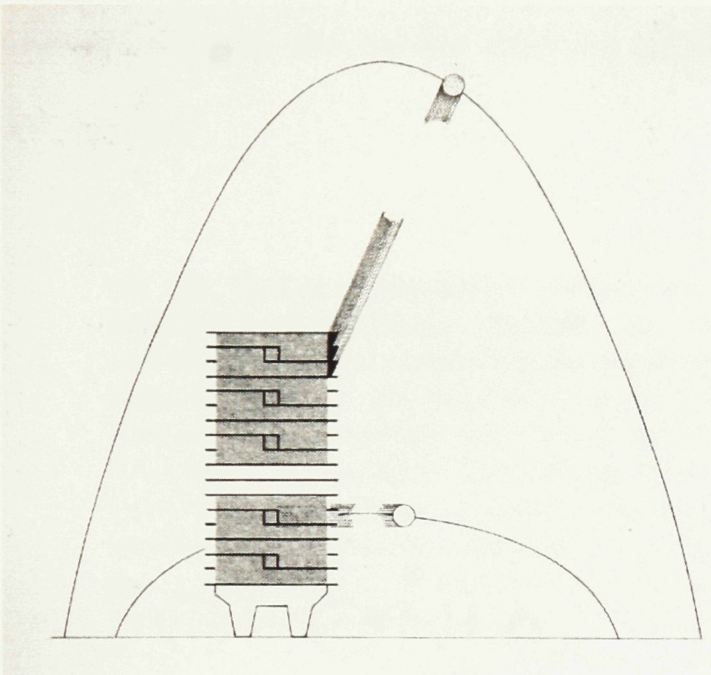

Fig. 28. Cross-section of the 'Unité' illustrating the course of the sun in summer and winter.

All the basic requirements of the spatial programs of the 'Unité' are enclosed within the structural envelope. Le Corbusier does not use the traditional domestic forms and ornamental details in the construction of the 'Unité'. The ornamentation, which is reduced to simple geometric figures, and the horizontally layered floor slabs, which have become equally flat are projected onto the building envelope. The rectangular glazing of each dwelling unit is articulated in the façade to form a series of private balconies. Le Corbusier creates a contrast between the geometrically patterned façade wall which represents a well-thought out design with the horizontal rough surface of the slab strip that is produced by the imperfections of the plank molds used to make it. The effect of the horizontally layered strips mimics the form of the 'Dom-ino' support structural system. Since the building envelope is divided into horizontal layers with geometrical figures and elevated above the ground, the overall form shows unity and lightness.

> "In the Dom-ino principle a contradiction that disturbs the eye is introduced: load-bearing elements are reduced to the point of incredibility in their material quality and dimensions, and something that actually is 'heavy', the floor level, seems to escape from the group and float away. A completely new view of these connections, which is not to be completely revealed to Le Corbusier himself until it is translated into concrete designs, means a reversal of the static and constructive ideas for implementing architecture that had prevailed until this time. Something that at first seems to be required as 'pure' prefabrication is transformed into an aesthetic norm by being perceived in a new way."[42]

Another motif that distinguished Le Corbusier's unique housing philosophy in the building of 'Unité d'Habitation de Marseilles' is the three horizontal planes of interactive zones for occupants: the ground floor that is articulated by the '*pilotis*'; the 'street' housed with service facilities located at the intermediate level; and, the shared terrace of open gardens positioned on the roof

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[42] Ruegg, Arthur. Le Corbusier: Paris-Chandigarh. Basel; Berlin; Boston: Birkhauser, 2000. P 28.

of the building.[43] The elevated open ground space underneath the building serves as the public area which can be used in a variety of ways including parking for bicycles and as a play area for children (Fig. 29). At the intermediate level, there is a double-height corridor with window openings at the side that serves as a 'street', and an indoor communal space with all the required service facilities (Fig. 30). By positioning the communal facilities at the intermediate level an attempt is made to minimize the walking distance between dwellings and communal facilities. The rooftop of the 'Unité' is designed with a landscaped garden that is shared by occupants and is linked by the lifts at both ends of building. The roof terrace that avoids noise and pollution from city traffic, includes playground areas, a small swimming pool, a gym, a running track, and an open-air garden (Fig. 31 and 32). This design by Le Corbusier attempts to promote healthy living conditions and to provide an interactive platform for its occupants under the open sky. Le Corbusier considered such layouts as a medium to address individual preferences for an interactive environment. It can be argued that the 'Unité' is an example of a revolutionary approach in high-rise housing design that suggests its own way of living.

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[43] Frampton, Kenneth. Le Corbusier: Architect of the Twentieth Century. New York: Harry N. Abrams, 2002. P 96.

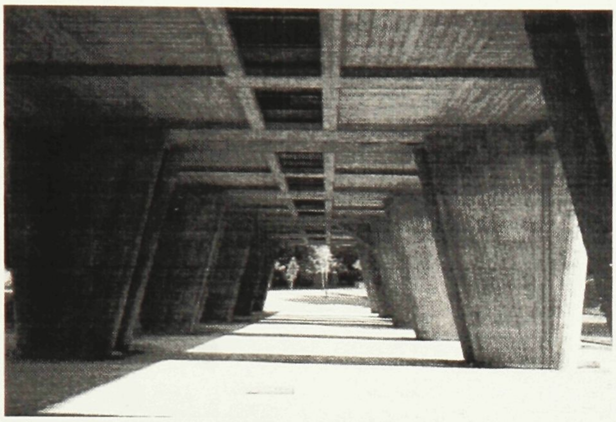


Fig. 29. A view showing the ground floor area underneath the building (left).
Fig. 30. The internal 'street' houses all the required communal facilities for the occupants (right).

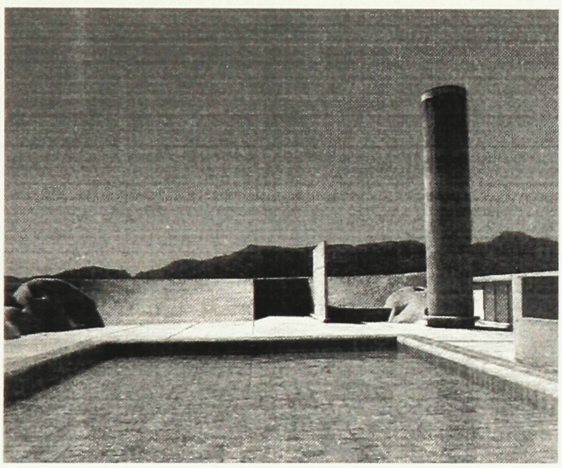
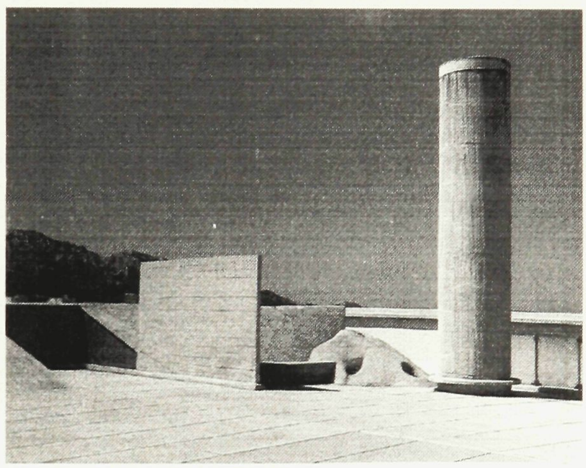

Fig. 31. View of the swimming pool situated on rooftop (left).
Fig. 32. View of the roof terrace (right).

According to Le Corbusier, a correlation can be established between an aesthetically pleasing built form and assembly-efficient production.[44] For example, the open floor plan that is derived from the 'Dom-ino' structural system

[44] Frampton, Kenneth. Le Corbusier: Architect of the Twentieth Century. New York: Harry N. Abrams, 2002. P 156.

can increase the rate of erection, as most of the building components can be mass-produced from the factory, then positioned within the 'Dom-ino' support structure. Le Corbusier's vision of assembly-efficient production for mass-produced housing has moved a step ahead by exploring structural forms that ease the assembly process via the use of prefabricated components. From a different perspective, the aesthetic quality of a house is derived by an innovative structural system that generates flexible spatial configurations. Having discussed Le Corbusier's 'Dom-ino' system in the prefab construction of the 'Unité', and his housing philosophy comprised of the 'five points of architecture' to provide an interactive living environment, it is clear that structural form and housing philosophy can be integrated as part of an aesthetic expression in housing developments.

4.4 Moshe Safdie-- Modular System: Habitat 67

In 1967, Moshe Safdie, introduced an innovative modular system for the high-density housing development of Habitat 67, built as part of the Expo '67 world housing showcase in 1967, Montreal, Canada. Habitat 67 exemplified the use of prefabricated dwelling modules with unique three-dimensional modular configurations to form a multi-storeyed residential building (Fig. 33). It was a unique modular configuration that demonstrated an alternative to the monolithic apartment block and demonstrated Safdie's unique expertise in designing adaptable prefabricated housing. He provided a theoretical framework that integrated architectural design with diverse modes of living. Habitat 67 was the realization of Safdie's thesis entitled A Case for City Living, A Study of Three Urban High Density Housing Systems for Community Development, where he investigated the possibility of a three-dimensional modular building system. The project provided a high-rise residential setting that introduced features only found in suburban garden homes.[45] It was an experimental project constructing an interactive neighbourhood and fundamentally cheaper housing for the masses while being more responsive to the occupants' needs. Also, it was an attempt to revolutionize housing construction technology through a modular assembly system.[46] Safdie addressed several essential design objectives: creating multileveled mass-produced housing; the employment of prefabricated building

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[45] Kettle, John, ed. Moshe Safdie: Beyond Habitat by 20 Years. Montreal: Tundra Books, 1987. P 52-53.
[46] Kohn, Wendy, ed. Moshe Safdie. St. Catharines: Vanwell, 1996. P 41.

techniques in an assembly-efficient construction; and the creation of high-rise 'villas' (a self-support community) which incorporated a variety of community facilities at the neighborhood level. Originally, Safdie's design had been conceived as a multiple-use project that would include a minimum output of 950 dwelling units as well as shops, offices, and institutions within the compound. But his dream was not realized because of countless obstacles, such as shifts in political interests, lack of collaboration between industries, and mainly a lack of financial support. In addition, the project was considered as the most innovative and challenging building construction at the time because of obstacles such as cold weather conditions, the unfamiliar construction skills required from the builders, and the pioneering structural system with novel assembly sequences. As a result, fewer than 158 dwelling units, ranging from 600 square feet to 1700 square feet, were actually constructed.[47] The contractor of Habitat 67 estimated that the production-efficiency of the modular assembling system at the beginning stage was only ten percent compared to a conventional construction system of using reinforced concrete formworks that had about thirty to forty percent.[48] The 'innovative' approach required more practice and familiarity before the system could become an efficient option for building construction. Unfortunately, the final construction costs of each dwelling proved to be prohibitive when compared

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[47] Kettle, John, ed. Moshe Safdie: Beyond Habitat by 20 Years. Montreal: Tundra Books, 1987. P 88-89.
[48] Ibid. P 113

against well-developed conventional building systems such as the skeletal structural system.

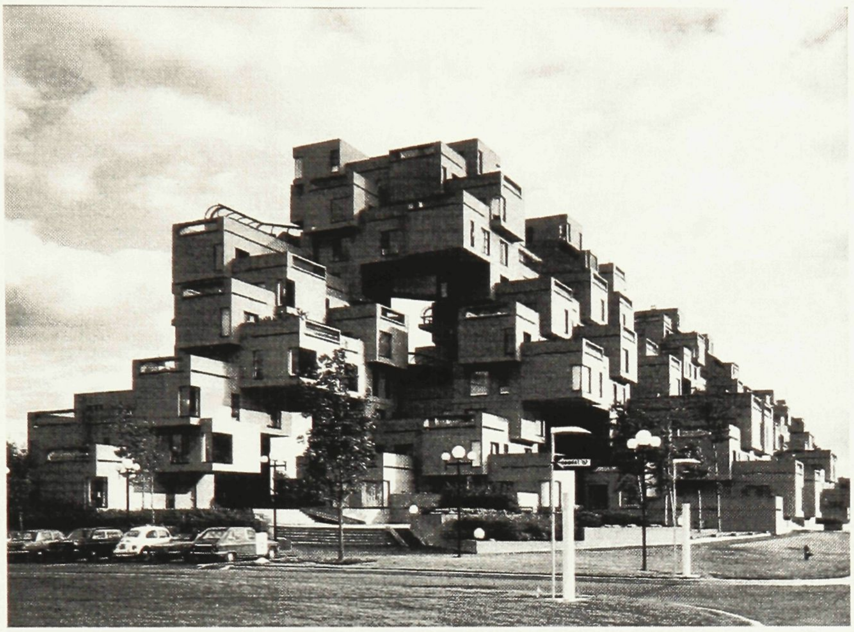

Fig. 33. View modules configuration of Habitat 67, Montreal, Quebec, 1967.

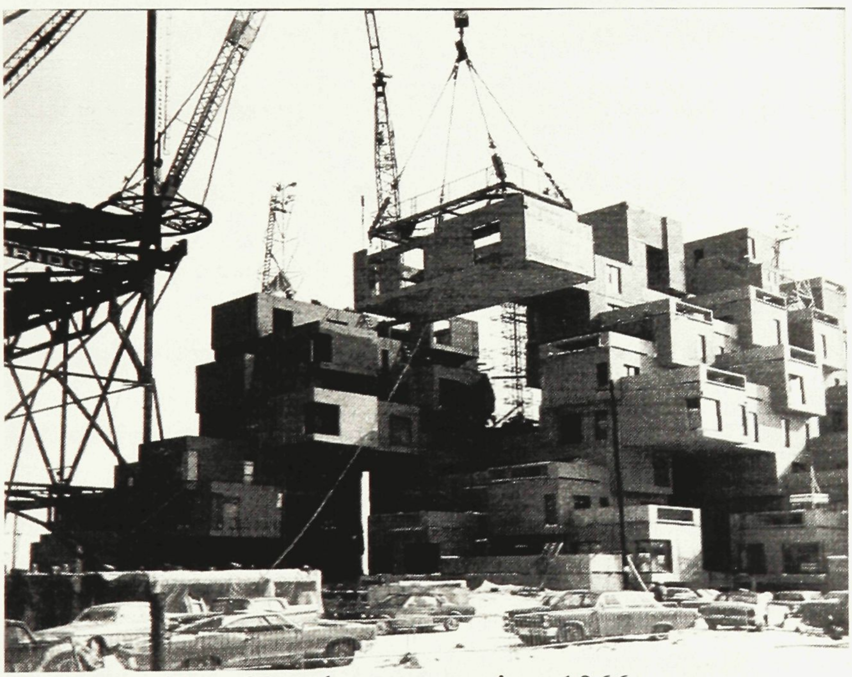

Fig. 34. Habitat 67 under construction, 1966.

The modular system applied in the Habitat 67 project involved prefabrication of a completely assembled dwelling unit or a completely enclosed dwelling space, generally called the 'modular unit'. It relied on the multiple-use of specifically designed repetitive modules that could be arranged systematically to configure diverse dwelling layouts. Each module was constructed at the factory using pre-assembled reinforcing cage with concrete poured into the mold (Fig. 35). Most of the assembling was completed in factories located adjacent to the building site, in order to facilitate the transportation of the prefabricated modules. Required service components such as kitchens, bathrooms, window frames, insulation and fixtures were installed into the modular unit, and then the whole unit was lifted into place by a crane for quick erection (Fig. 34). Simplifying the erection process by assembling most of the components in the factory is the main principle of the modular system. The Habitat 67 project was planned as a prototype of the modular system and was intended to streamline the erection process and reduce construction costs. The essence of the modular system was not only the ease of erection on site but also the ease of manufacturing a series of identical modules with adaptable characteristics to form the overall built form.[49] The objective of a modular system was not to set a standardized system for the building industry. It was a 'closed building system' where prefabricated modules are purposely made for specific housing design schemes. The 'closed building system' for Habitat 67 created a well-designed

[49] Carreiro, Joseph, et al. The New Building Block: A Report on the Factory-Produced Dwelling Module. Vol. 8. Ithaca; New York: Cornell University, 1968. P 15-18.

and well-made building using high-quality precision materials and formworks that were project specific. As such, the formwork for the modules was specifically designed with the required use of specialized equipment and the application of new construction techniques. From a technical standpoint, Habitat 67 was a first-class product constructed with advanced building technologies. It required a substantial degree of innovative architectural design and building technology in order to be realized.

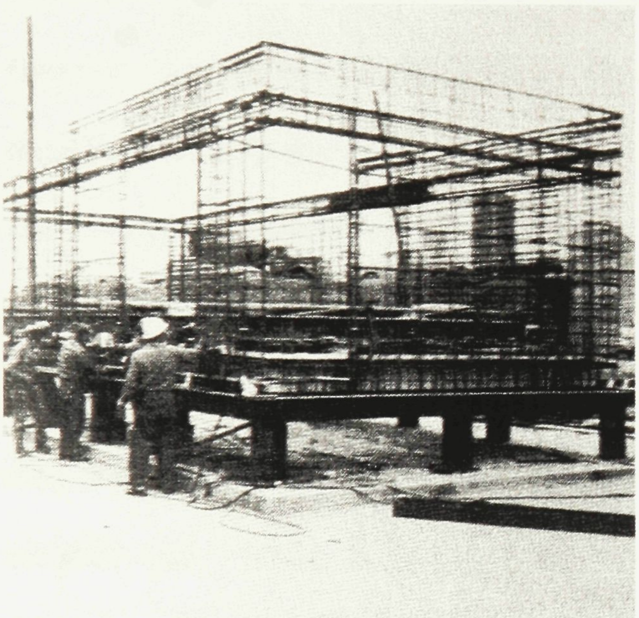

Fig 35. A single module of the reinforcing cage ready to be transported into the mold.

Moshe Safdie adopted the modular building system in order to addresss diverse household needs and preferences by providing a variety of spatial layouts in Habitat 67 (Fig. 36 and 37). He was dissatisfied with both suburbia, that destroys the surrounding city environment and limits the inhabitants' enjoyment of the amenities of city life, and with the concentrated high-rise residential blocks in the city that lack both privacy and outdoor space. He was convinced that an adequate housing development could find a way to accommodate many people in a small space, yet provide the residents with at least some sort of living pleasures by offering sufficient outdoor spaces. Consequently, Safdie designed an unique modular configuration through combining shelters with all the attributes of modern life. Habitat 67 was built by placing and stacking the standardized 354 modules vertically and horizontally together. The modules were grouped and positioned in a spiral formation around a spine of three hill-shaped structures.[50] However, the individual modules had to bare the weight of the units above them, therefore, the modules at the lower level were actually constructed with thicker and stronger reinforced concrete walls. The steel cables integrated into the modular structure were used as a tensioning device to fasten the modules onto the hill-shaped structure.[51] The individual dwelling unit layouts vary and are connected throughout the complex by a series of horizontal sky walkways covered with curved transparent plexiglass. In addition, the modules were designed to be adaptable and to be arranged in a set of combinations forming coherent but diverse dwelling layouts. There were one to four bedroom unit options with a total of fifteen different spatial layouts. Each dwelling unit had its own garden space situated on top of the unit immediately below providing a private outdoor area for residents (Fig. 38). The arrangement of the modules

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[50] Murray, Irena Žantovská, ed. Moshe Safdie: Buildings and Projects, 1967-1992. Montreal; Kingston; London; Buffalo: McGill-Queen's University Press, 1996. P 48-49.
[51] Kettle, John, ed. Moshe Safdie: Beyond Habitat by 20 Years. Montreal: Tundra Books, 1987. P 104.

provided privacy for individual households, and the variation in dwelling layouts with a private garden space offered a sense of individuality and uniqueness. The results of the unique modular arrangement of Habitat 67 is that many families were housed in a single compound while responding to the desire of suburban dwellers for gardens.

> "Everything about it gives me the feeling of a house and yet it gave me all the other things I had always wanted in a house but never found in the isolation of the anonymous suburb."[52]
> Moshe Safdie

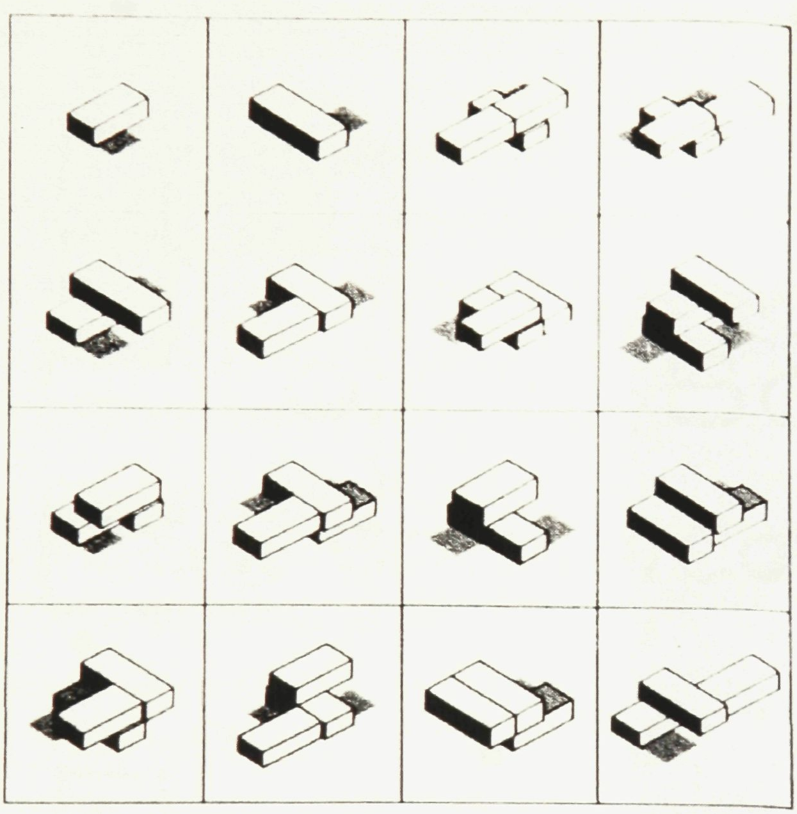

Fig. 36. The variety of module configurations of Habitat 67 with the use of a repetitive module.

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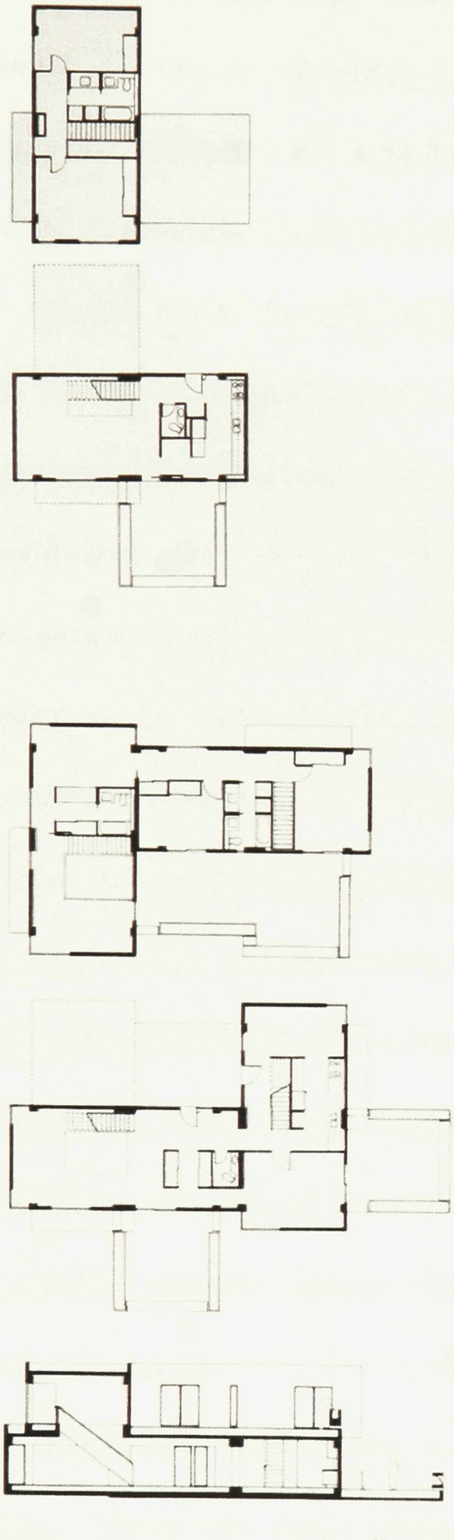
[52] Ibid. P 12.



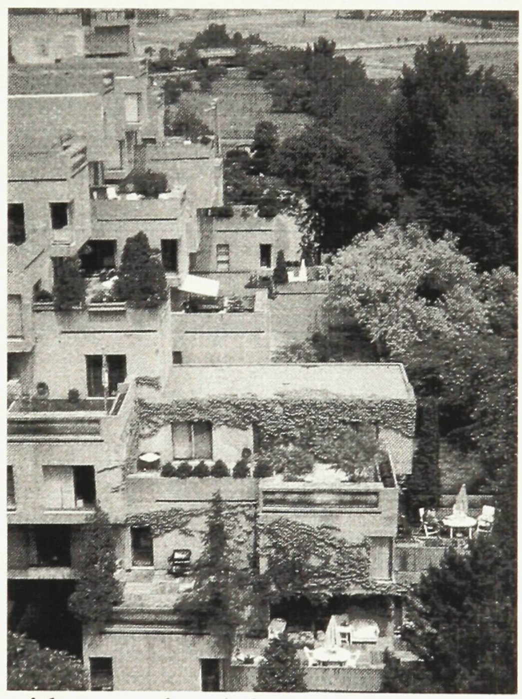


Fig. 37. A typical 'three-box' unit floor plan with upper level, lower level, and section (left).
Fig. 38. A series of private gardens situated on units immediately below (right).

Like all assembly construction systems, the modular system used in Habitat 67 has its advantages and disadvantages. The advantages include production efficiency and acoustic privacy. With the application of the modular system, less manpower is required and also the erection time is shortened at the construction phase. In addition, dwelling units are grouped and stacked in such a way that the reinforced concrete modules form a double wall between units thus providing acoustic privacy. Its disadvantages include no provision for spatial modification, and restricted design possibilities. With the inherent limited arrangement of the prefabricated modules, reallocations of module units can only happen at the planning stage, and cannot be modified once construction is completed. Therefore, it is difficult for residents to expand their units by cutting through the reinforced load bearing partition wall of adjoining modules. Also, the formation of the modular system has a symmetrical configuration that restricts design possibilities for the overall built form.[53] Given these characteristics, the standardized module limits design possibilities both internally and externally as compared to the skeletal framing system. In spite of the limited adaptability of the modular assembly system, Habitat 67 is a new architectural form in the vein of an exciting piece of cubist sculpture. It was introduced as a housing showcase that emphasized advancement in construction and enrichment in high-density living. These two areas, along with the provision of high-rise living with suburban gardens, have displayed the architect's ability to integrate these uplifting

[53] Ibid. P 102-103.

conditions into a new way of city living. Habitat 67 addressed the need for a balance between the desire to produce aesthetically pleasing architecture and the economic advantages offered through prefabricated building construction.

4.5 High-Tech Groups

The modern adaptable prefabrication approach is tending towards high-tech production. This tendency can transform prefabrication in a new architectural direction.[54] Extraordinary experimental high-tech projects in the prefabrication sector have resulted from an unprecedented proliferation of ideas, dreams, and imaginations. High-tech housing applies the 'closed building system' of prefabrication because most of the models are independently designed and are not subject to standardized specifications from existing manufacturers' catalogues. The high-tech housing models are uniquely designed and represent a rational architectural expression that departs from conventional prefabricated housing methodologies. There are two common design strategies applied to these high-tech homes, namely, adaptability of components and employment of advanced materials. The first strategy is applied where the architects seek to build high-tech high-rise residential buildings from an assemblage of identical factory-made adaptable components that offer a variety of housing types. The second strategy is applied when architects employ new materials such as factory-produced metals and plastics, in order to facilitate on site accurate and rapid erection. Technically, these high-tech housing projects specify the design of the components to be factory-made but many of the experimental projects have yet to be executed. These experimental projects are still works-in-progress and have not been mass-produced. Notwithstanding the plethora of imaginative ideas, the

[54] Cook, Peter. Experimental Architecture. New York: Universe Books, 1970. P 13.

building industry faces challenges with the production of prototypes and the lack of financial resources.[55] However, examples such as Buckminster Fuller's '4-D Dymaxion', Herbert Ohl's 'Space-Cell System' and Archigram's 'The plug-in-City' have shown that ideas of adaptable prefabricated components with high-tech innovative assembly techniques can be designed and, at times, realized.

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[55] Davies, Colin. The Prefabricated Home. London: Reaktion Books, 2005. P 38.

4.5.1 Richard Buckminster Fuller: 4-D Dymaxion

In 1927, Buckminster Fuller's first experimental proposal, the 4-D Dymaxion house design, truly demonstrated an innovative method for assembling adaptable prefabricated construction (Fig. 39). The word '4-D Dymaxion' is coined from terms that Fuller used frequently in his lectures: "4 D" (fourth dimension), "dynamic", "maximum" and "ions" (or "tension").[56] They are terms that were meant to articulate his concern for humanity, 'time-based architecture' (refers to construction efficiency and adaptability), and space. He realized that the apparent issues of housing design were linked to "invisible networks of distribution and social organization, as well as to the selection of appropriate materials and building methods."[57] Michael Gorman, the author of Buckminster Fuller: Designing for Mobility, admired Fuller's philosophy of housing as "practical", "doable", and "hands-on". It focused on the idea that a good and effective philosophy should be applied mechanically.[58] Instead of analyzing his perception of housing in favour of the modern movement for mass-production, Fuller suggested a new perspective on housing design that demonstrated ideal dwelling through assembly performance. Driven by his philosophy of 'more with less' in assembly performance, Fuller approached the challenge of reducing the quantity of materials required in a way that involved an awareness and

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[56] Gorman, Michael. J. Buckminster Fuller: Designing for Mobility. Ed. Luca Molinari. Milano: Skira, 2005. P 41.
[57] Ibid. P 9.
[58] Ibid. P 10.

understanding of the strength and adaptability of materials.[59] He perceived this as the principle of rational engineering that is based on the ability to use minimum materials to achieve maximum span. Fuller put forward the idea that a dwelling designed with a superior assembly system requires a minimum number of components. The 4-D Dymaxion house design is an architecturally pioneering work designed for domestic use. The design included features that suggested flexibility (expandable nature of the dwelling) and the speed of modern life. The tree-shaped structural form could be converted as a single dwelling unit or as an apartment with a series of stacked units (Fig. 38). The design of 4-D Dymaxion housing is not permanent, but a temporary and transportable home that can be adapted and altered, even replaced at regular intervals.[60]

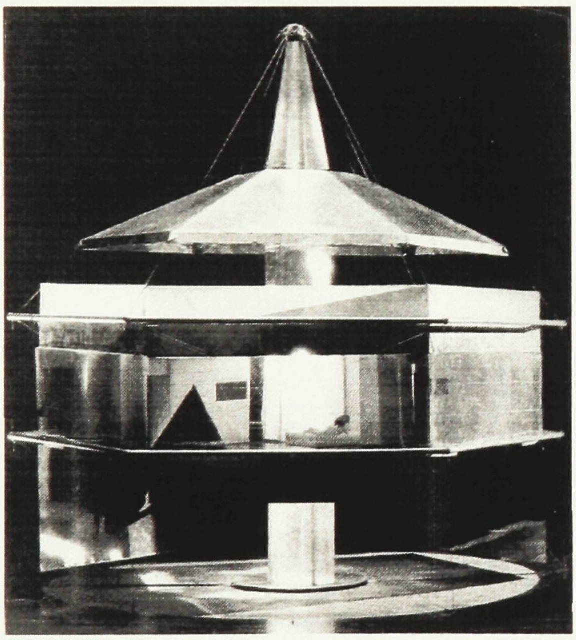

Fig. 39. Dymaxion House model, 1927.

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[59] Curtis, William. Modern Architecture since 1900. 3rd ed. London; New York: Phaidon Press, 2003. P 266-267.
[60] Schwartz-Clauss, Mathias, and Von Vegesack, Living in Motion: Design and Architecture for Flexible Dwelling. Berlin: Vitra Design Stiftung gGmbH, 2002. P 39.

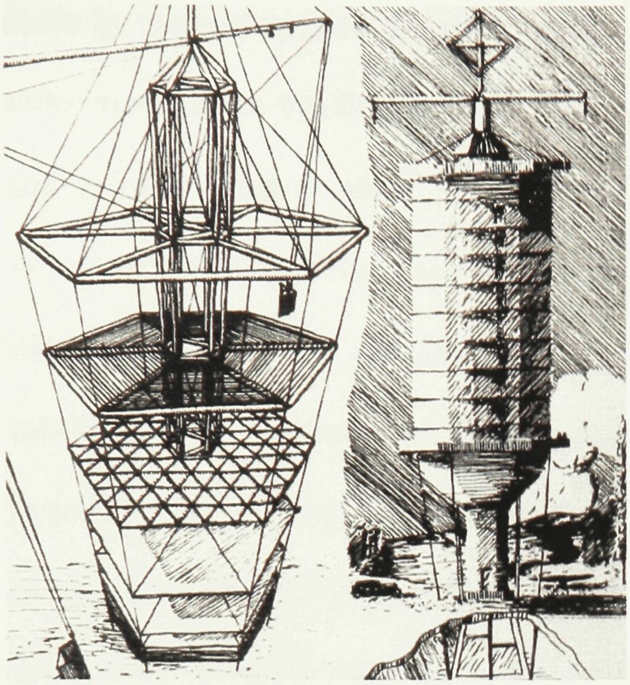

Fig. 40. Sketch of the structural arrangement- tension and compression, Dymaxion House in a multi-story format.

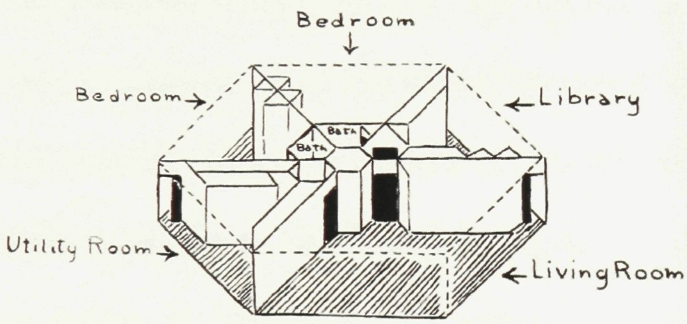

Fig. 41. Divisions of living space in Dymaxion House.

Four innovative concepts have evolved from the 4-D Dymaxion house, namely the structural tension cable system, geometrical building form, symmetrical dimension, and a climate management system. First, the hexagonal tension-suspended floor is hung from a central structural mast (Fig. 40). The skeletal frame is shaped like an umbrella where all forces can be transferred onto the singular central mast. The design strategy is to hold the weight of structural loads by converting gravitational force into the tension of the structural frame in order to minimize bending stresses. The cables are exposed on both the interior and exterior sides to allow viewers to see the highly sophisticated high-tech structural formation. The space beneath the suspended floor is liberated from any structural components, and can therefore be adapted to any kind of habitation such as a garage or storage room enclosed with metal blind sheets. Second, Fuller believed that a hexagonal format is more stable and more efficient than a rectangular building layout. A hexagonal building allows a fluidity of activity zones while grouping mechanical, electrical and plumbing services at the center core. Third, spatial layouts are equally divided into five sections to correspond to the hexagonal shape (Fig. 41). The identical geometry of each section facilitates ease of adapting or interchanging between building components thus expanding the possible spatial configurations. Fourth, the hexagonal dwelling layout was shielded mainly by prefabricated components composed of reflective glass panels (a system of mirrors through translucent walls) and a lightweight curvilinear streamlined Duralumin roof. He incorporated structural arrangements and the reflective-characteristics of materials in the design as a means of achieving perfect climate control to upgrade living conditions. Later, Fuller demonstrated that his 4-D Dymaxion was comfortable, pleasant, and habitable by displaying a nude female mannequin in the bedroom. He claimed that his dwellings were "[…] environment-controlling machines, […] just as cars were becoming miniature palaces, air-conditioned and electrified."[61] The message conveyed was that his 4-D Dymaxion house had perfect ambient temperature (Fig. 39).[62]

This high-tech design clearly illustrated the design philosophy of transferring advanced technologies from every discipline of prefabrication into architecture. In general, the innovations of the 4-D Dymaxion house design could be attributed to its ability to attain maximum strength, minimum weight, and assembly efficiency through a symmetrical arrangement of building form, and to its understanding and use of the characteristics of materials that allow for comfortable living conditions. Simply, the form of the 4-D Dymaxion house was neither derived from the spatial programs nor from the site, but from its own structural order. The overall structural system could be considered as a high-tech and lightweight version of the skeletal framing system. The proposal was an industrial and architectural breakthrough: its innovative structural design was architecturally promising with intrinsic degrees of adaptability and superior technical virtuosity.

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[61] Architectural Design. The Transformable House. Ed. Jonathan Bell and Sally Godwin. London: Wiley-Academy, 2000. P 17.
[62] Gorman, Michael. J. Buckminster Fuller: Designing for Mobility. Ed. Luca Molinari. Milano: Skira, 2005. P 47.

4.5.2 Herbert Ohl: 'Space-Cell' System

In 1966, the architect, Herbert Ohl designed an innovative 'space-cell' assembly system as a research project to develop a prefabricated modular high-rise residential building, for the Ulm Institute of Industrialized Building. The objective of the 'space-cell' assembly system was to develop an adaptable and customizable dwelling unit based on principles of modularity and prefabricated construction. It was an attempt to use standardized prefabricated components for a variety of dwelling layouts (Fig. 45). Ohl emphasized that his space-cell system contained the essential characteristics of adaptable prefabricated construction, namely, diversity and standardization. He focused his efforts on exploring advanced assembly systems for designing prefabricated housing that could adapt to extensive combinations of spatial configurations. A system, he believed could be capable of adapting to diverse household needs and preferences.[63] Subsequently, he proposed a series of building forms from low-rise scale to high-rise that incorporated the standardized 'space-cell' component (Fig. 42, 43, and 44).

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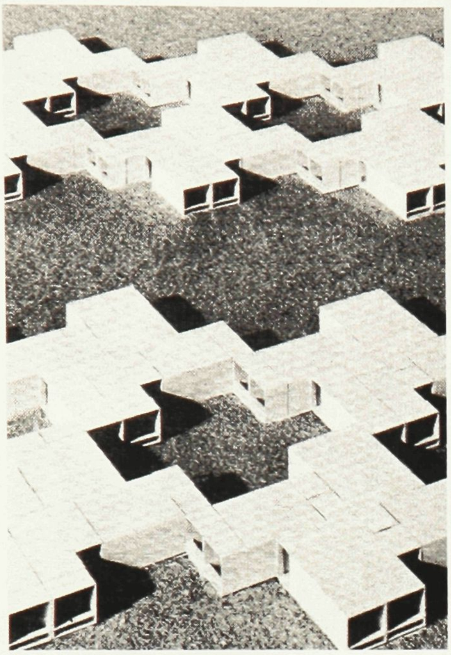
[63] Carreiro, Joseph, et al. The New Building Block: A Report on the Factory-Produced Dwelling Module. Vol. 8. Ithaca; New York: Cornell University, 1968. P 205.



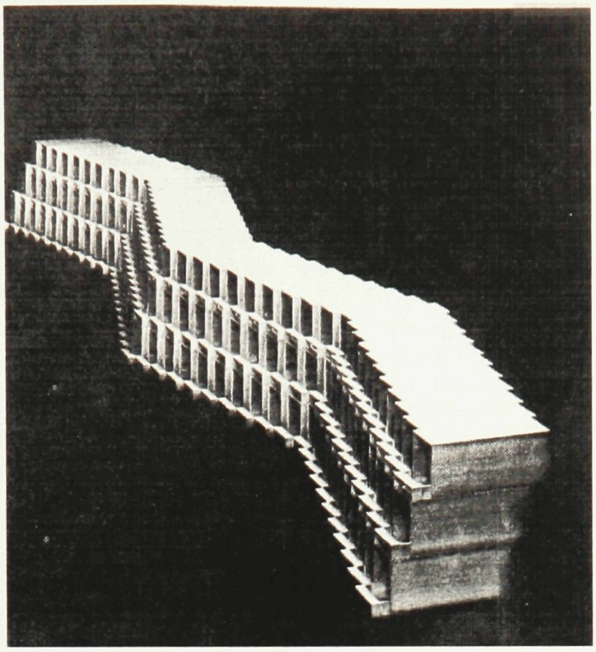


Fig. 42. Single storey semi-detached houses with space-cell system (left).
Fig. 43. Low-rise housing with space-cell system (right).

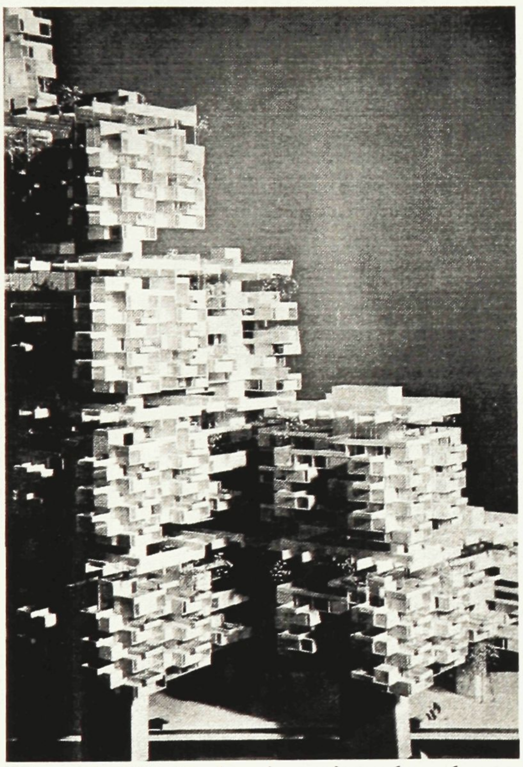


Fig. 44. High-rise housing development with space-cell system.

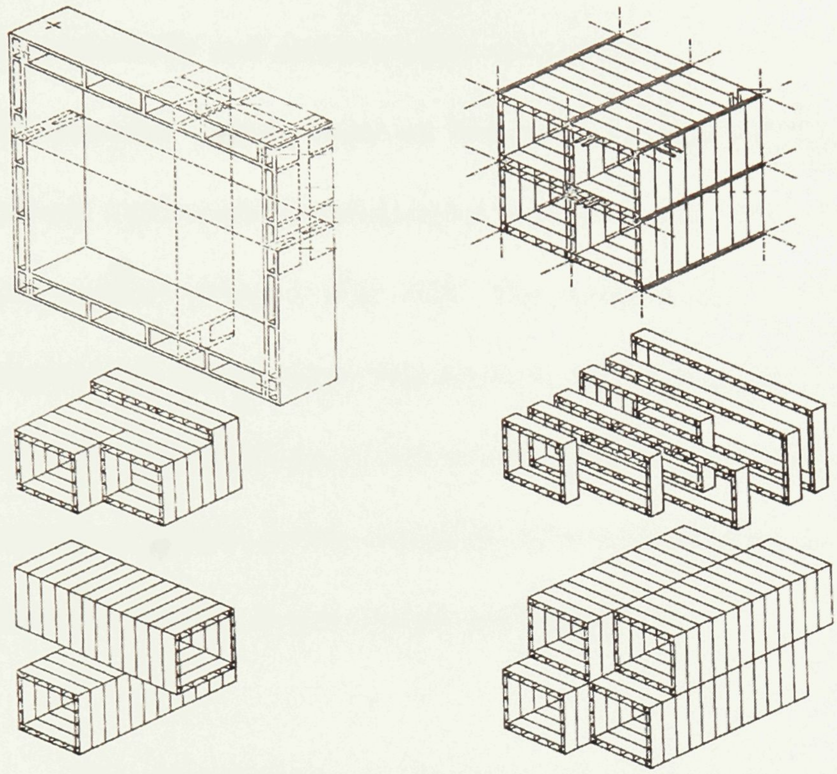


Fig. 45. Space-cell assembly system, showing the hollow-wall module being arranged to form a variety of dwelling combinations.

There are innovative adaptable prefabricated building solutions found in every design aspect of the suspended 'space-cell' system. The concept differed from other modular systems being proposed in that the unit is manufactured as one monolithic module. The 'space-cell' system was comprised of a series of standardized hollow double-walled square tubes (Fig. 45). Each dwelling unit is formed by fastening a series of these rectangular steel structural tubes together and stacking them on top of each other to form the desired configuration for a variety of possible dwelling layouts.[64] The pragmatic feature of the design was its extension of space through the positioning of additional modular tubing

[64] Ibid. P 205-207.

components. The uniquely designed modular tubing assembly system was the most technically and architecturally interesting. The advantages of this "space-cell" assembly system with its distinctive hollow-wall tube design were its relatively lightweight prefabricated components and the easily flexible placement of the conduit elements (Fig. 45). The prefabricated modular steel tubes were designed with joining edges that could be sealed with gaskets and were designed to meet the specifications of various site conditions. As a result, the design of the standardized hollow double-walled modular tubes has become highly adaptable as a means to generate diverse spatial configurations.

The characteristics of diversity and standardization in Ohl's conceptual assembly system highlight the variety and flexibility of choice in dwelling configurations, as well as the unity in design of the efficient construction. This simple, yet extraordinary concept introduces another efficient assembly method into housing construction with the benefits of spatial design possibilities and time efficiency, definitely an appealing concept of adaptable prefabricated construction. Overall, the "space-cell" system has shown that the concept of adaptable prefabricated construction does not only assimilate assembly-efficient production, but also addresses individual needs by generating diverse spatial configurations.

4.5.3 Archigram: The Plug-in-City

The Archigram group, comprised of experimental British architects, was formed in the 1960s. It visualized mass-produced housing as dynamic, flexible, adaptable, and fashionably high-tech. The group invented a series of modular units referred to as "capsules" and "pods" (Fig. 47).[65] One of the noteworthy Archigram projects, the 'Plug-in-City' proposed in 1964, envisioned mass-produced housing with modular 'capsules' as a form of prefabricated mega-structure (Fig. 46).

> "The buildings themselves, of course will need to become more three-dimensionally organized. The services and the structure will no longer be a self-contained system… Both demand lightweight materials and interchangeable parts. Many of the lessons of the world of product design had only slowly come to be recognized as valid for buildings. It is certain that the future of architecture will be in system-building."[66]
> Peter Cook

The mega-structure of the 'Plug-in-City' was comprised of different types of modules that were standardized in dimensions and systemized in assembly techniques. Archigram intended to assemble enormous systemized structures that permitted expansion of the structural composition. It combined the hardware of metropolitan existence-- streets, mono railways, high-speed elevators-- with multi-level separation and high-density living conditions. Networks of streets within the mega structure were suspended high above ground. The structural form was highly adaptable, as thousands of specially designed living 'capsules'

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[65] Cook, Peter. Experimental Architecture. New York: Universe Books, 1970. P 108-109.
[66] --. Architecture: Action and Plan. London; New York: Studio Vista; Reinhold Publishing Corp. 1967. P 80-81.

could be lifted up to hundreds of storeys and plugged into the framework by using cranes.[67] The goal was the provision of housing to millions of people as long as the adaptable mega structure permitted the expansion of the project.

This structural system extended beyond the typical range of assumptions regarding future housing demands. The concept of adaptability of living 'capsules' suggested that the mega-structure was capable of responding to the day-by-day, and year-by-year changes in living preferences. With all the living 'capsules' in place, the mega structure system was not only seen as the replacement of one house type by another, but as a process of restructuring and extending the existing structure to accommodate the growth, ever-changing household needs, and desires for housing. Theoretically, the 'Plug-in City' illustrated the diverse mode of living within a compound; however, the design and other technological requirements of the project were not realistic.

> "The Plug-in City is a replacement city, the capsule is a replacement house and they are both examples of the consistent reply."[68]

This statement establishes an interesting platform to examine the combination of realism and fantasy as defined by Archigram. The design of the Plug-in-City was intended to accommodate miscellaneous households within a compound by providing various choices of living 'capsules' with adaptable characteristics. It symbolized the idea of high-tech machinery with an adaptable

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[67] --. Experimental Architecture. New York: Universe Books, 1970. P 105.
[68] Ibid. P 129.

housing design philosophy. The objective was to design a living compound that could be open and flexible to expand and be altered. Philosophically, it suggested a new perspective on housing, that the 'house' could quickly reflect the changing tastes and requirements of individual preferences, just as the world of automobile production could. At the same time, the proposed futuristic structural compositions were entirely surreal because its required technology was completely inaccessible at the time to the building industry. Hence, the apparent message that was delivered by Archigram was that they had attempted to bridge the gap between the surreal dream of building high-tech housing for diversity of individual preferences and the idea of the mass-production of prefabricated building components.

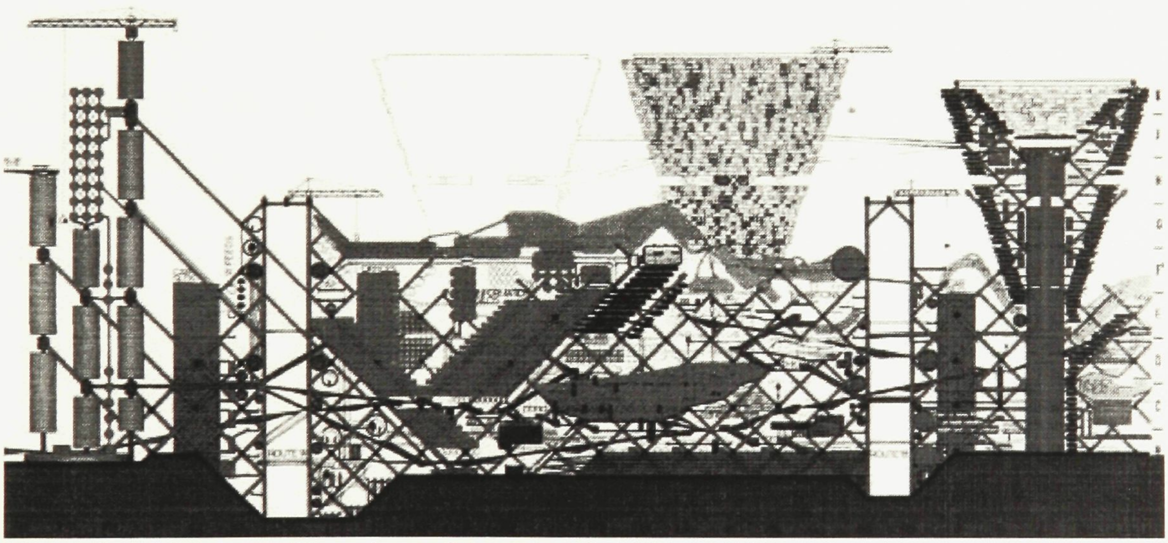

Fig. 46. Archigram, Drawing of the Plug-In-City, 1964.

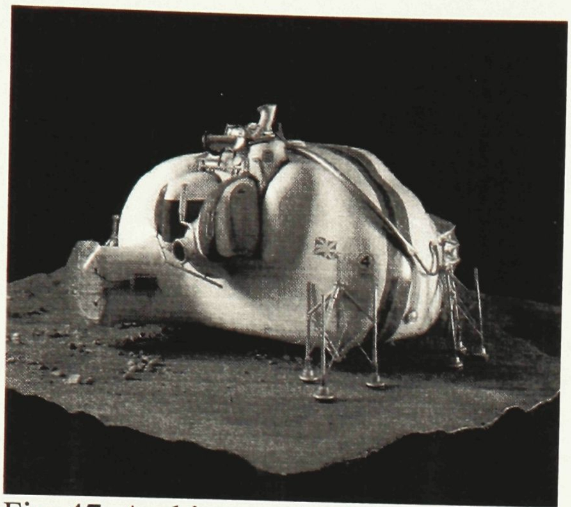

Fig. 47. Archigram, A Living Pod model.

Chapter Five

Automotive 'Unibody Modular' assembly system as a Model for Adaptable Prefabricated Construction

5.1 Introduction

> "The new technologies make it possible to solve problems where the given characteristics of producing a series of homes can be made compatible with the building of individual private homes."[69]

The concept of adaptable prefabricated construction combines the criteria for assembly-efficient systems, with the adaptability of prefabricated building components. Production of prefabricated building components has long been associated with Henry Ford's invention of the mass-production of cars. With this, the groundwork had been laid to mass-produce building components on assembly lines that would be similar to those of Ford's first mass-produced automobiles, the Model T.[70] According to Ivan Margolius, in Automobile by Architects, the history of prefabrication has proven that assembly-line methods from the automobile industry have become compatible with building construction. Architects have gone further and researched ideas for more appropriate construction methods using the design adaptability of structural systems from the automobile industry. It has been the ambition of architects to design not only assembly-efficient and durable mass-produced housing, but also to formulate designs of prefabricated assembly systems that permit greater construction

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[69] Asensio, Paco. Prefab: Adaptable, Modular, Dismountable, Light, Mobile Architecture. Trans. Bill Bain. Ed. Alejandro Bahamon. New York: HBI; LOFT, 2002. P 76.

[70] Ford, Edward R. The Details of Modern Architecture, 1928- 88. Vol. 2. Cambridge; London: MIT Press, 1996. P 245-249.

possibilities.[71] This chapter will begin with the analysis of the design approaches of architects who have successfully drawn analogies from the automobile industry. Then it will investigate commonalities of assembly processes of automobiles and buildings by examining the adaptability of the automobile 'unibody' structural frame. The objective is to integrate the adaptable characteristics and assembly-efficiency of an automobile design into adaptable prefabricated construction for high-rise housing units that could be classified as the 'unibody modular' assembly system.

[71] Margolius, Ivan. Automobiles by Architects. Chichester: Wiley-Academy, 2000. P 5-6.

5.2 Architects and automobiles

> "In the automobile works, all the various phases of the execution process come together. It is a great school for any architect."[72]

With the success of the assembly line method from the automobile industry, Henry Ford changed the way in which other industries approached the production process. Assembly line production allows for greater cost-effective production, higher quality control, and less manufacturing time.[73] According to Robert Kronenburg, "efficiency and economy are important [...] the ultimate aim of innovative design is to find out how to make more appropriate, more beautiful, more efficient buildings for more people."[74] In Towards a New Architecture, the architect, Le Corbusier, described houses as machines to live in, and considered machinery as a legitimate trend for the future of building prefabrication and automobile production. He uses examples of automobiles, airplanes and steamships to illustrate how machines within their precise technical capability can influence prefabrication methods.[75] Similarly to Le Corbusier, Kronenburg believes that architects should study engineer-designed machines such as automobiles to find inspiration and solutions, in order to move towards an advanced prefabricated assembly system in the building industry. Often, it is the new assembly system that generates its own expression in the finished work.

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[72] Dini, Massimo. Renzo Piano: Projects and Buildings, 1964-1983. Milan; NewYork: Electa; Rizzol, 1983. P 38.
[73] Batchelor, Ray. Henry Ford: Mass Production, Modernism and Design. Manchester: Manchester University Press, 1994. P 1-2.
[74] Kronenburg, Robert. Spirit of the Machine: Technology as an Inspiration in Architectural Design. London: Wiley-Academy, 2001. P 20.
[75] Le Corbusier. Towards a New Architecture. London: Rodker, 1931. P 4-8.

> "While car-makers can learn from architects; so architecture can learn from car design."[76]

There are many well-known architects who have been interested in adaptable prefabrication that is related to automobile design. For example, the architects Jean Prouvé and Renzo Piano in collaboration with Peter Rice, have taken the ever-improving assembly techniques from the automobile industry and the influences of cars in our daily life, as the motivating factors for designing prefabricated products. Their design is based on the adaptability of prefabricated components that are interchangeable/alterable, and have multi-task purposes. These architects have experimented with different structural forms and have applied assembly methodologies that are derived from automobile production.[77]

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[76] Margolius, Ivan. Automobiles by Architects. Chichester: Wiley-Academy, 2000. P 7.
[77] Ibid. P 9.

5.2.1 Jean Prouvé-- Maxeville workshop

Combining skills as an engineer, constructor and architect, Jean Prouvé's admiration of automobile aesthetics can be detected in his early sketches. Prouvé believed that the beauty and quality of automobiles were defined by the adaptability of each specific component and not by the overall architectural form. He recognized the conformity and adaptability of automotive components, and suggested that the beauty of a building could also be manifested by the adaptability of components through multi-task purposes.[78] He was inspired to use car parts such as chassis and body panels that were made with corrugated and folded steel sheets, as the models to define a series of building components that could adapt to various uses (Fig. 48, 49 and 50). His concept was applied in his Maxeville workshop where every prefabricated component was uniquely designed to have multi-functional purposes. For example, the prefabricated component called the "Shed" served either as a structural frame or a cladding component (Fig. 51 and 52).[79] In addition, he promoted the idea that the adaptability of prefabricated components was a solution to the problem of obsolescence. Prouvé stated that products manufactured from his workshop were highly adaptable and flexible; they adapted to changing needs, and they could be reused or converted into new components to serve different purposes.

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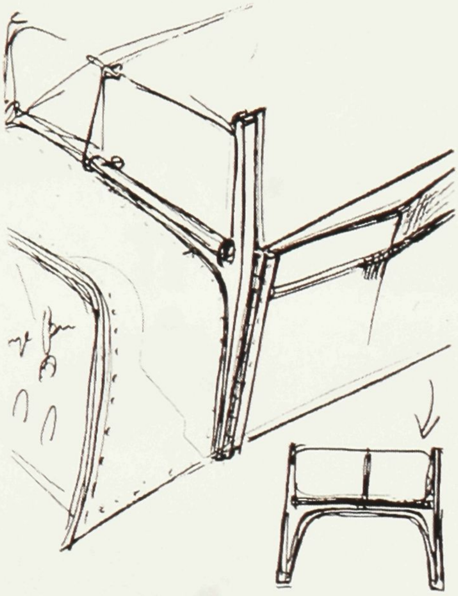
[78] Prouvé, Jean. Jean Prouvé, Prefabrication: Structures and Elements. Trans. Alexander Lieven. Ed. Benedikt Huber and Jean-Claude Steinegger. New York; Ishington; London: Praeger, 1971. P 38-46.

[79] Ibid. P 30-31.



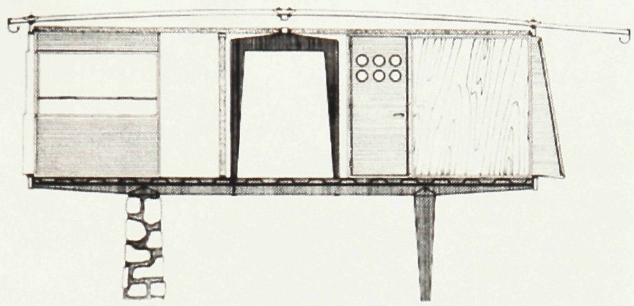


Fig. 48. A sketch of automobile bodywork later known as 'Jointed Frames' component, 1957 (left).
Fig. 49. The 'Jointed Frames' component inspired by automobile bodywork (right).

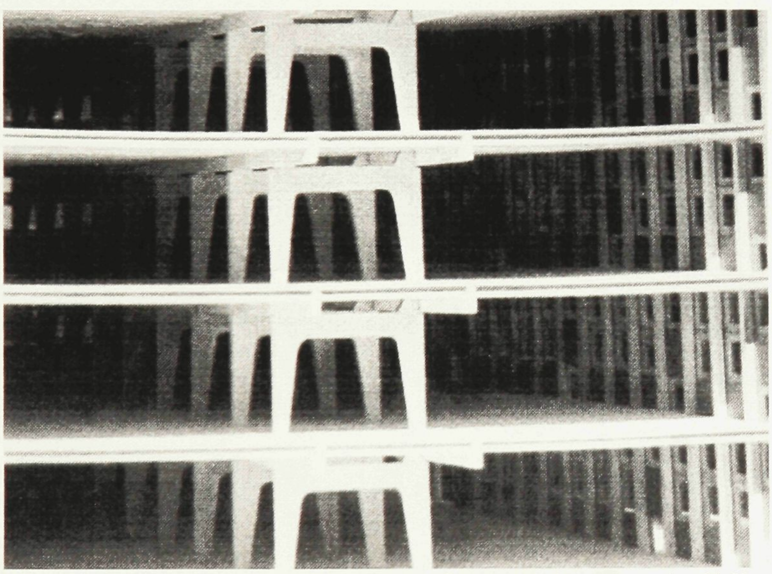


Fig. 50. Structural exploration for multi-storey buildings using 'Jointed Frames' components, 1963.

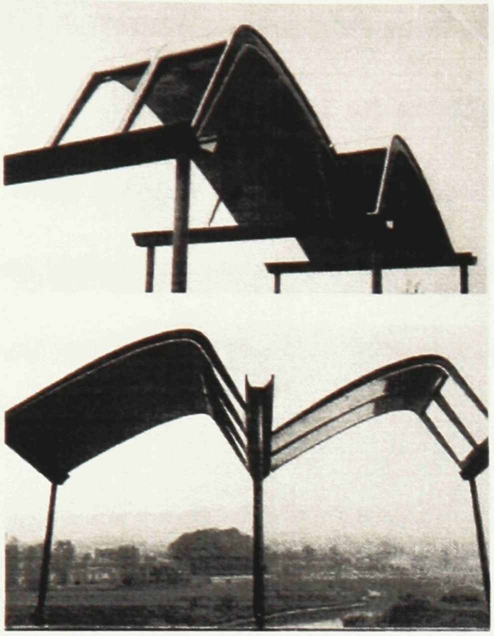
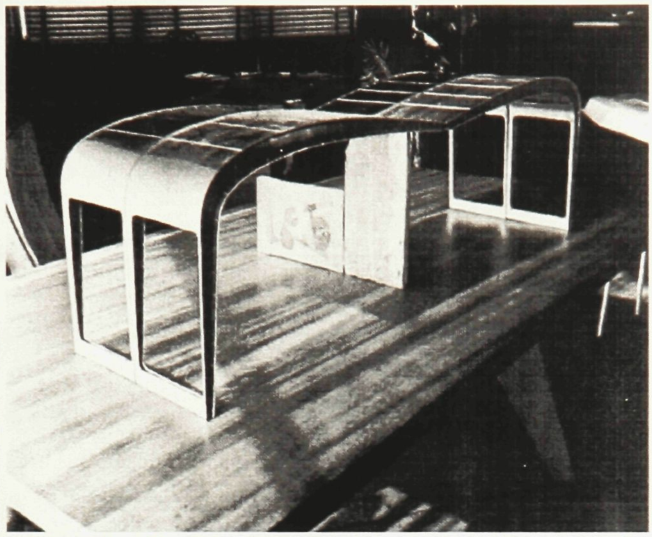



Fig. 51. and Fig. 52. Study models with 'Shed' type components, demonstrate the various design possibilities by employing identical components.

5.3 Automotive assembly methodology—The 'Unibody' structural frame

The state-of-the art assembly approach in the automobile industry is the application of an adaptable structural frame for a range of car models that facilitates design adaptabilities with assembly-efficiency. This approach was explored by the Italian architect, Renzo Piano, who collaborated with Peter Rice, a structural engineer, in analyzing new ways of designing and manufacturing cars for the Fiat automotive company in 1978. The objective for the experimental car, Fiat VVS was the reduction of the cost of production, and the weight of the vehicle, while improving safety and establishing the adaptability of the structural frame to serve several model types (Fig. 53). The solution required establishing an assembly line process that separated the production of the structural frame and the body panels rather than producing both of them as one unit. Different styles of body panels were subsequently attached to the overall structural frame, to form an assembly system that Piano called a 'subsystem', a skin and skeleton system, otherwise described as the 'unibody'

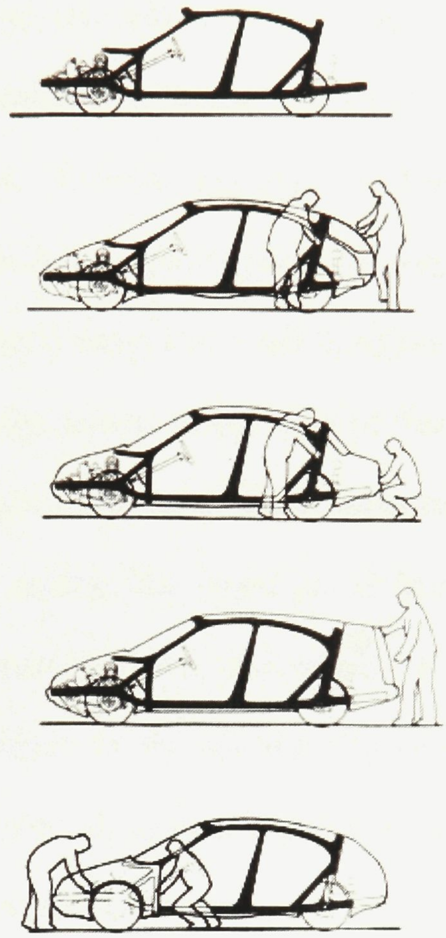


Fig. 53. A single structural frame serves a variety of models, Fiat VVS Experimental Car.

structural frame/module in the automobile industry.[80] Renzo Piano was convinced that there was a strong linkage between the adaptable characteristics of structural form and the properties of materials used. He believed that creativity in adaptable prefabrication would foster deeper knowledge and understanding of the materials used and of the process of construction. As result, the structural frame for the Fiat VVS automobile, was built with galvanized, spot-welded and gauge-type metals. It was a strong and adaptable structural frame that could be adjusted for design modification and was compatible across several model types of Fiat's flagship VVS (Fig. 54). The uniquely designed structural frame supported hatchback, sedan and station-wagon bodywork models that suited the different preferences of buyers. Renzo stated that his design was not a fixed object, but a flexible technical element which could be adapted to the specific desires of users.[81] He also stated that a good designer was not only talented in designing the finished product, but integrated individual preferences in the process of building the product.[82] By adding different styles of body panels onto the adaptable structural frame, Piano and Rice made simple and economical variations to car models that have influenced the way cars are currently designed (Fig. 55 and 56).

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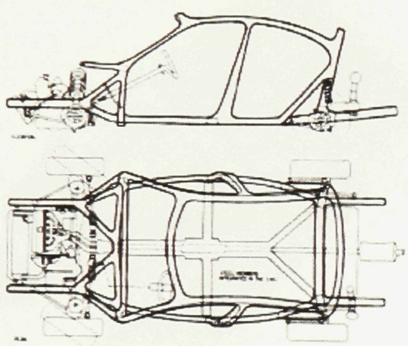
[80] Buchanan, Peter. Renzo Piano Building Workshop: Complete Works. Vol. 1. London: Phaidon, 1993. P 45-46.
[81] Margolius, Ivan. Automobiles by Architects. Chichester: Wiley-Academy, 2000. P 107-110.
[82] Buchanan, Peter. Renzo Piano Building Workshop: Complete Works. Vol. 1. London: Phaidon, 1993. P 45-46.

Fig. 54. Structural frame of prototype Fiat VVS Experimental Car, 1978.



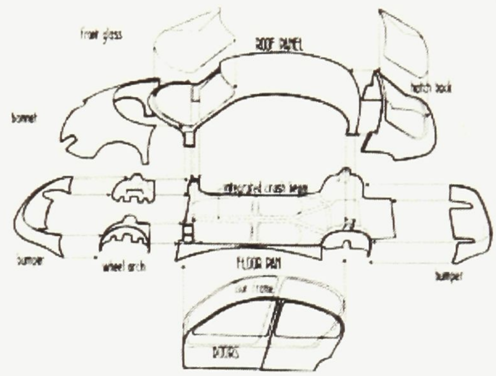


Fig. 55. and Fig. 56. Different body panels completely enclose the structural frame.

Currently, the advanced version of Renzo Piano's structural frame is the 'unit-frame-and-frame-less-body' or simply the 'unibody' structural frame.[83] The 'unibody' structural frame is stamped from sheets of steel metal then bonded and welded together by computer-guided robotic machines to obtain a high quality and precisely finished product. This single piece of rigid shell structure is composed of three main elements, the chassis, the skeletal frame, and the body

[83] Barone, Martin R. Modern Automotive Structural Analysis. Ed. Mounir Kamal, and Joseph Wolf, Jr. New York; Cincinnati; Toronto; London; Melbourne: Van Nostrand Reinhold Ltd., 1982. P 4.

panels (Fig. 57). The integration of these three main elements improves the rigidity of the whole structure and reduces the amount of material used so that assembly-efficiency is maintained. The use of cornered and folded metal panels to accent styling lines also increases the stiffness of the structure. The use of an identical structural frame across a range of car models decreases production cost while generating greater design possibilities. This approach can be executed in the building prefabrication industry as the driving force to advance prefabricated assembly systems.

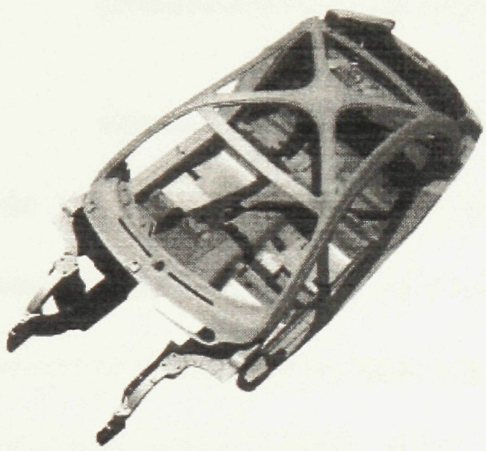


Fig. 57. 'Unibody' structural frame.

5.4 'Unibody modular' assembly system

Previous examination of the 'unibody' structural frame revealed two main advantages, namely an efficient assembly process and design adaptability. These advantages will be applied to the prefabrication methodology and will be incorporated into the design strategy of the proposed assembly system called the 'unibody modular' system.

> "Presently building is already gradually assuming the characteristics of an assembly line; the assembling of normalized, machine-produced parts. Just like our cars (Ford, Fiat, Citroen), our dwellings will be factory-produced within the foreseeable future [...] in the same manner as mass-produced articles, in the grand industrial way."[84]

Borrowing from the assembly-efficiency of the 'unibody' structural frame, the 'unibody modular' system would utilize a standardized module to form various dwelling models, in which specific styling and design of each model would be determined by attaching adaptable prefabricated components. The use of a standardized module would reduce production cost as well as enhance the employment of an efficient assembly process. For example, efficient use of standardized module with the built-in adaptable characteristics in a modular system and pre-production of the 'unibody' module containing all the service elements of a dwelling would create fewer components to be assembled on site. Altogether, construction mistakes would be minimized as assembly mechanisms would be simplified, the prefab components would be precisely fabricated, and the amount of labour would be reduced thus lowering production costs.

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[84] Theo van Doesburg, Misunderstanding Cubist Principles in Czechoslovakia and Elsewhere. Vol. 3., No. 10. Hauge: Het Bouwbedrijf, 1926. P 346.

Resembling the design adaptability of the 'unibody' structural frame for automobiles, the 'unibody' module would be seen as an 'incomplete' module such that variations of prefabricated building components could be attached or altered later during the final construction process. This incomplete 'unibody module' would offer products in which the final design would be finished according to the buyers' preferences. Potential buyers' would participate in the design phase and would be active as form givers. The buyers' choices in the adaptable prefabricated components would alter not only the type of building materials, styling of windows and doors but would also affect the formation of floor layouts that would constitute the overall building form. This design process would allow occupants to think of their dwelling as 'one-of-a-kind' and would represent their personal desires and needs. In the 'unibody module', the main elements, building service components such as duct works, plumbing systems, and electrical wiring system, would be embedded in the structure of the module itself. The integration would enhance the stiffness of the structural frame and would strengthen the modular form. In all, the 'unibody modular' system would apply the usefulness of assembly-efficiency with the built-in adaptable capability of modular design that would provide the potential buyers with greater dwelling layout options.

As previously stated, homeowners are interested in the architectural design of their homes especially regarding their individual preferences. At the same time, developers favour an efficient building assembly system. As elsewhere, building developments in Hong Kong will not hesitate to implement a more profitable and efficient design system. The 'unibody modular' system, as a hybrid of automobile and building prefabrication assembly systems, would apply the advantages of efficient assembly and design adaptability characteristics of the 'unibody' structural frame. It is a proposal that integrates the methodology of prefabricated construction that it is assembly-efficient and design-adaptable. With its design schemes of 'incomplete' module production, the concept of the 'unibody modular' system would widen design possibilities and would incorporate the homeowners' participation in the design process. It is a feasible assembly system in which the notions of adaptable prefabricated construction methodology would be appropriate for high-rise dwelling construction in Hong Kong.

Chapter Six

Site Characteristics

6.1 Proposed Site-- Yau Ma Tei area, Hong Kong, China

In 2001, Hong Kong Special Administrative Region Government (HKSARG) launched a competition called the West Kowloon Reclamation (WKR) development, for a master plan of the Yau Ma Tei to transform the 40-hectare-waterfront area into an integrated art, cultural and entertainment district with residential developments.[85] One of the final winning schemes for WKR named 'Pack of Arts, Recreation and Culture' (P.A.R.C) by Sunny Development Ltd. included a master plan for a residential development at the eastern tip of the Yau Ma Tei area. This thesis proposes a detailed design of a residential complex at the eastern tip of the Yau Ma Tei area. A significant landmark of the targeted site from the design scheme of "P.A.R.C" includes a series of canopies covering at least 55 percent of the 40-hectare area, spreading out horizontality and flowing along the waterfront area with panoramic views of Victoria Harbor. In addition, the site is adjacent to the entrance of the Western Harbour Crossing Tunnel Portal, and the Airport Railway's Kowloon Station which comprises a multi-purpose development of a 102 storeys commercial tower and a series of 70 storeys high-rise residential buildings that are all constructed on top of a podium. Currently, the eastern tip of the Yau Ma Tei area is temporarily used as the loading dock for

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[85] WKR Concept Plan Competition. Department of Housing Planning and Lands Bureau, The Government of Hong Kong Special Administrative Region. 3 November 2005 <http://www.hplb.gov.hk/competition/design.html>.

cargo ships and has been considered to be a misfit in the surrounding area. Despite the overwhelming high-density environment of Hong Kong, a transformation of the eastern tip of the Yau Ma Tei area can be perceived as an appealing and valuable opportunity to extend the existing urban fabric and to turn the vacant land into habitable space. It is a unique opportunity for the City of Hong Kong to emerge from conventional residential developments and develop its own conception of living standards for future housing design. In this thesis, the proposed high-rise residential complex would be situated at the eastern tip of the Yau Ma Tei area in an attempt to promote a new way of living for the saturated uniform housing condition in Hong Kong.

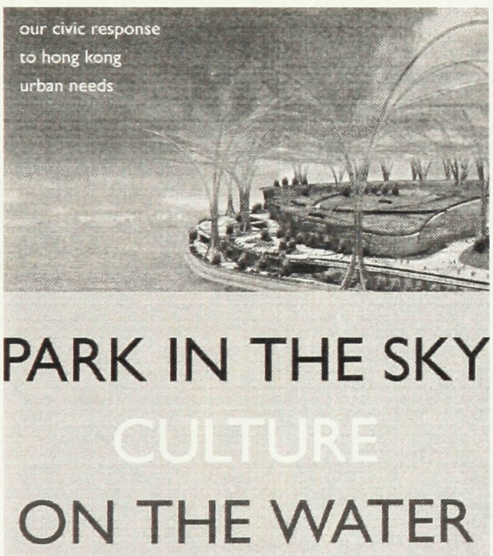


Fig. 58. 'P.A.R.C' project brochure: theme and conceptual approach (left).
Fig. 59. Ariel photo of the proposed site, eastern tip of Yau Ma Tei area, Hong Kong (right).

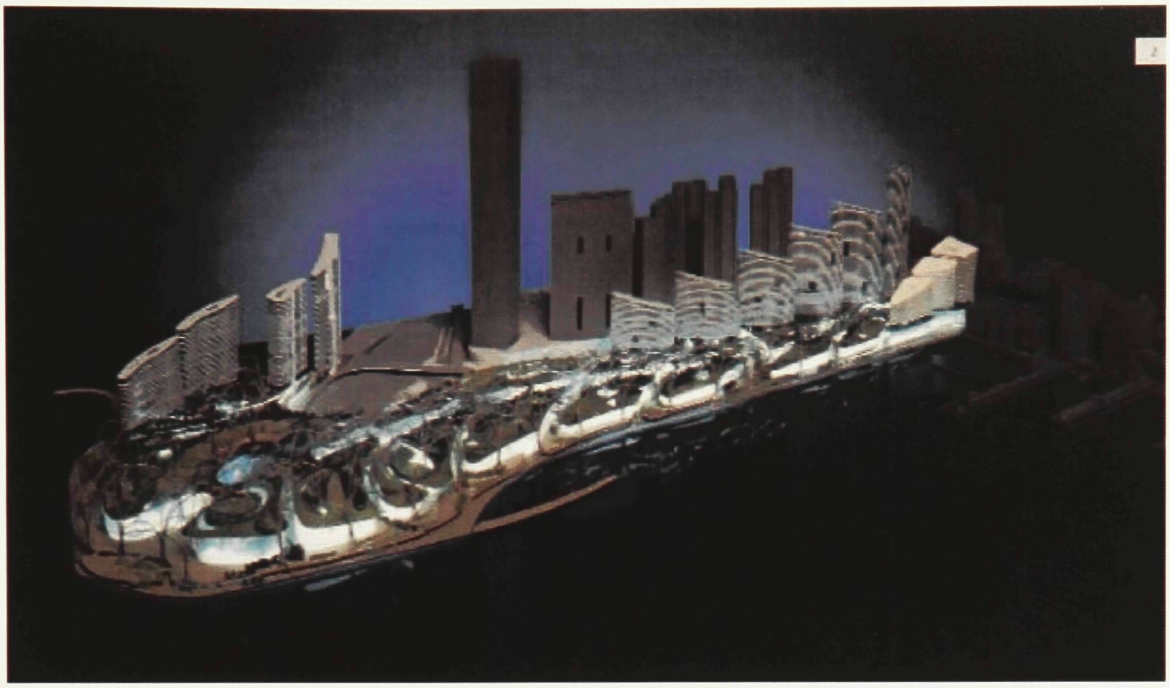


Fig. 60. A model of 'P.A.R.C' master plan of WKR development.

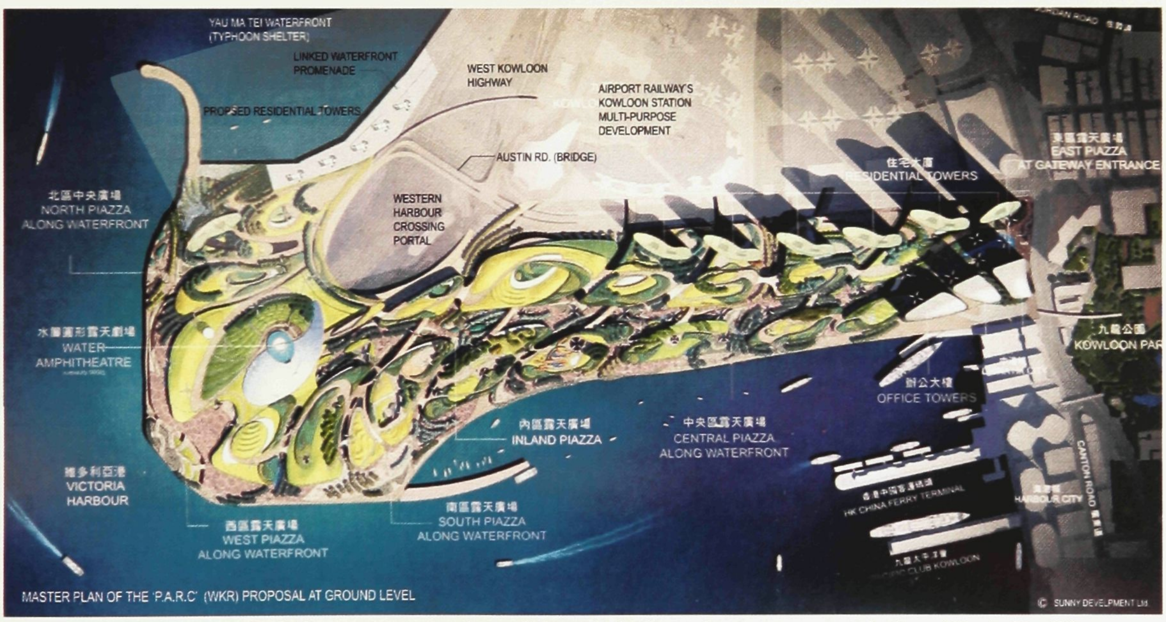


Fig. 61. Site plan of the proposed residential development and the 'P.A.R.C' (WKR) development.

Chapter Seven

Response

7.1 Design proposition

> "[…] combine the aesthetic activity of the architect with the economic activity of the entrepreneur, thus establishing a happy union […] between art and technics."[86]

The proposed residential complex will apply the concepts of adaptable prefabricated construction that will offer diverse spatial configurations and assembly-efficient construction in the design of a high-rise residential tower in Hong Kong. In addition, the proposal addresses the desire for a more responsive, interactive and harmonious living environment between households, along with flexible dwelling design possibilities in order to customize individual household preferences. The concept of adaptable prefabricated construction would be executed by using the 'unibody modular' system to provide assembly-efficiency and design diversity in the dwelling layouts.

In general, the proposed high-rise residential complex aims at fulfilling two objectives: to use **diverse design dwelling layouts** while facilitating assembly-efficient construction inherent through the **'unibody modular' system** to meet developer's desires and individual household preferences; and to apply adaptable dwelling layouts to form a series of grouped **semi-private open spaces;** and, relocating the communal spaces into the vertical built form named as '**green**

[86] Herbert, Gilbert. The Dream of the Factory-made House: Walter Gropius and Konrad Wachsmann. Cambridge: MIT Press, 1984. P 35.

pockets' that would provide the possibility for a harmonious living environment and an interactive neighbourhood in a high-rise building format (Fig. 62 and 63).

Fig. 62. Perspective of the proposed residential complex, front facade.

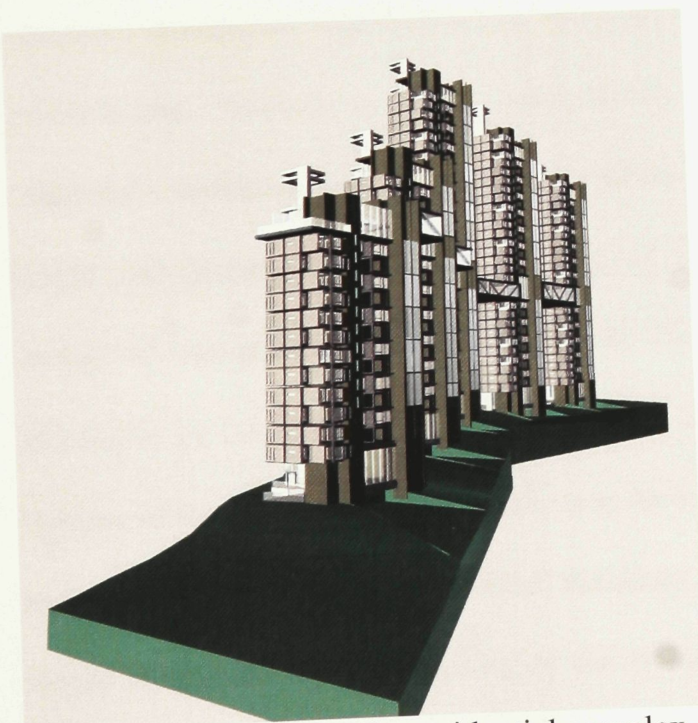
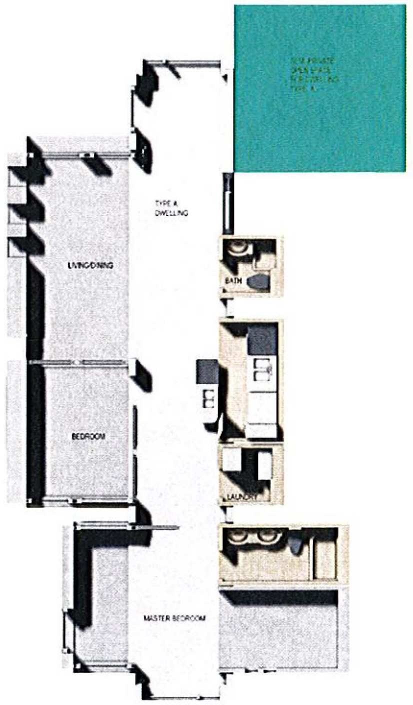


Fig. 63. Perspective of the residential complex, east façade.

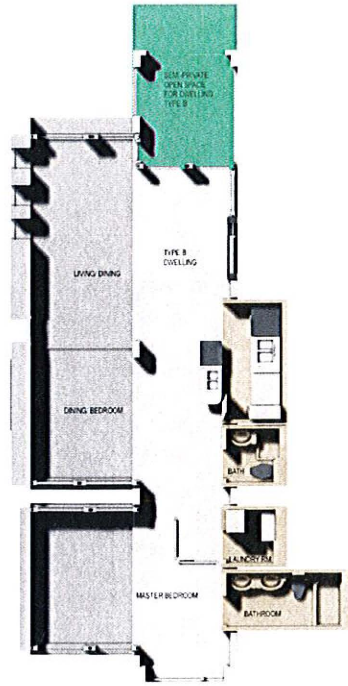
7.2 Diverse dwelling layouts

In the hyper-dense living environment of Hong Kong, diverse dwelling layouts in a high-rise building format are needed to suit various household compositions and provide more customized living spaces to the homeowners. For that reason, in the proposed high-rise residential complex, dwelling layouts would be varied by a series of different dwelling types and by the application of the 'unibody modular' assembly system.

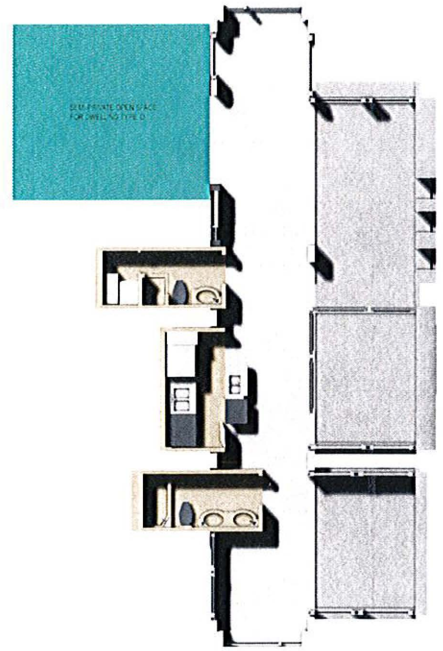
The diversity of dwelling layouts would be reflected in the proposed design as a strategy to offer potential buyers a range of dwelling types from bachelor to four bedroom units (Fig. 64, 65, 66 & 67). The layout of dwellings would be based on a 2.5 meters wide by 2.8 meters in height by 14 meters deep standardized 'unibody' module. The 2.5m x 2.8m x 14m measurement is the optimum dimension resemblance to the size of a 40 ft container such that the prefabricated 'unibody' module components can remain transportable. The 'unibody' module allows units to be stacked vertically to produce a series of single and double-high duplex dwellings of various dimensions (Fig. 68). The design of two-storey dwellings resembles those in the Unité d'Habitation de Marseilles by Le Corbusier. The double-high dwelling would increase the spatial volume of the living room and break away from the horizontal stratification found in conventional high-rise residential buildings. The large window facing south would illuminate the high ceiling of the living room. Other building elements such as doors, windows and partition walls within the dwelling units would be constructed as interchangeable panels with built-in joining connections for quick installation. The prefabricated partition panels would come in three different models: solid wall; wall with a strip window; and one-storey-high window. Additionally, the partition panels would be attached in a variety of combinations allowing for easy customization. For example, the master bedroom facing the living/dining area could feature solid wall panels to maximize privacy, or a series of one-storey-high window panels to create a direct visual connection with the living/dining area and the assigned semi-private space. To facilitate flexible spatial arrangements after the completion of the building, each partition panel would be prefabricated with standardized joining edges for simple alteration (Fig. 69). The intention of providing a series of dwelling types is to emphasize spatial diversity and a healthy social mix in which households from different social strata can be accommodated within the residential complex.



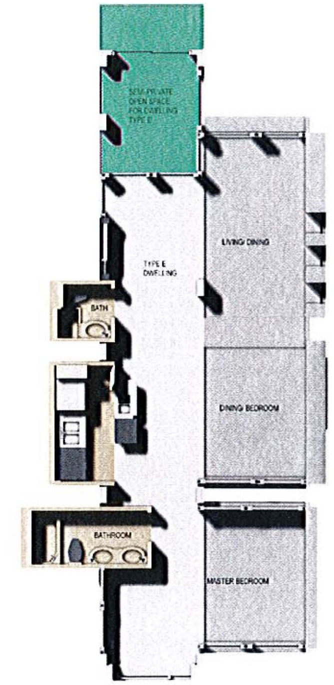
TYPE A DWELLING
- ONE STOREY
- 1 OR 2 BEDROOMS
- LOWER LEVEL, EAST WING



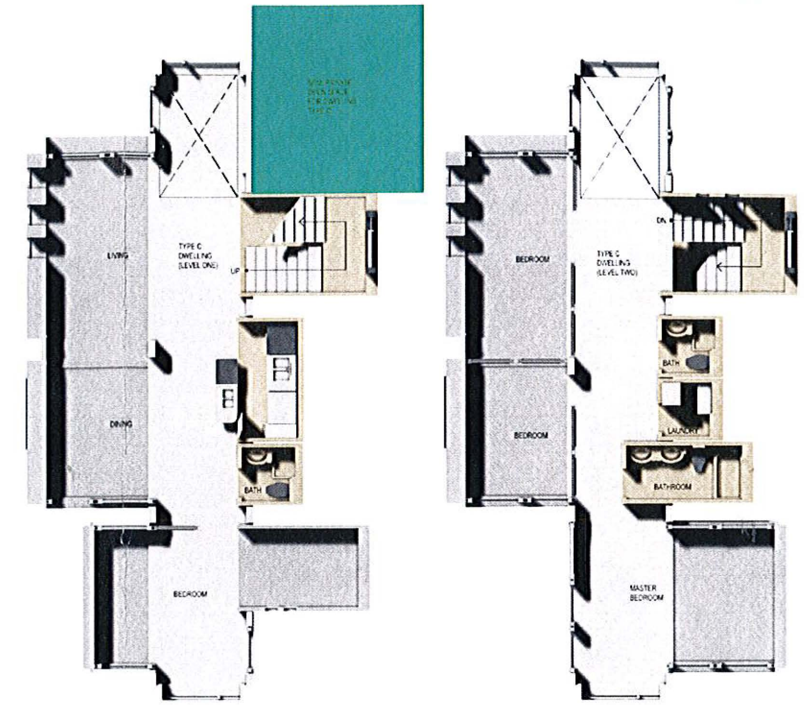
TYPE B DWELLING
- ONE STOREY
- 1 BEDROOM
- UPPER LEVEL, EAST WING



TYPE D DWELLING
- ONE STOREY
- 1 OR 2 BEDROOMS
- LOWER LEVEL, WEST WING

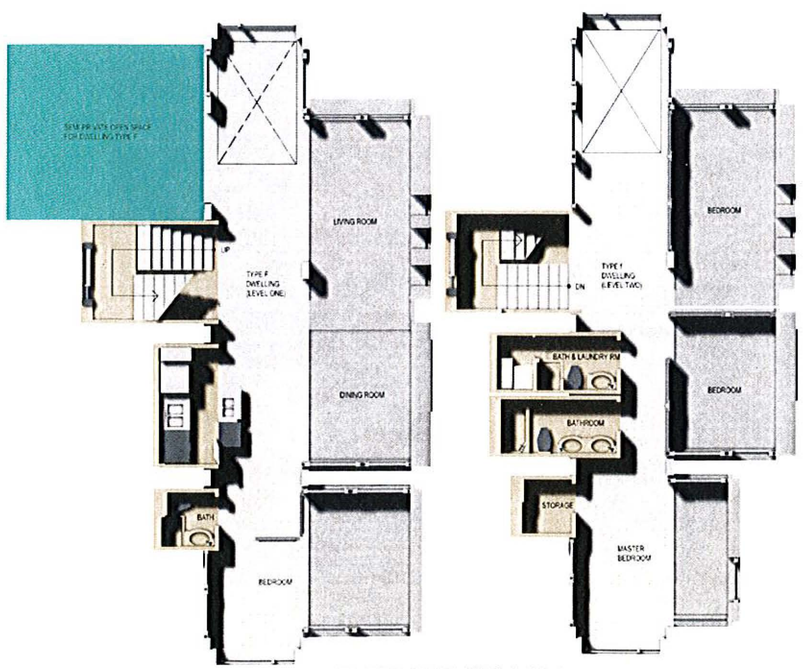


TYPE E DWELLING
- ONE STOREY
- 1 BEDROOM
- UPPER LEVEL, WEST WING



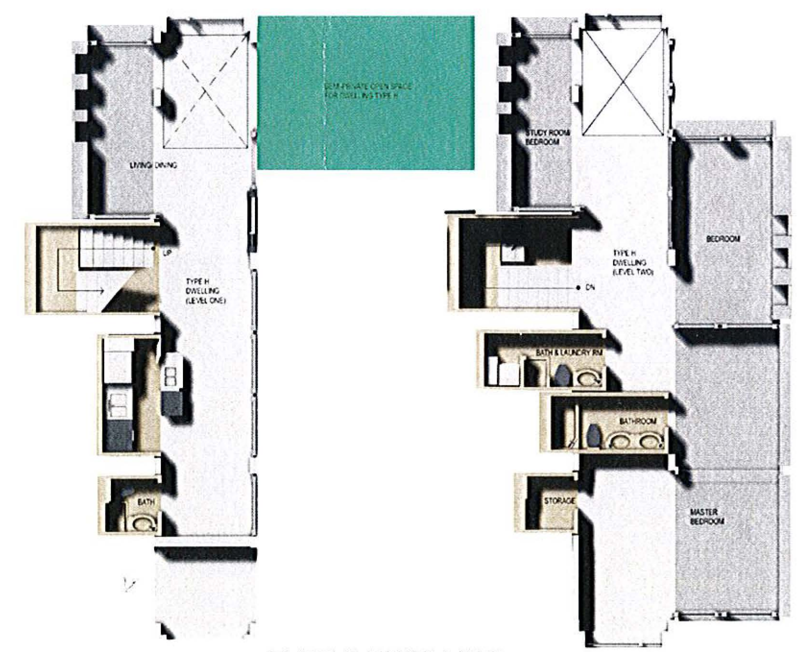
TYPE C DWELLING
- TWO STOREY, DUPLEX
- 3 OR 4 BEDROOMS
- EAST WING

Fig. 64. FLOOR PLANS OF THE 8 DIFFERENT DWELLING LAYOUTS



TYPE F DWELLING
- TWO STOREY, DUPLEX
- 3 OR 4 BEDROOMS
- WEST WING

TYPE G DWELLING
- TWO STOREY, DUPLEX
- 2 OR 3 BEDROOMS
- EAST WING



TYPE H DWELLING
- TWO STOREY, DUPLEX
- 3 OR 4 BEDROOMS
- WEST WING

Fig. 65. Floor plan of the lower level dwellings.

Fig. 66. Floor plan of the upper level dwellings.

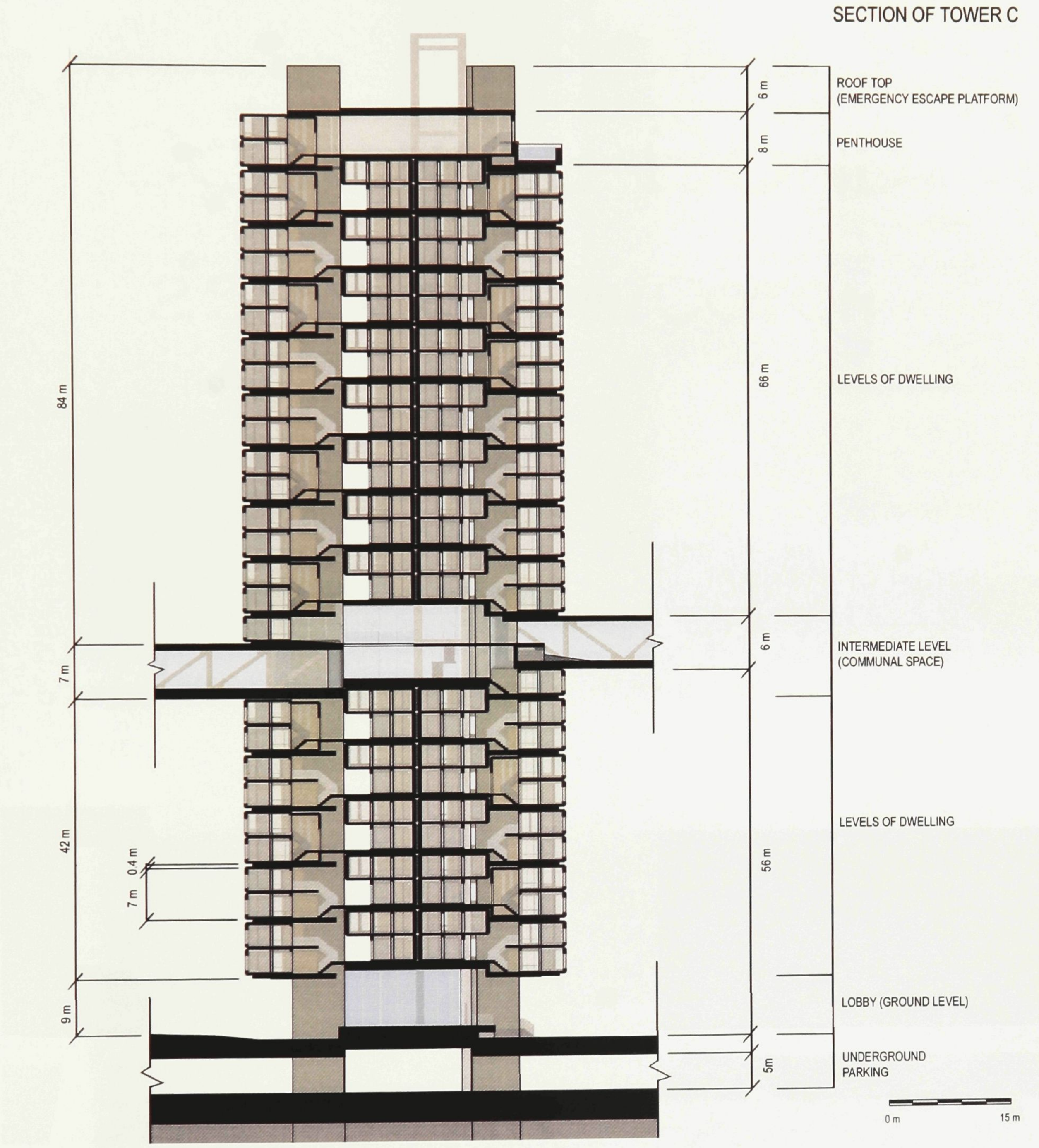


Fig. 67. Section of Tower C.

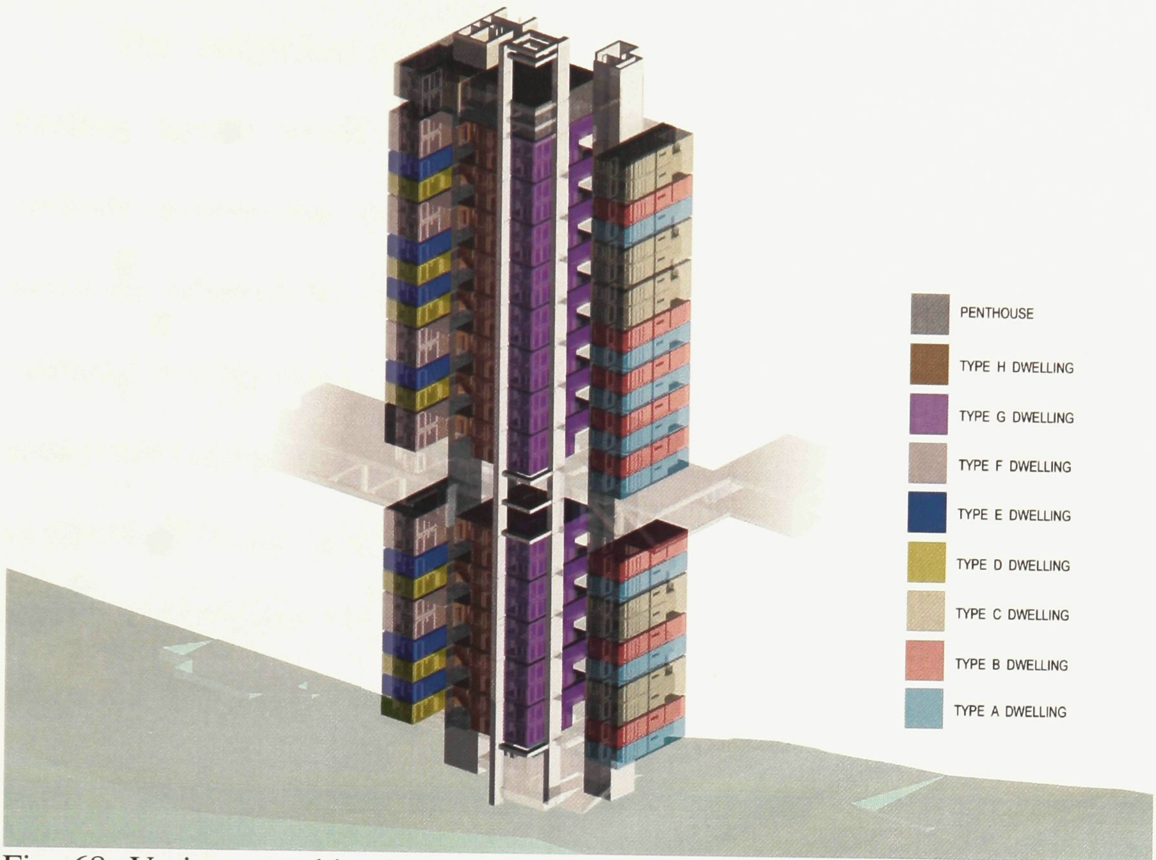


Fig. 68. Various combinations of dwelling types are permitted to accommodate mixed household compositions within the residence.

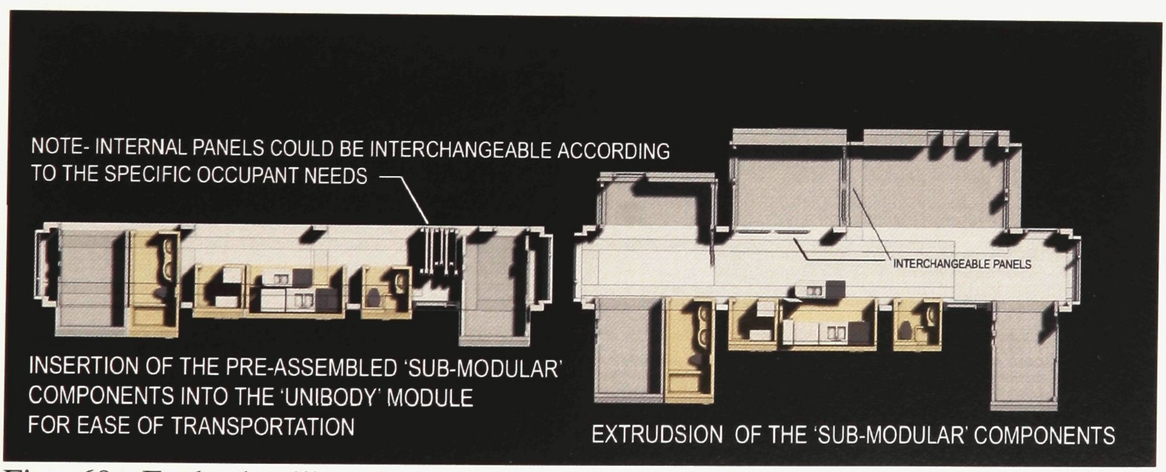


Fig. 69. Each dwelling is equipped with interchangeable partition panels to generate various spatial configurations.

7.3 'Unibody modular' assembly system

The integration of assembly-efficient construction with diversified dwelling layouts would be achieved by employing suites of prefabricated 'unibody' modules that could be adapted in numerous ways. Assembly-efficiency would be achieved by mass-producing an identical standardized prefabricated 'unibody' module with adaptable characteristics for a variety of dwelling layouts, and by minimizing the types and numbers of components that would be required to manufacture and assemble during the construction process. The goal is to realize an alternative prefabricated construction method that could bring mass production and mass customization together in a high-rise residential building design that would accommodate households from different social strata along with the complexity of its household needs in the Hong Kong building industry.

7.3.1 'Sub-modular' system

The 'unibody modular' assembly system involves an array of prefabricated 'sub-modular' components that can be mixed and matched, and attached onto a standardized 'unibody' module to form a variety of dwelling configurations to customize the preferences of potential buyers. Each of the 'unibody' module sides undergoes selected cuts, forming a series of openings for the extrusion of the 'sub-modular' components. This solution is quick and easy and also permits the choice for contractors and the potential buyers to plug-in the 'sub-modular' components that are base on varying household desires and needs (Fig. 70). Different arrangements of the 'sub-modular' components and design options of 'unibody' module would allow for easy modification of the dwelling characteristics. In general, there are four main types of prefabricated 'sub-modular' components that would be attached onto the 'unibody' module: the master bedroom component, the service component, the living/dining and bedroom component, and the component built with sliding panels for the semi-private space (Fig. 71).

Design efficiency is facilitated by pre-assembling the services components, such as the HVAC unit, kitchen appliances and bathroom fixtures as 'sub-modular' components, and inserting them into the 'unibody' module. These 'sub-modular' service units for each dwelling would be assembled as a finished module and housed in the spaces between the 'unibody' module and the elevator core structure. For an example, on-site installation normally required for the HVAC units and the ductwork after the dwelling is constructed would be greatly reduced, as the HVAC modular component would be pre-assembled within the 'unibody' module to enhance assembly-efficiency.

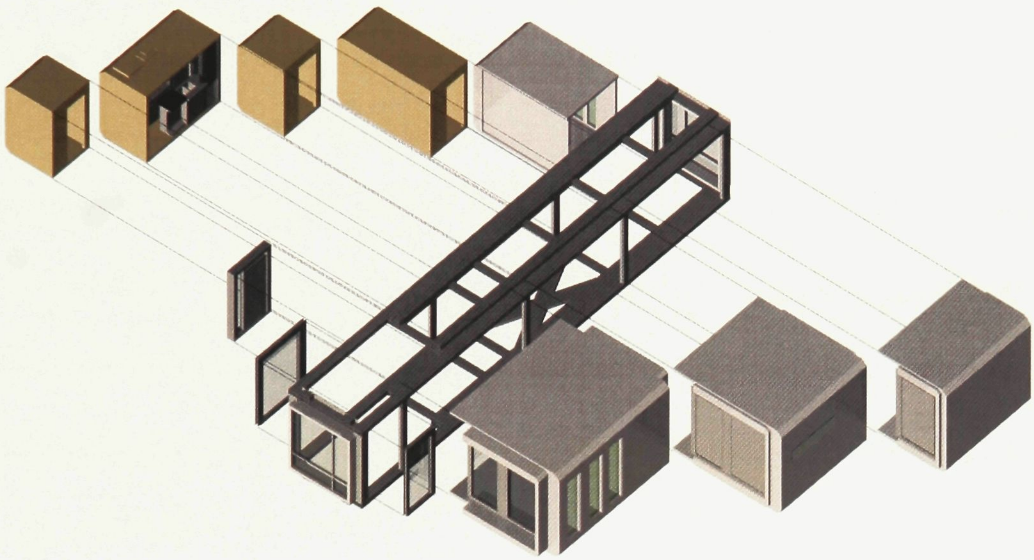


Fig. 70. Insertion of 'sub-modular' components onto the 'unibody' module frame of Type A dwelling.

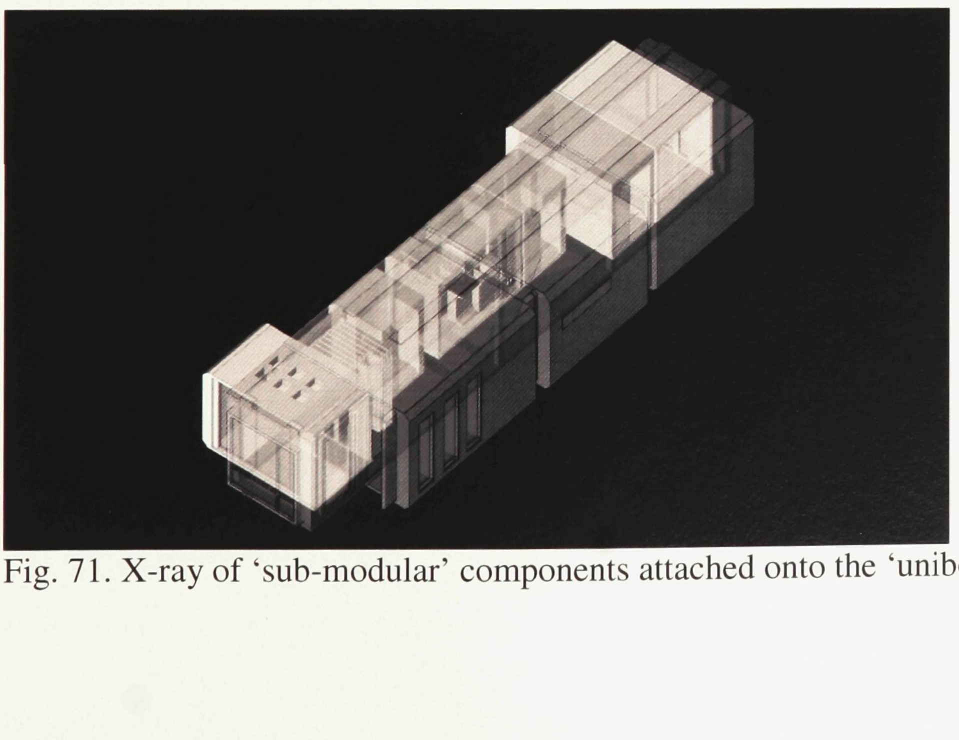


Fig. 71. X-ray of 'sub-modular' components attached onto the 'unibody' module.

7.3.2 System integration

The 'unibody' module, as described before, will be a prefabricated and pre-assembled structural steel frame that would be self-supporting and able to be joined and assembled adjacent to one another allowing the formation of a range of dwelling types in various dimensions. Because it is prefabricated, it needs to be transported from the factory to the final construction site. With that in mind, each 'unibody' module would be structurally designed to withstand the rigors of transportation. It would be made of welded steel members with predrilled holes and connections to which a variety of prefabricated components would be attached with screws and bolts. Structurally, the design of the proposed 'unibody' module integrates mechanical elements into the structure of the module itself, and uses the mechanical elements as part of the structure of the 'unibody' module. Each 'unibody' module would contain almost all the required mechanical elements such as ventilation ducts and electrical wiring that would be conventionally installed after the construction of the structure is completed. This would speed up the assembling process (Fig. 72 and 73).

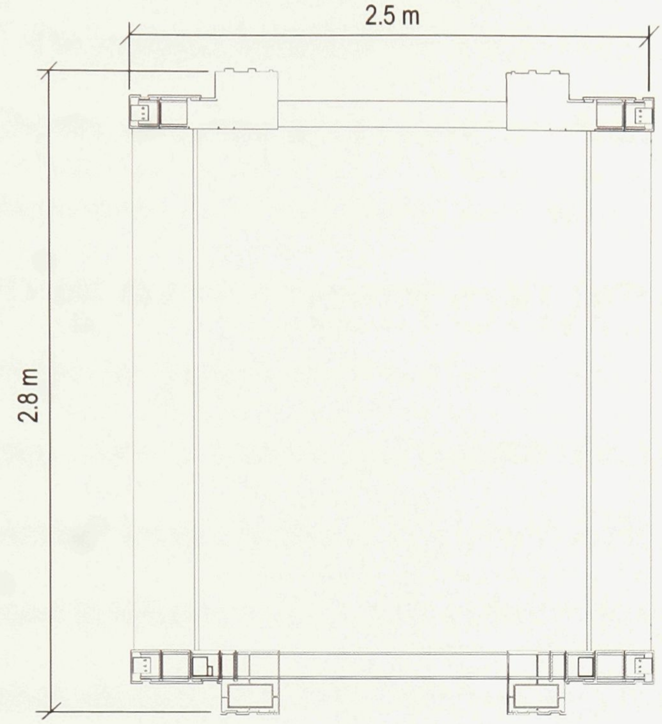


Fig. 72. Section of the ‘unibody’ module.

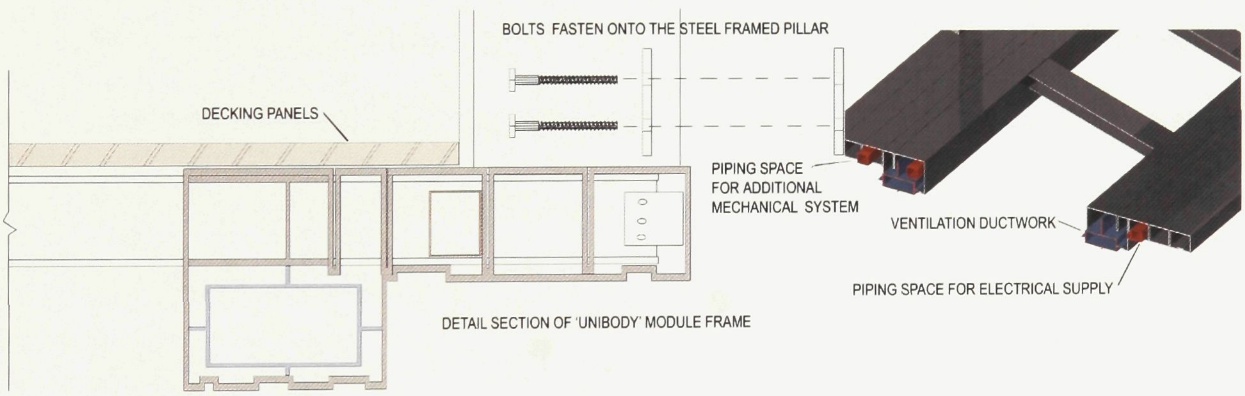


Fig. 73. Detail section of the ‘unibody’ module base.

7.3.3 Construction sequence

The structural system of the proposed high-rise residential buildings is to combine the advantages of steel framing for the central core with a modular building system. Steel framing would be applied for the entire structure of the central core and the construction of the 'unibody' module because steel is lightweight yet strong enough to serve as the main structural support for the building. This is reiterated by Frampton who suggests that today's building construction should transform from 'wet' techniques to 'dry' techniques, as described in Chapter Two.[87] The 'unibody modular' assembly building system eliminates the formworks required for reinforced concrete construction on site. The application of the 'unibody modular' system has considerable advantages over the more traditional reinforced concrete framework system: greater construction efficiency; less environmental impact to the surrounding site during the construction process as major work involves mainly bolting and welding the 'unibody' modules together; and, quality control is increased by prefabricating most components at the factory. In general, the construction process would have two phases: On-site construction of the central core and off-site fabrication of the 'unibody' modules. The main benefit of having off-site fabrication is the reduction of on-site construction time. The construction efficiency would be achieved by the overlapping of off-site and on-site activities.

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[87] Frampton, Kenneth. Studies in Tectonic Culture: The Poetics of Construction in Nineteen and Twentieth Century Architecture. Cambridge, London: MIT Press, 1995. P 1-12.

First, the on-site construction involves constructing the steel skeleton framework of the central core. Each central core consists of three components: three elevator shafts built-in with the energy-supply and plumbing systems; the passage platform; and two prefabricated emergency staircases. The core is structurally composed of three steel framed pillars and in turn the pillars are bolted with girders to rigidify the core (Fig. 74). On top of each core during the construction, a crane would be assembled. One of the elevator shafts would serve as a base for the crane to lift the building components to be built around the core. For speed of construction, the supporting structure of the passage platform would be composed of a series of joists which could be pre-assembled on the ground and then lifted into position. The method is based on the fact that it is easier to assemble the passage platform by bolting and welding at ground level, than at an elevated level. The design of the central core supporting structure derives from Buckminster Fuller's 4-D 'Dymaxion' structural system of distributing the load of the dwelling modules to a giant pillar.[88] Overall, the load of the 'unibody' modules directly distribute onto the structural pillars of the central core, per every dwelling level, via the built-in supporting edges of the 'unibody' module onto the central core (Fig. 75). Thus, the dwelling modules at the lower levels would not need to bear the weight of the modules above them, and the module components could be fabricated with standardized dimensions to simplify the prefab production process.

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[88] Gorman, Michael. J. Buckminster Fuller: Designing for Mobility. Ed. Luca Molinari. Milano: Skira, 2005. P 41.

The second phase of construction would be off-site fabrication where the 'unibody' modules are pre-assembled with 'sub-modular' components, such as the bedroom units, kitchen appliance, bathrooms fixtures, HVAC unit, and the required service elements. During the construction phase of erecting the central core, a series of assembled and prefabricated components, the 'unibody' modules, and the emergency staircases would be trucked to the site. Once on the site, the selected types of prefabricated 'sub-modular' components for specific dwelling layouts can be re-configured and re-inserted into the 'unibody' module, like a drawer, then be lifted by crane and positioned onto the supporting edge of the central core. The inserted 'sub-modular' components are conceptualized as a sort of add-on appliance and spatial extension. The flexibility of the buyer to interchange these 'sub-modular' components as he wishes is permitted before the 'unibody' module is positioned in its final destination. The developer can configure a wide range of dwelling types by interchanging a series of 'sub-modular' components to accommodate each customer's choices.

The 'unibody' module is thus regarded, first, as an absolute solid. In the displacement or shipping phase, it is assembled as an enclosed mass of packed module. After the 'unibody' modules at the lower level are positioned, the modules for the next level would be immediately positioned on top and would be bolted in place onto the central core structure and the adjacent 'unibody' modules. The construction sequence of lifting the 'unibody' modules onto the final position would be the same for every floor level. Each of the 'sub-modular' components will be enclosed and compacted within the 'unibody' module until after it is shipped to the lifting position for the crane to assembled onto the central structural core. Before the 'unibody' module is assembled in its final position, the 'unibody' module turns inside out by extruding out the 'sub-modular' components, sliding out, like drawers, thus freeing up the entire internal space of an 'unibody' module, and afterwards offering its smooth surface to the interior (Fig. 69). The occupant is thus surrounded by this active inner façade, opening on to all the programmed 'sub-modular' components. The 'unibody' modules would be pre-assembled with the cellular decking panels that form an even floor surface after the extrusion of the 'sub-modular' components. The need for construction of the conventional floor finishing would be eliminated, therefore, less labour required to complete the work, and faster completion. The intention is to form the 'unibody' modules as complete components, thus the labour required to construct on site would be reduced.

Based on the structural nature of the 'unibody' modules, as described before, the modules are designed to withstand the rigors of transportation. The stiffness of the modules would further be utilized as part of the building structure by bolting the 'unibody' modules to both the above, below and the adjacent modules that are connected to the adjacent central core. The concept uses the stiffness of the 'unibody' modules that are bolted directly onto the central core structure and joined to adjacent modules to rigidify the structure of the entire building. The overall construction sequence of building the central core structural system along with the application of the 'unibody modular' assembly system produces economies of scale from prefabricated construction while allowing for design flexibility. The proposed project is an example of uniting the advantages of a central core supporting structural system with the assembly-efficiency of modular construction (Fig. 76).

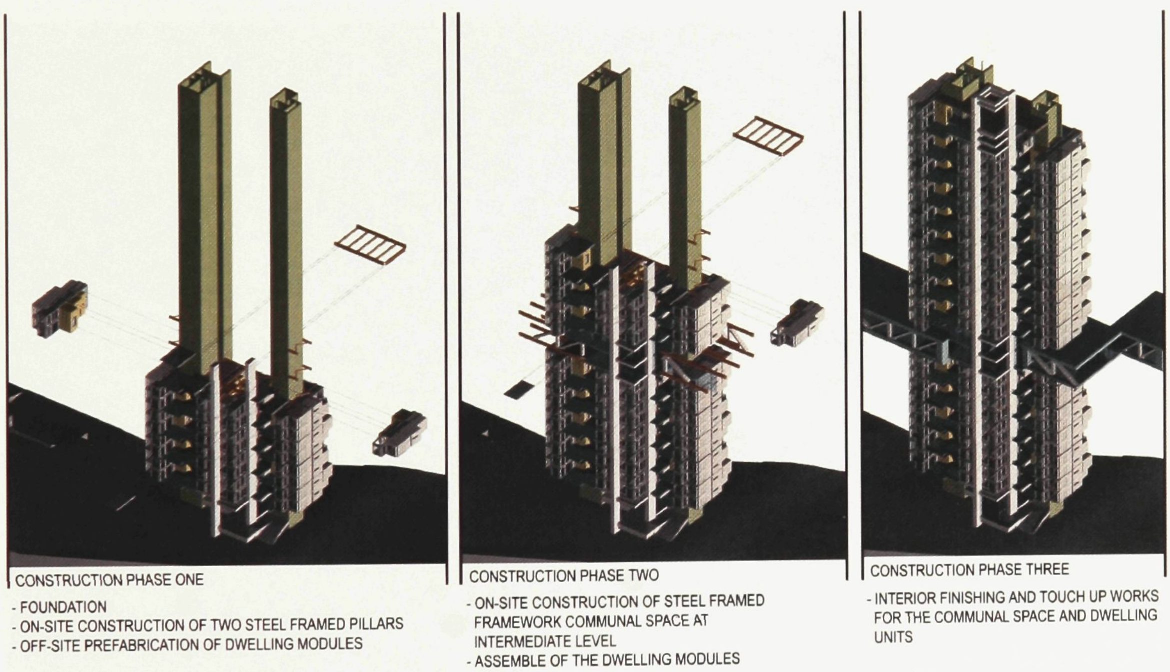

Fig. 74. Construction sequence of Tower C.

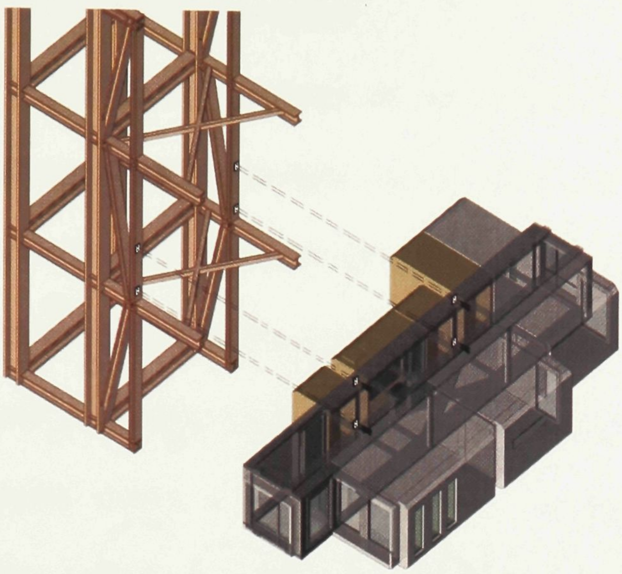

Fig. 75. 'Unibody' module bolted onto the central core.

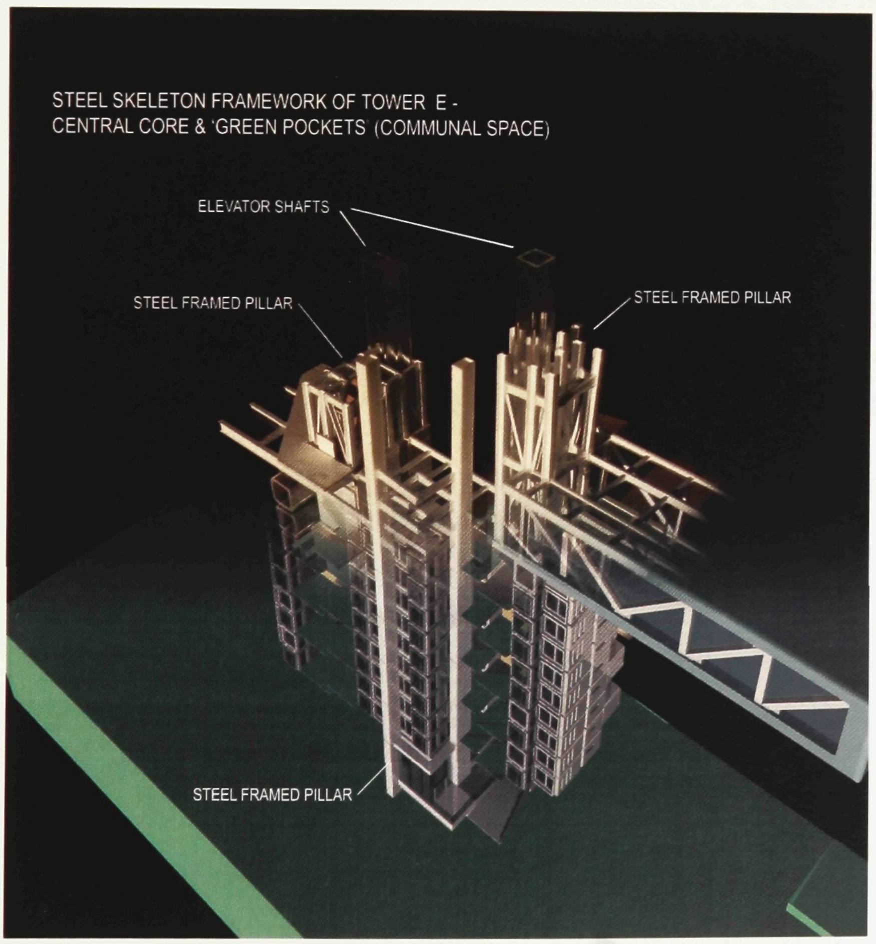

Fig. 76. The structural layout is formed with three giant pillars that are jointed with girders for every two storeys.

7.4 Semi-private open space

Studies and analyses of residential designs and trends in Hong Kong reveal that dwelling designs should have more open-green spaces and should create an interactive neighbourhood for residents. In that respect, it is insufficient for recent residential buildings in Hong Kong to have the open-green space and grouped communal facilities only at the podium, for such a large population of occupants within a single residential compound. The proposed residential complex intends to integrate green-spaces into the design by relocating open spaces into the vertical built form (Fig. 77). Each dwelling unit would be assigned an open space to enhance a sense of ownership so that households would have the freedom to interpret it either as a semi-private adaptable open space, an extension of the living/dining area, or an additional bedroom space for the dwelling. The semi-private spaces can be modified after the completion of building by repositioning the interchangeable partition panels. Such multi-purposes of the semi-private space would enable the households to combine and coordinate their activities (Fig. 78).

Typical strategies are used to enhance spatial arrangements of the compartmentalized corridor space. These design strategies included avoiding the enclosed long corridors design plan, combining circulation zones with the assigned semi-private open space, positioning each dwelling to have opposite views of the surrounding, and inserting window openings to visually enlarge the passage platform (Fig. 79). The assigned semi-private open space would be an engaging outdoor area facing south with the scenic views of the WKR development and the Victoria Harbour. All of the semi-private open spaces are positioned and angled to maximize solar exposure during all seasons. The semi-private open spaces of each dwelling would be visually grouped together to form a series of interactive balconies at various levels of the building (Fig 80). The principle of visual connection between the assigned semi-private spaces is captured in the physical form, bonding the householders with a greater degree of interactive relationships, and thereby constituting the whole neighbourhood as a small community. The idea is to extend interactions between households from the overall community to the 'neighbourhood' level. Instead of walking through conventionally long and enclosed corridors, the grouped semi-private open spaces would be connected to the buildings' elevator core circulation systems. These semi-private open spaces would become a 'fabric' of the enclosed passage platforms. The passage platform of the central core would connect the opposite ends (east wing and west wing) of the dwellings every two storeys (vertically apart) to reduce the number of platforms required for segregation of the dwellings. Additional half-deck flight staircases are used to allow accessibility from each passage platform to the above and lower level of dwellings. The intention is to group a series of dwellings together by sharing a single passage platform while permitting all the dwelling units to capture the views of the north-south directions (the Victoria Harbour to the south and the Yau Ma Tei waterfront connection with the assigned south-orientated semi-private open spaces. To break up the internal space perimeter, 'sub-modular' components facing the semi-private open space would be built with a tracking system that would permit interchangeable panels to slide. The idea of releasing the barriers between internal and semi-private open spaces holds the promise of creating interactive living environments between neighbours, while maintaining appropriate levels of privacy, and the aesthetically pleasing living conditions that are commonly neglected in high-rise built forms.

Fig. 77. The proposed residential complex is integrated with green-spaces situated in the vertical built form.

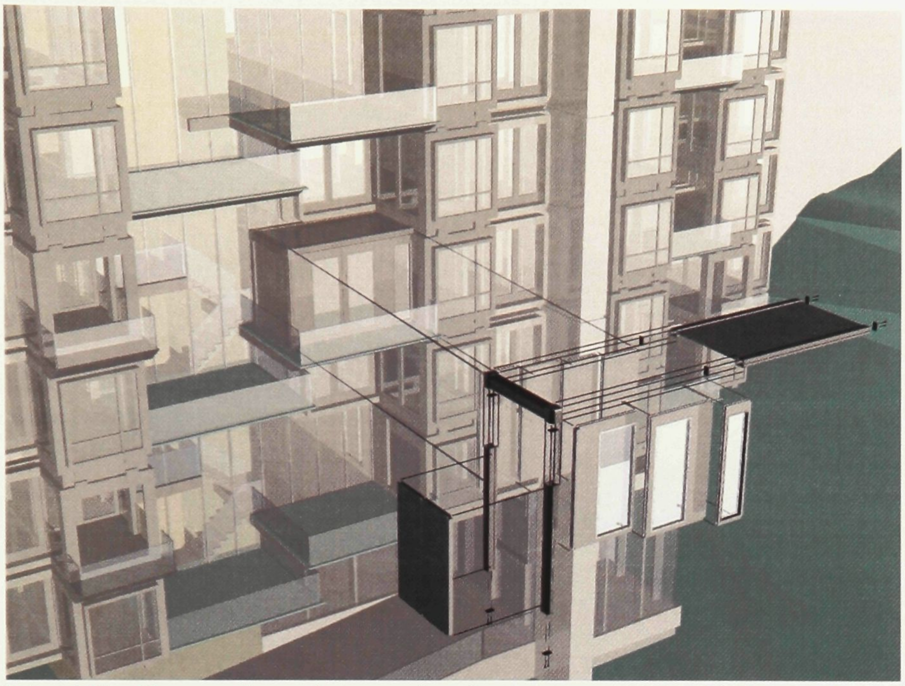

Fig. 78. Converting the semi-private open space into enclosed internal dwelling space.

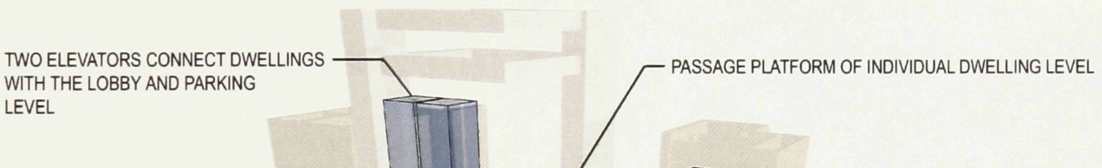

Fig. 79. Configuration of semi-private open space with the overall circulation layout.

Fig. 80. Semi-private open spaces are visually grouped together to form a series of interactive balconies at various levels of the building.

7.5 Site Strategy- 'Green Pocket' communal spaces

The project attempts to explore the possibilities of high-rise living and to examine the future of Hong Kong's residential development. The term 'high-rise' has been used quite often to describe the current urban conditions, a city defined by the close proximity of built forms and tightly knit infrastructure networks. Successive, piecemeal planning of recent residential podium design schemes has resulted in fragmented developments that are poorly integrated. In most recent residential developments, it is the chunks of landscape space that receive the developers' attention in order to permit their podium design scheme, while the narrow spaces (linear strips) are overlooked, under appreciated, and marginalized. Current residential development approaches of the podium design scheme can no longer sustain this type of urban development for the narrow-shaped site. In addition, the ever-increasing complexity to the modes of living and demand for more open-space inevitably leads to a necessary reconsideration of current residential planning approaches and construction methods. This project seizes the opportunity to exploit previously ignored linear spaces in an attempt to redefine the potential of new urban forms for the Yau Ma Tei area.

The orientation and profile of the proposed residential complex are derived from the site, in particular from its linear nature and to integrate with the surrounding built environment. In detail, the orientation of dwelling layouts takes advantage of the unique qualities of the surrounding area by allowing each dwelling to have the views of Victoria Harbour, the Yau Ma Tei's waterfront area, and the assigned semi-private open space (Fig. 81). In response to the noise and lighting issues generated by the highly populated WKR tourist district, the dwellings would be designed with bedrooms facing north in an opposite direction away from the adjacent WKR development (Fig. 82).

Because of the linearity characteristic of the site, the priority is to devise a way to facilitate open green spaces that work at the neighbourhood scale. Dynamic clusters of towers that are connected via multi-layer 'green pockets' are conceived as communal spaces that will foster community interaction. The linearity of the site setting, circulation, and demanding needs for more open greenery atmosphere are the key generators of the multi-layered 'green pockets' design scheme. The characteristics of the proposed site with the adjacent WKR development become major design elements for guiding the overall design plan of the 'green pocket' communal spaces, lending specific distinction to the design (Fig. 77 and 80). Studies of current residential developments in Hong Kong reveal that the residents are normally confined by dwellings that are orientated to face each other and offer the residents little green open space. How to break those confinements are the concerns of this location. The intention of the 'green pockets' design scheme is to avoid repeating Hong Kong's dominant tendency to provide tall residential towers that are built on top of a podium.

One of the significant aims of the proposed high-rise residential building is to accommodate the growing tourism in the (WKR) development, and to recognize the characteristics of nearby canopies and the surrounding green landscaping environment. For that reason, the proposed high-rise residential building blends in with its environment by designing its two horizontal planes of interactive zones: the ground level and the intermediate level (Fig. 67 and 83). The first dwelling level of the proposed residential building would be elevated to create an open space at the ground level and it also produces a continuous landscape from the street level, encouraging pedestrian movement. The ground level open space would comprise the access to the main lobby of each tower and a landscaped ground plane as an extensive public park to be enjoyed by tourists and occupants. This organic relationship between public and private contrasts with many of the current residential developments in Hong Kong. The openness of the ground level produces a translucent view between the tourist district of the WKR development and the northern tip of Yau Ma Tei area. Further, the elevation of the first dwelling level three storeys above ground enhances the privacy of the dwellings in the first level. The residential complex would be entered from the Austin Rd. to the car parking at level one. Residents then walk to one level above (a continuous vehicle-free landscaped platform) that is defined by a landscaped open space. The parking areas would be embedded under the landscaped garden and the main lobby, and would connect to elevator cores that travel up to the dwelling levels (Fig. 61).

A series of 'green pocket' platforms that separate the upper and lower portion of the building would create communal spaces used for a variety of events, a swimming pool, an indoor gym, a lounge and a children's playground (Fig. 84 & 85). These 'green pockets' would serve as communal spaces overflowing with plants and small trees, circulated by walkways, and surrounded by benches facing scenic views, a platform for inhabitants to enjoy the panoramic views of Victoria Harbour and surrounding views. The design is a celebration of outdoor leisure and ties the proposed residential complex with the WKR developmental theme of 'Park in the Sky'. In addition, it is an attempt to create a highly interactive communal open spaces, as well as enclose spaces; that is, to positioning a series of 'green pockets' communal spaces at an intermediate level creating additional habitable spaces for inhabitants to interact beyond their own dwellings. The term 'intermediate' describes how these 'green pocket' interactive communal spaces become the key design feature to correspond with the adjacent WKR development. The positioning of these communal facilities at the intermediate level minimizes the walking distance between dwellings and these 'green pockets'. The communal facilities would be approximately 12-15 storeys high to avoid positioning dwellings at the height where the structure of the nearby canopies of the WKR development would block the view of Victoria Harbour (Fig. 82). These 'green pocket' spaces not only feature the communal facilities, they also provide a grand sense of access to nature, and promote the importance of pleasurable green spaces as a catalyst to improve the interaction between inhabitants both visually and physically. These 'green pockets' would be conceived as an urban park and an extension of the green open space at street level, together forming a lushly planted multilevel landscape that creates an intimate, neighbourhood-scaled encounter with a single communal open space situated on top of a podium. It is a device to initiate interaction at the community level along with all the facilities that are necessary to support the residents' needs. Seen from the façade of the complex, the 'green pockets' communal spaces along with the semi-private open spaces would form a series of green decorations on the building envelope which creates a visual excitement and adds an architectural expression that ties the complex with the WKR theme of green landscaped architecture.

The positioning of the ground level open space and the communal facilities with gardens (green pockets) at the intermediate level resembles the design features of Unité d'Habitation de Marseilles that promote an interactive living environment at both the community and neighbourhood level for its occupants and the public. Overall, the multi-layered landscaping strategy forms the backbone to enhance the interaction both at the community and neighbourhood level, creating an experiential journey for its inhabitants through a sequence of green communal spaces (Fig. 86). The orientation of the proposed residential towers with its 'green pockets' is designed to embrace its neighbours, the exterior completing a composition with the adjacent WKR development, residential towers and office buildings. The goal is to propose a new typology of urban form, essentially consisting of interconnected communal spaces (green pockets) that can reinvent spatial conditions in the city (Fig. 87, 88, and 89).

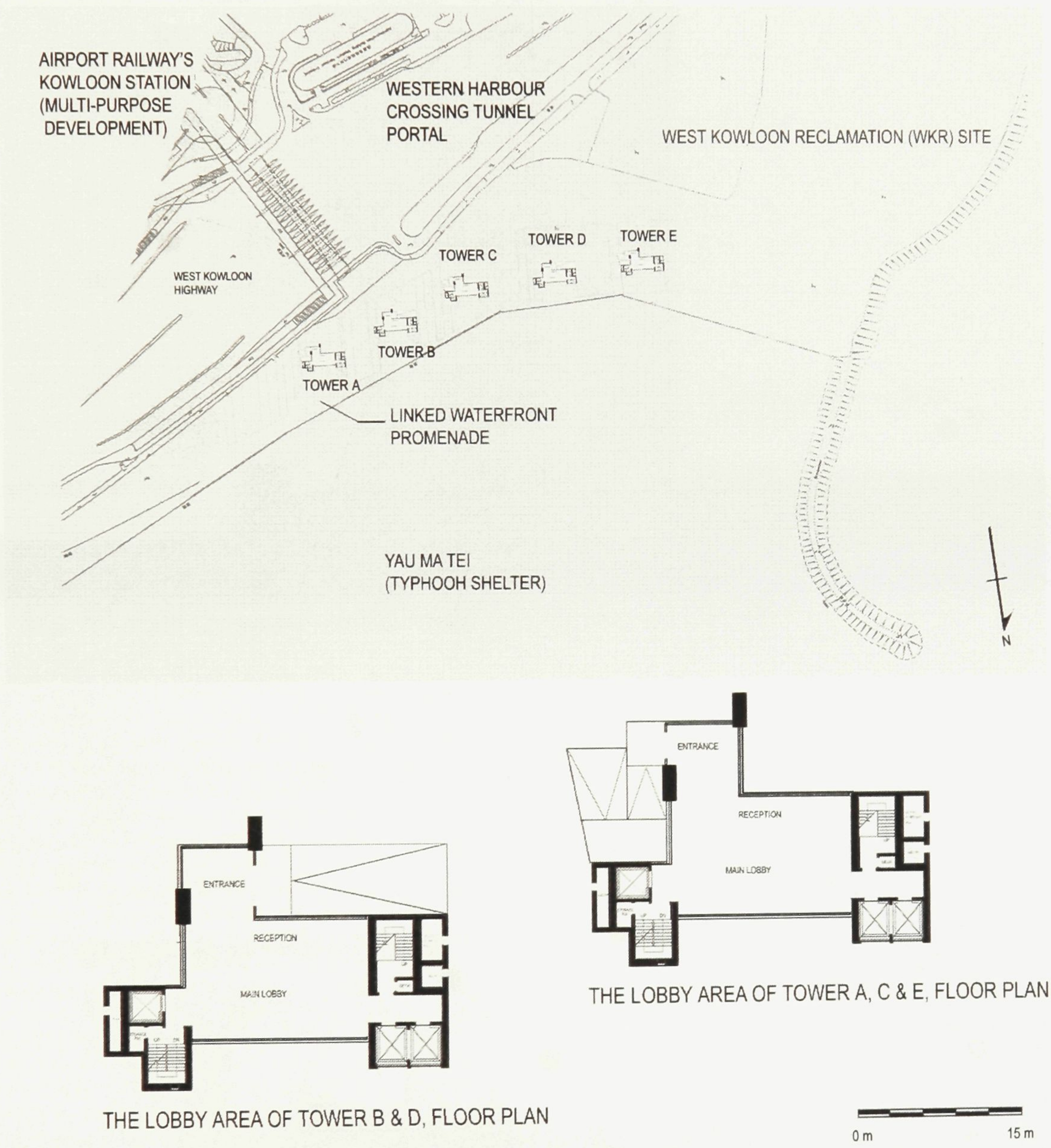

Fig. 81. Ground floor plan.

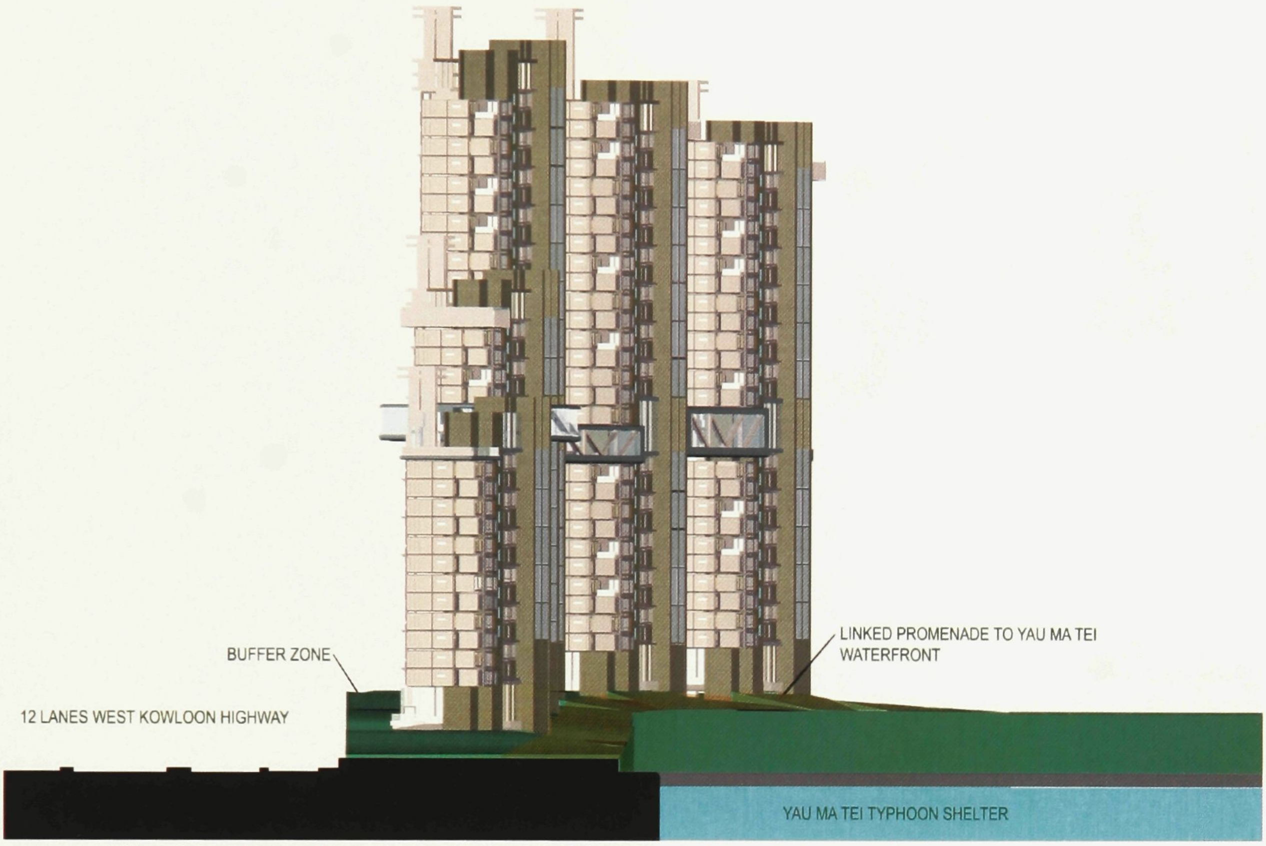

Fig. 82. East elevation of the proposed residential complex.

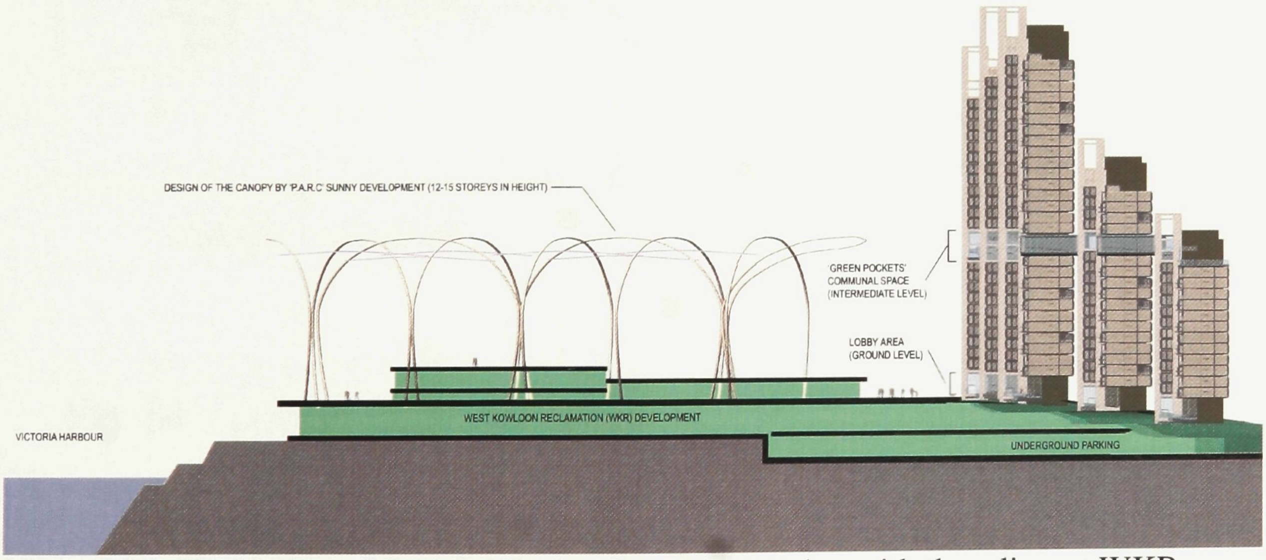

Fig. 83. Section of the proposed residential complex with the adjacent WKR development.

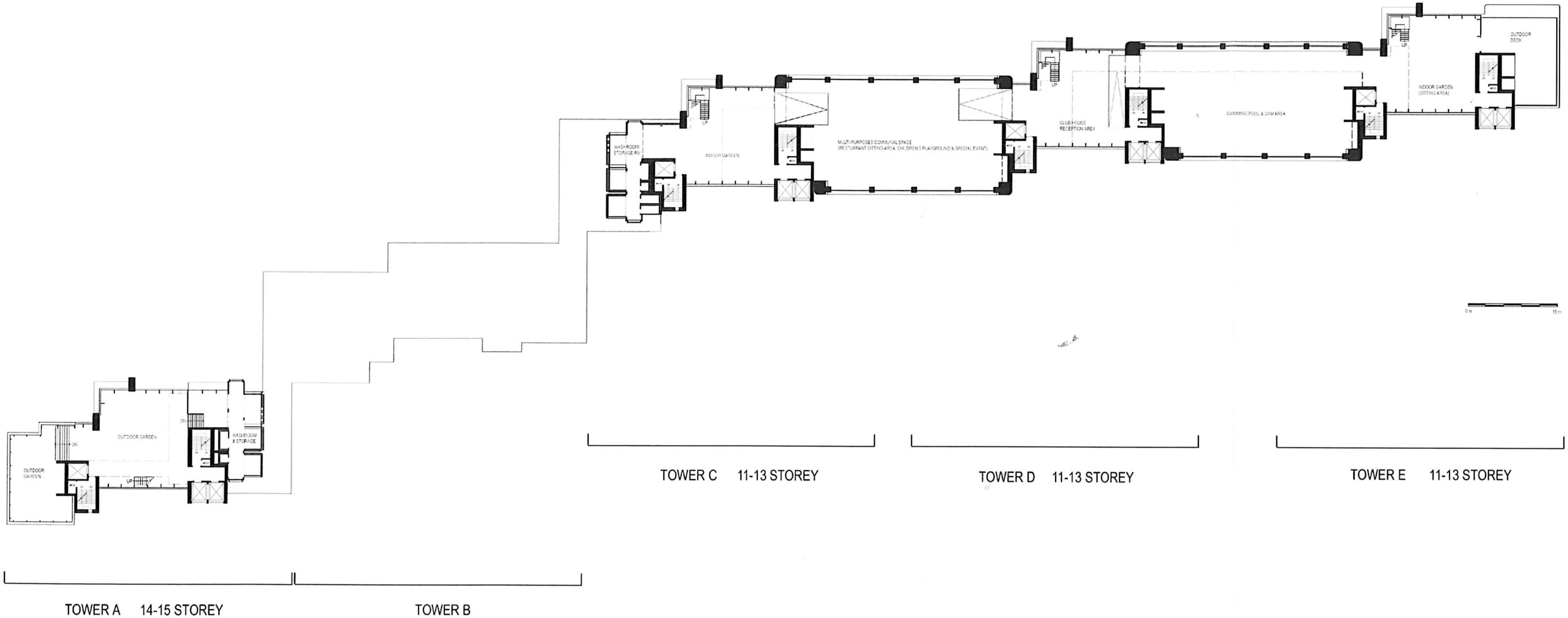

Fig. 84. LOWER LEVEL OF THE 'GREEN POCKETS' COMMUNAL SPACES, FLOOR PLAN.

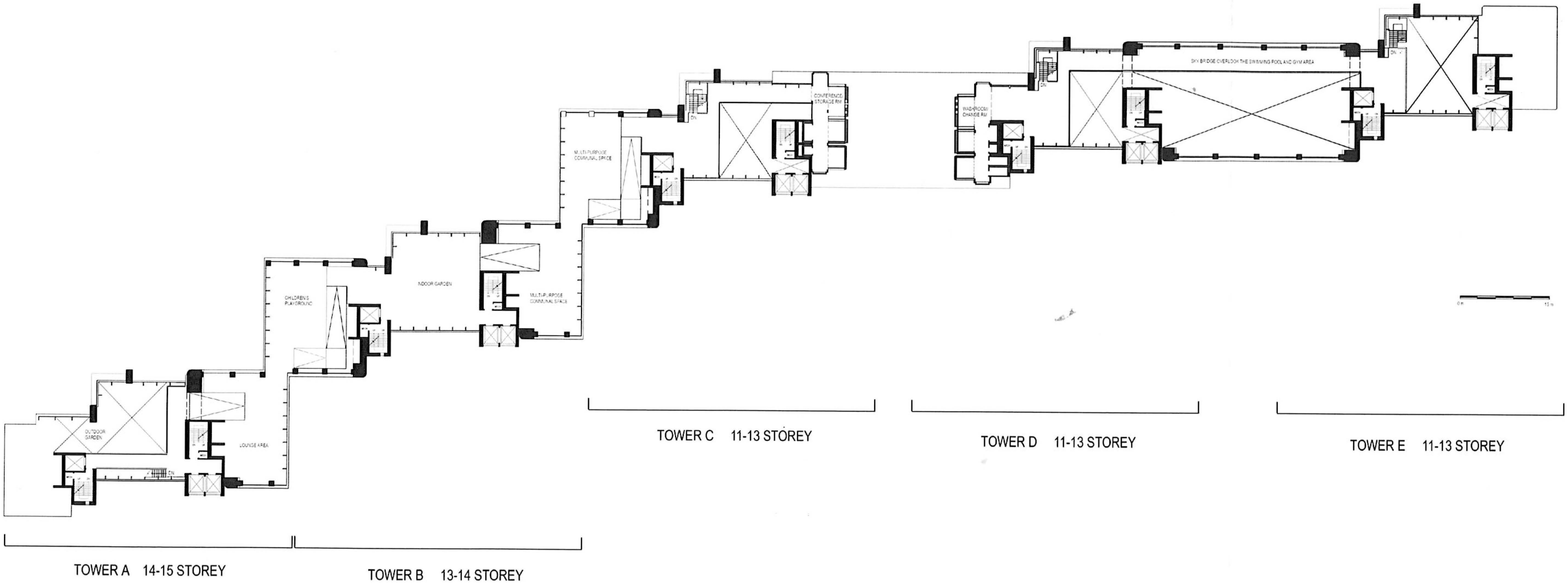

Fig. 85 UPPER LEVEL OF THE 'GREEN POCKETS' COMMUNAL SPACE, FLOOR PLAN.

Fig. 86. Perspective of the communal space at intermediate level of Tower D.

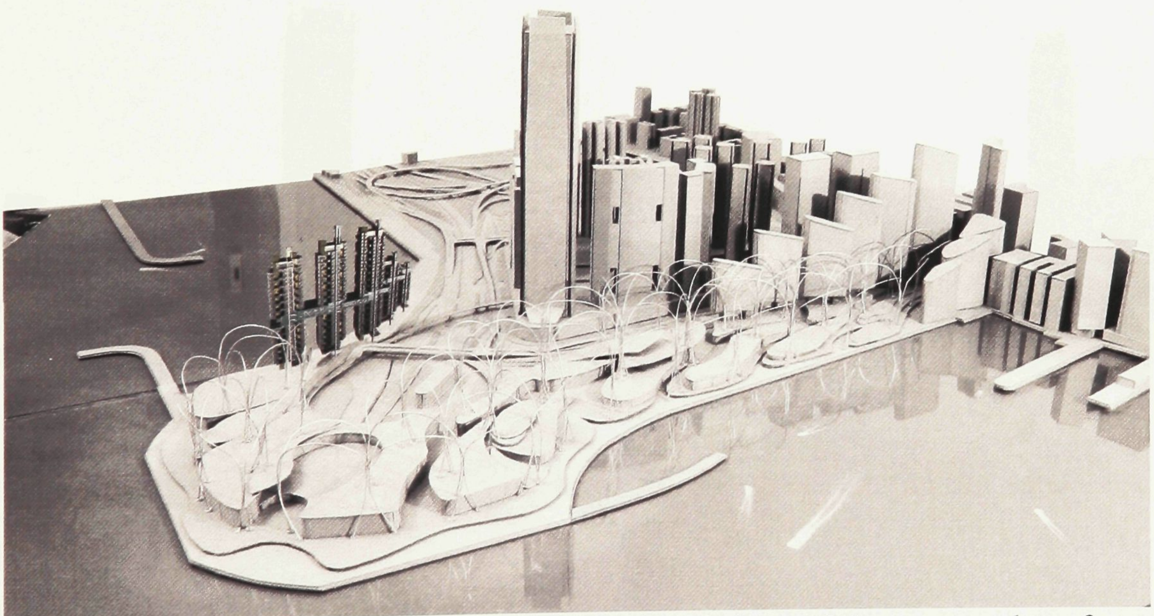

Fig. 87. Ariel view of the proposed residential complex and the master plan of 'P.A.R.C' WKR development.

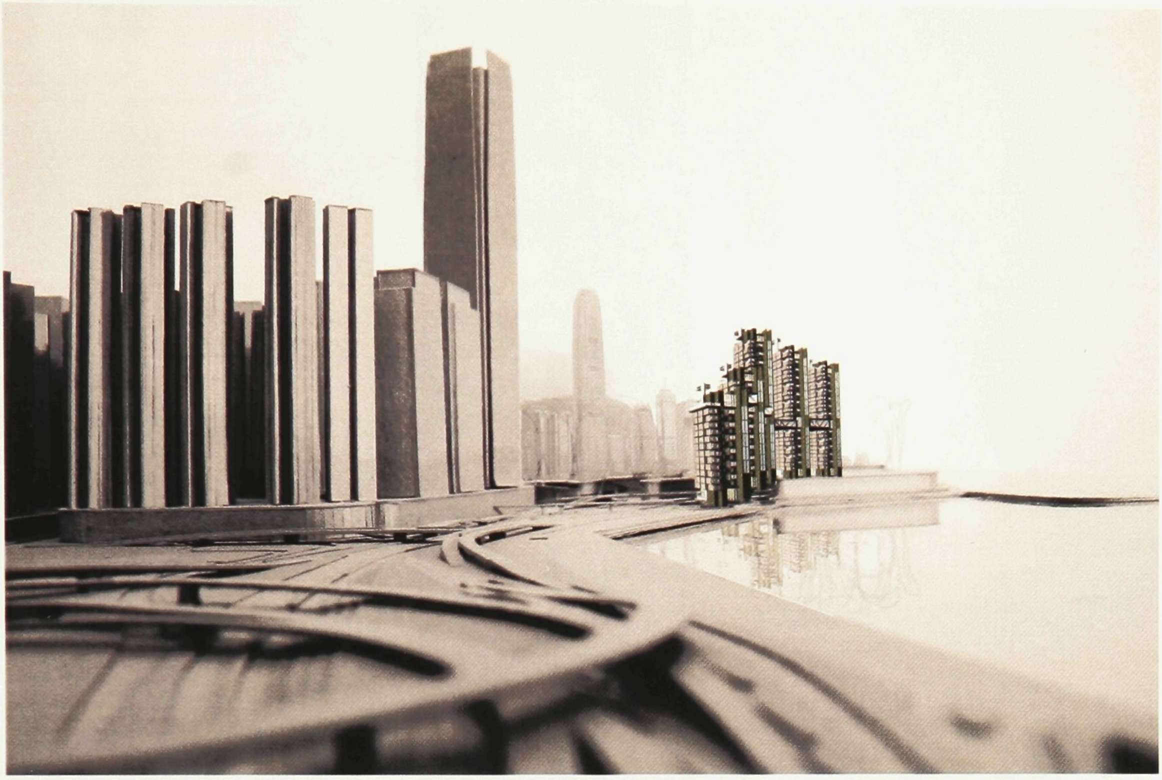

Fig. 88. Perspective of the proposed residential complex with West Kowloon Highway, Airport Railway's Kowloon Station development, and the background of Victoria Harbour.

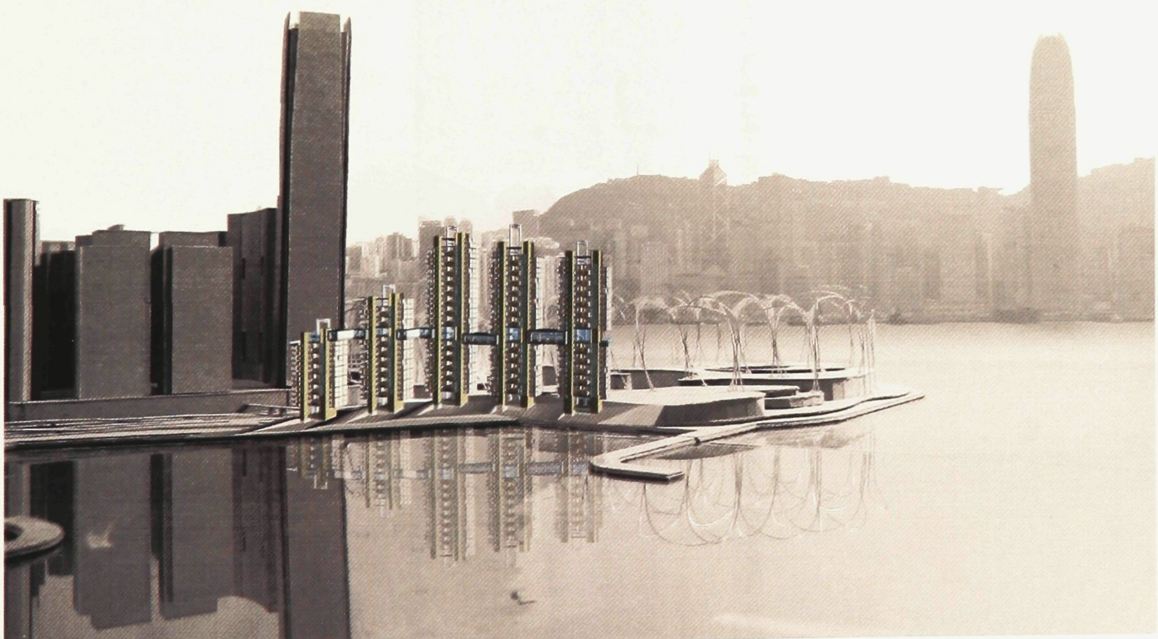

Fig. 89. Perspective of the proposed residential complex viewing from Yau Ma Tei sea.

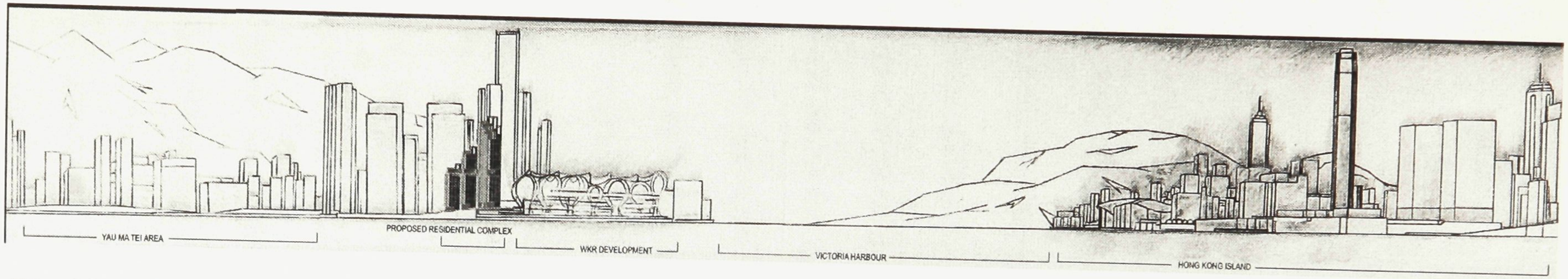

Fig. 90. A sketch showing significant landmarks of the proposed site.

Chapter Eight

Conclusion

The City of Hong Kong has transformed itself into a highly commercialized high-rise living environment comprised of a uniform residential design approach with homogenous spatial arrangement that does not respond to diverse household compositions and individual preferences. The high-rise buildings are however equipped with 'fanciful' decorations and presented in the form of theme parks. In line with the theme park housing approach, recent residential developments have been guided by a simple formula of fashioning dwellings with collective themes of fantasy that do not satisfy individual preferences in housing. The local residential developers believe that by selling their dwellings with artsy and highly decorative facilities, they can impress their potential buyers enough to guarantee profitable returns on their investments in the competitive housing market.[89] Studies have shown that the satisfaction of occupants with their homes has little connection with the fanciful residential atmospheres created by developers.[90] Offering such a fanciful design for housing would work only if the majority of households had common residential habits and the general prospects for wealth were universally shared. However, it is undeniable that perceptions of 'home' are frequently subjected to changes in the way people live and organize their household units, in the way they work and

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[89] Laurent Gutierrez., Ezio Manzini, and Valerie Portefaix, eds. HK LAB. Hong Kong: Map Book, 2002. P 224-226.
[90] Ibid. P 320-321.

enjoy their leisure time, grow and interact with family members, and in the way they choose lifestyles. These unpredictable variables in human behaviour cannot be satisfied with a single design formula for housing.

The culture of mass production and standardization in Hong Kong's residential developments means that architecture is often demoted to providing a common shelter that's duplicated for everyone. The issues confronting architects and housing developers in Hong Kong include the provision of adequate and acceptable quality of living conditions, and the provision of efficient construction of prefabricated high-rise residential building with diverse spatial layouts. The drive to have an assembly-efficient building method that incorporates the diverse housing preferences of occupants into dwelling design is evident. It is imperative for developers in Hong Kong to find a building construction system that can replace the homogeneous dwelling layouts in an assembly-efficient manner. For that reason, perceptions of an ideal dwelling have to be reformulated. Dwelling units in high-rise residential buildings should be designed to suit individual householder needs wherein diverse compositions can be accommodated within the same residential development without any social and physical separation. It is not practical for designers to propose a universal dwelling design that would be suitable for the whole spectrum of household compositions and individual preferences. However, an optimal situation would involve homeowners' participation at the design stage responding to their needs and desires. The perception of adaptable prefabricated dwelling construction is an architectural interpretation in search of a more pleasurable living environment. As illustrated by the precedents, one of the benefits of adaptable prefabrication over fixed-designs, is that individual choices can be realized by allowing for diverse spatial design possibilities. The architects of these precedents have explored the possibilities of technologies currently available as well as those yet to be discovered, while attempting to address the complexity of living expectations from diverse households. Their pioneering work and concepts are worth examining. Indeed, adaptable prefabricated construction is an assembly-efficient solution for obtaining diverse spatial configurations in response to the growing complexity of the hyper-dense environment and diverse household compositions in Hong Kong.

In summary, the analysis of the current housing situation in Hong Kong considers the demographic and economic factors. These factors are related to the need to accommodate a wide range of household compositions within a compound and the need to ameliorate the current compartmentalized living conditions. The optimal approach would be the application of advanced adaptable prefabrication methods in the construction of high-rise buildings. The proposed high-rise residential complex will have distinct features such as diverse spatial layouts, semi-private adaptable open spaces, and grouped contiguous units that would foster interactivity and allow for harmonious living environments between households. It is an attempt to depart from the monotonous high-rise built forms in Hong Kong. The unique stratified appearance of the building complex would be determined by diverse dwelling layouts and various façade treatments. In turn, the diverse dwelling layouts would be carefully designed according to household preferences, and adapted by the design flexibility of the 'unibody' module which has the advantages of maximum assembly-efficiency and spatial diversity. The challenge with this approach would be at the execution and implementation stages where the assembly-efficient building construction methods and the choice-based homeowner participation process would be synchronized to define the particular high-rise living conditions. The assembly-efficiency of the 'unibody modular' system would represent a feasible future prospect for residential design that would be efficient in construction and would permit diverse spatial configurations. In addition, the building envelope is designed to be site-orientated, and the design of the 'green pockets' communal space and the semi-private spaces assigned for individual dwelling is to foster a harmonious interactive living environment. This project has confronted issues of community, and has attempted to enhance the interaction between households at neighbourhood and community levels in a complicated urbanized condition.

All 'unibody' modules and the required 'sub-modular' components would be fabricated and assembled at the factory, allowing the dwelling design to respond directly to owner specifications. In order to maximize assembly-efficiency, dwellings assemblies are designed to utilize as many prefabricated modular components as possible, and to minimize the number of components involved in the on site construction. Thus, efficiency would result from less on-site labour and simple on-site assembly of the fully-fitted prefabricated 'unibody' modules. The year–round indoor factory production of prefabricating most of the building components would result in a constant production rate, a high-quality control of the modules, as well as the reduction of construction waste on site. From the design of the overall built form to the integration of assembly-efficiency with diverse dwelling layouts, the proposed high-rise residential complex is designed to accommodate diverse household compositions, to provide harmonious interactive living conditions, and to integrate into the surrounding environment – it would be a redefinition for more satisfying, habitable high-rise living conditions.

This thesis has discussed the usefulness of the assembly-efficient construction method of the conceptual 'unibody modular' system, the design flexibility of dwelling layouts, the choice-based homeowner participation, and the provision of interactive living environments. The combination of all these attributes is in effect a way of rediscovering hidden possibilities in high-rise residential design. Inspired by technological advances and challenged by social and economic realities, the proposed 'unibody modular' assembly system endeavors to push the boundaries of not just the benefits in building prefabrication, but the idea of housing itself. Undoubtedly, the conventional homogenous high-rise buildings are outmoded and insufficient and, therefore, the proposed advanced adaptable prefabricated high-rise residential complex will modify the current expectations for housing in Hong Kong.

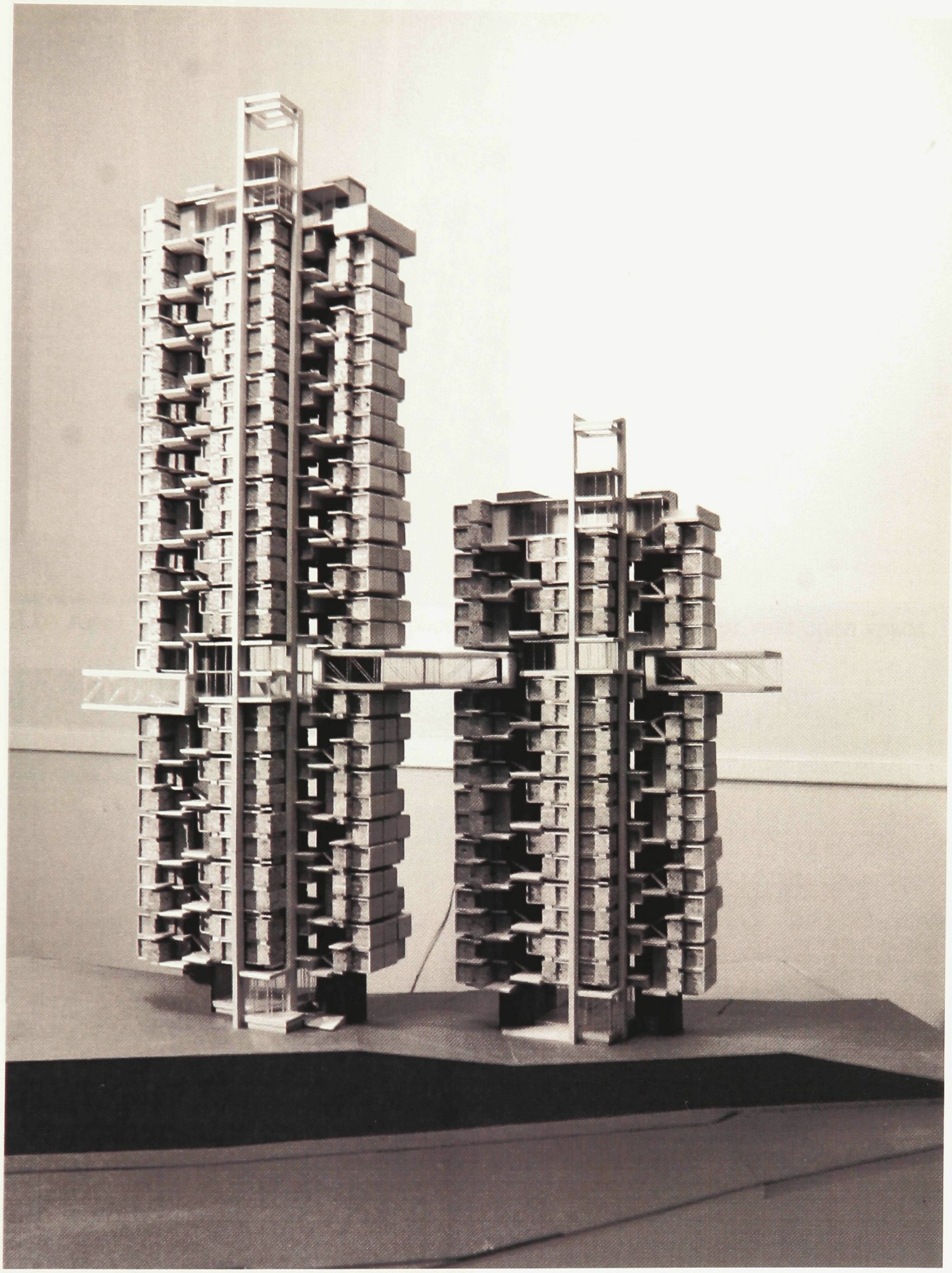
This thesis does not propose to reinvent a new housing paradigm or to provide list of recommendations for action. However, it is an attempt to investigate the factors that architects and developers have overlooked in their design schemes for high-rise residential developments in Hong Kong. Residential development is essentially a collaborative enterprise between architects, contractors, accountants, marketing people, and developers, even more so when it comes to the building methodology of prefabrication. Neither one of the participants can be excluded from the list of collaborators in the design process. Of course there must be one in charge of coordinating all the parties' interests through professional experience and ethical knowledge. This can well be the architect. Architects may not be able to provide an ideal solution for housing that can satisfy the different parties' interest, but architects can provide an appropriate model to address the unfathomable relationship between the design and the actual user's interpretation of the living space. With projects that are related to prefabricated construction, architects have to pay much closer attention to the processes of manufacturing and later to the patterns of use, which then leave little room for architects to develop a design that fully recognizes the unique human and environmental factors. However, it is essential for architects to realize that every occupant is uniquely varied from place to place and from time to time. These unpredictable variables in human living conditions and lifestyles cannot be resolved with a single design solution. The notion of 'home' cannot be guided by practicing innovative models or design approaches without architectural principles established from previous examples. It is more appropriate for architects to make 'evolution' rather than 'revolution' in designing housing by simply learning from the analysis of current design approaches. It is the architect's responsibility to promote modified solutions of housing that are based on the circumstances of the society and appropriated to create complex environments. Studies and analysis of current residential designs would be of great value to architects as they search for an equilibrium in which the interests of all parties are valued equally.

This thesis has addressed two issues related to current residential developments in Hong Kong: the limited variation in dwelling layouts results in a limitation of household compositions within the compound; the clustered tower design on top of a podium with the 'theme park' marketing strategy lacks the awareness of the relationship between the dwelling design and site context, and restricts the interaction between occupants at neighbourhood level. These current issues addressed in my research are unacceptable and are directing current living conditions in the wrong direction. The application of adaptable prefabricated construction is the proper architectural response to search for more satisfying high-density living conditions. The new approach towards housing should address the need of accommodating a wide range of household compositions and improving the current compartmentalized living conditions with a more interactive living environment. The attempt is to reveal hidden design solutions that are economically sound and architecturally appropriate for living. This thesis attempts to promote a stronger relationship between spatial aesthetics and the methods of construction by envisioning an alternative design approach (the 'unibody modular' assembly system). It is an effort to derive an aesthetic of architectural design and construction efficiency by using new building applications as a springboard for creativity and imagination that addresses issues of the built environment and high-rise residential developments. In other words, it is not to apply a veneer, nor beautify or decorate, but to recognize alternative building construction and to satisfy individual preferences for living space. In conclusion, I hope this thesis will open up the possibility of constructing residential buildings that are not merely about function, utility, and luxury living, but respond to individual desires and needs as they relate to high-density living.

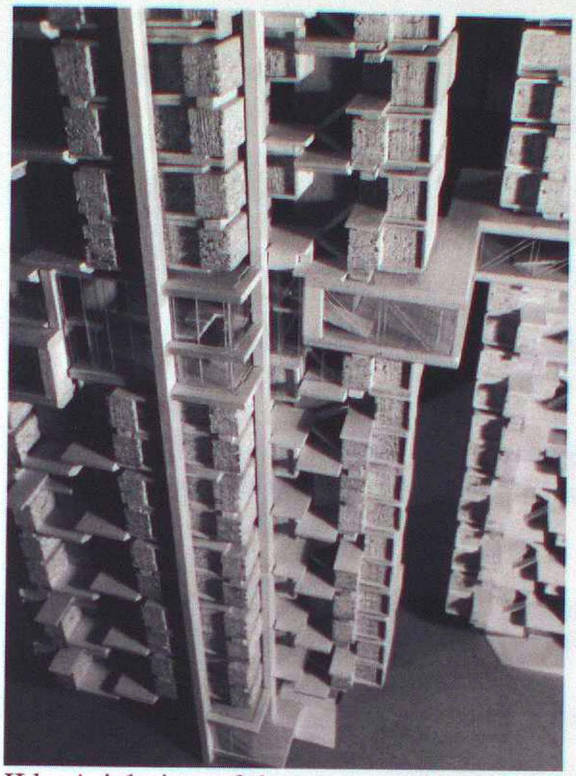
I.a - Overlooking to the current site from the nearby bridge.

I.b - 360° view angle of the current site at ground level.

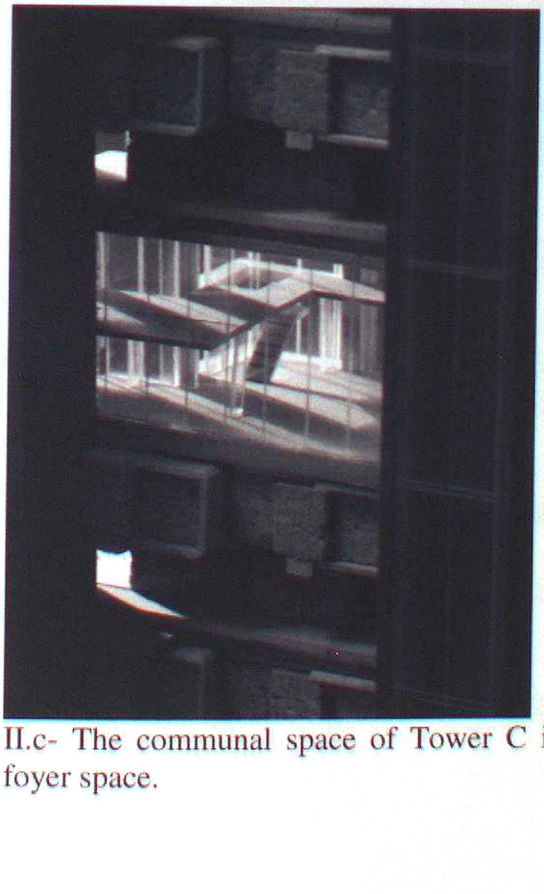
Appendix II : Photos of the physical model at scale 1:200



II.a- Front façade of the proposed residential Tower B and C, view from south.



II.b- Ariel view of the communal space and the grouped semi-private open space.



II.c- The communal space of Tower C is designed with three storeys, well lit foyer space.

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