

ADAPTABILITY AND MODULARITY IN HOUSING: A CASE STUDY OF RAINES COURT AND NEXT21

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ABSTRACT

Adaptable buildings are widely recognized as intrinsic to a sustainable built environment. The term adaptable architecture describes an architecture from which specific components can be changed in response to external stimuli, for example the users or environment. Further, if the parts that do change over time are designed for assembly, disassembly and reuse, if not recycling, this is an additional benefit in the service of a sustainable future. The paper presents idea to transform and industrialized the Malaysian construction industry to be more innovative in architectural design towards adaptability and modularity. The modular housing of Raines Court in London and adaptable housing of NEXT21 in Osaka was selected as a case study to assess the stage of modularization and adaptation of the building. The cross-sectional case study was carried out by semi-structured interviews and observation. They are used to evaluate the level and method of adaptation for the cases. Different levels of adaptation are determined to pinpoint the relations between the different connotations of adaptable. To generalize the outcome of the analyses the different components of the building are categorized. As a conclusion, the studies suggested the series of specific design strategies such as integrated building design, and concept of recyclability and adaptability, as well as green effect to be carried out in Malaysia. Then it would meet the requirement of new techniques and a new level of adaptability for Malaysia as can be concluded as Architectural Programming.

Keywords: Adaptable Housing, Modular Housing, Industrialized Building System (IBS), Support & Infill, Innovative Architectural Design

INTRODUCTION

The need for adaptability and modularity in housing, especially the latter, has always been present. History demonstrates repeatedly that house form was influenced by several aspects of the environment, among the climate, existing materials, religious and cultural factors. The housing process is the common action of a society to fulfill certain condition without which its existence would not be possible. In many countries, the housing necessity of the masses remained an unresolved problem. The necessity for living accommodations has forced many dwellers to find their own alternatives to the problem of housing with the least amount of governmental support. Some actual returned to the source of the matter, regressing to a previous time era where the user built his home according to his needs, whether be it financial, technical and/or familial. Increased housing demand led to mass production. The apartment was designed and built for the unknown client. This anonymous buyer had to be flexible enough to adapt his needs within the limitations of the dwelling unit. This paper will describe the case study of adaptable and modular housing and will define the basic terms in adaptability which will be discussed further.

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ADAPTABLE ARCHITECTURE

Adaptability refers to the capacity of buildings to accommodate substantial change. Over the course of a building's lifetime, change is inevitable, both in the social, economic and physical surroundings, and in the needs and expectations of occupants. Adaptation and flexibility have played an important role in experimental architectural projects in the Industrial era.

Various definitions of adaptable architecture are used in literature, but coherence between these is lacking. Different connotations are given, which are related to different levels of adaptation. Dekker (2006) stated that interactivity is specially used as an indicator of change in an installation or environment that a person can enforce, taking into account the mechanical, physical and psychological implications. According to Edler (2006) dynamic architecture or structures adapt to the varying needs of the users, to changing environmental circumstances or to the designers desires and imaginations. Kronenburg (2002) said, in which the ultimate flexible interior may be one that is completely amorphous and transitional, changing shape, color, lighting levels, acoustic, temperature, as the inhabitants moves through it-abandoning flat horizontal surfaces and demarcations between hard and soft, warm and cold, wet and dry. It seems that there are several technicalities involved when defining aspects of adaptation.

The building is usually divided into structure and infill (Habraken & Teicher, 2005) and, envelope and services (Leupen, 2002; and Lichtenberg, 2005). The division is made on the basis of a difference in lifespan and the separation of functional performance. Therefore building undergoes changes when flexibility is applied. The general lifespan of each building layer is shown in Figure 1 as follows:

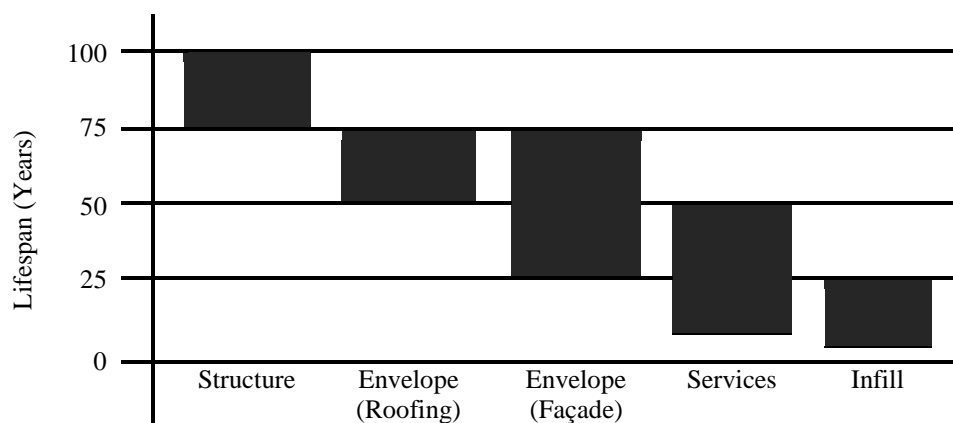


Figure 1. General Lifespan of Building Layers (Gijsbers, 2006)

The adaptability of buildings is inextricably linked with the coordinating and preferred size of the component for residential buildings. The adaptable house must distinguish between two different decision-making levels i.e. support and infill to ensure that buildings can be optimally modified to meet changing (future) use.

Essiz & Koman (2006) found that design demands (artistic and technical) increase with each further step towards industrialization. According to Zulkefle et al (2010), the combination of building standards together with functional and aesthetic designs could utilize the full advantage of IBS without creating lifeless buildings and environment. Erman (2002) claimed that aesthetic considerations became an inseparable part of building components without putting its primary function aside. On the other hand, the MS 1064 Part 10 as the standard of reinforcement concrete components for Modular Coordination (MC) played an important role for architectural design by utilizing precast concrete. In addition, the feasibility of joints and connections can be improved with the Concept VII of Joints and Tolerance in Modular Design Guide (CIDB, 2009). Therefore, the concept of adaptability for home design could be realized (Zulkefle et al, 2010).

A basic interpretation of adaptability is the refitting of a physical environment as the result of a new circumstance. Friedman (2002) defined adaptability for homes as “providing occupants with forms and means that facilitate a fit between their space needs and the constraints of their homes either before or after occupancy”. However, according to Zulkefle et al (2010) homes in Malaysia have followed another path. It has always been conceived as something necessarily static and safe. What happened to the “machine à habiter” that Le Corbusier proposed at the beginning of the 20th century? According to Jacqueline (2009), the problems arose from ‘social engineering’ resulting in ill-matched homes and users. Therefore, the organized and accessible standard such as MS 1064 as a design guideline to MC is crucial in promoting IBS as well as adaptability towards Open Building System in Malaysia. Thus, the MS 1064 should be reconfigured in a relatively straightforward manner in the designing stage as occupant living requirements change over time.

Since the home evolves through different stages and needs over its lifecycle thus the contributions of adaptability improvements by each of the users vary accordingly. The designers are expected to play the central role for the improvement (Rosli, 2004). However, architects are seen to have significant roles as they are responsible for the most design problems of the house. The Manufactured Home with an adaptability features is one which is able to respond effectively to changing household needs without requiring costly and energy intensive alterations. Therefore, Austin (2007) illustrates the priority for adaptability of the house in the UK in Figure 2 as follows:

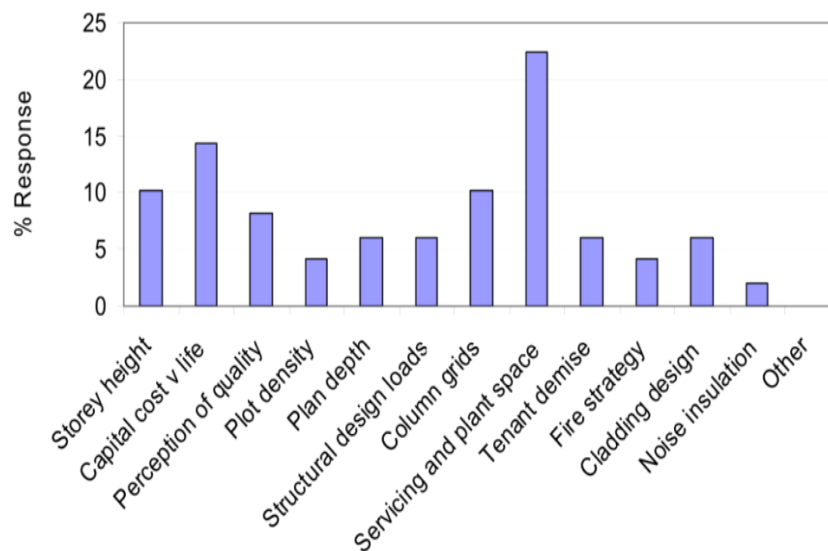


Figure 2. Priority for Adaptability (Austin, 2007)

FLEXIBILITY OF BUILDINGS

Flexibility is viewed as the cure for the rigidity of buildings. As Habraken (1998) divided building into structure and infill, adaptability was suggested by a new approach to flexibility-in-use of structural elements (Gijsbers, 2006), and a flexible façade elements which can deform into many different adaptable shapes (Suma, 2006) lead to great freedom in architectural design. Important factors that define the ease of adaptability are in-line with the advantages of IBS such as modularity, standardization of components, dry assembly techniques, disassembly, accessibility and technical and functional decoupling (Zulkefle, 2007). Daily building practice and the instable market reveal, however, that the applied solutions have not been satisfying until today. Gijsbers (2006) claimed that the function of a building consists of satisfying user demands through technical performance. Inevitably, demands remain that will not be fulfilled through mere flexibility of the infill. It is, therefore of great importance to know the degree of flexibility and adaptability that the individual elements ought to have in order to meet the changing user requirements. The result may be that implementation of flexibility into the infill alone may not be sufficient.

In this study the term adaptable architecture is used as a general definition of an architecture from which specific components can be changed in response to external stimuli (the user and/or the environment). The definition of the different terms of adaptation is explained below:

- **Flexible** – The possibilities of adjustments on specific components are by direct control of the user, which means that the component doesn't have the ability to change itself. The components of the building are changeable with an external force (Brand, 1994; and Leupen 2002). The different possibilities of change are limited. Flexible adaptation requires mechanical techniques such as bearings, which were developed in the middle ages.
- **Active** – An active building component will give a set reaction on a specific change; the action must be undertaken by the user or environment (Blok & Herwijnen, 2006). An example of active components is a light switch. The building component responds on an action of the environment/ users with a specific reaction. Active adaptation requires electricity as basic technique which is available for housing since around 1900.
- **Dynamic** – Dynamic architecture has the possibility to give different output on a certain input. The action-reaction relation is not a closed relation (von Stamm, 2003). More possibilities and settings are possible within one system (Rutten & Trum, 2000). These possibilities are bordered and set in advanced. The dynamic adaptation computer technology was ready for use in housing since around 1980 (Giddens, 1990).
- **Interactive** – A step further is taken with interactive architecture in which the building component has to ability to have a two way conversation with the users and/or its environment. A dialogue is set up between the user and system. An integrated system is needed for interactive relations (von Stamm, 2003). An example could be found in the relation between virtual and real-time are visualized with projections (Speicher & Sanders, 2006). The projection reacts on external data input. The behavior and reactions are set by the programmer; this will mean that interaction will take place within a specific framework. Interactive adaptation needs digital sensing what is available since around 1995.
- **Intelligent** – Intelligent architecture means the adjustment or transformation of the building component is selected by the system as a reaction on the external stimuli (Mollaert & Hebbelinck, 2000 and Blok & van Mele, 2003). The building can take its own conclusions for certain situation. Reactions on re-appearing situations will not logically lead to the same change or adaptation. The system has the ability to learn from its environment or users preferences. As an example the Chess Computers which have the ability to calculate indefinite possibilities of positions.
- **Smart** – Smart architectural components have the ability of self-initiative. The smart system is completely integrated in the life and behavior of the users and environment. The system is self-learning and would design itself (Vincent, 2001). Smart systems are pervasive systems with knowledge of Ambient Intelligence and should lead to systems which fully collaborate but have also the possibility to take over task when other systems drop out. Ambient Intelligence should anticipate on the users' desires or environment without conscious meditation (Collier et al., 2003). Ambient Intelligence should be an open tool, could be customized by the user, and could learn itself. Smart architecture will mean that ubiquitous computing will lead to digital relationships. These relationships should be parallel to human interaction, based on emotion and intuitive. To create smart adaptability new techniques need to evolve that are not yet available.

STRATEGIES AND CRITERIA FOR ADAPTABILITY

Building for living adaptation requires spatial flexibility and constructional openness. Spatial flexibility involves dimensional coordination with grid and zone. While constructional openness involves level separation and interface decomposability and decomposability (Lin, 2002). The latter requires components of generic shape, joints detachable and working process simple for construction (Lin, 2006). Geraedts (2006) recommended using pluggable connections or a plug and play for the interconnection of construction and installation components. These constructable connections will meet the following requirements as follows:

- **Disconnectable** – ensuring the changes or modifications at a lower level have no influence or effects on higher levels, and that they take place independently of each other.
- **Standardized connections** – components from one connection can be used with other components.
- **Size, shape and position tolerances** – to ensure that position and dimensional tolerances are taken into account in the connections (modular coordination).
- **Individual removable** – must allow for the removal of single construction and installation components without the need to first remove or replace other components.
- **Direct usable** – can be usable immediately after positioning and mounting without requiring any further maintenance, adjustment or control.

However, a major problem arising in the connection of units of different modular dimensions (Ricketts, 2004). The connection on site of the units is a distinct challenge. The adaptability of buildings is inextricably linked with the coordinating and preferred size of the component for residential buildings. The adaptable house must distinguish between two different decision-making levels i.e. support and infill to ensure that buildings can be optimally modified to meet changing (future) use.

USER REQUIREMENTS

In the construction industry, it is common practice that products are developed to perform according to the wishes and demands of the intended user. Not meeting these demands has as a consequence e.g. disappointing sales results and failure in the competitive market. Strangely enough, the exact opposite occurs in the building industry. The tendency nowadays is, however, users taking initiative to influence the market and they want their money's worth. At the moment, the building industry in Malaysia is not organized to provide this need, but the experiences sales figures of the industry should give ample motivation to turn the market from push into pull.

A high Structural Flexibility will increase the building's performance by allowing for possible future adoptions of the building layers, for example caused by changing user requirements (Blok & van Herwijnen, 2006). The types and terms of change of user requirements in buildings are characterized and illustrated in Table 1 as follows:

Table 1. Types of change of user requirements, terms of change and characteristics (Dobbelsteen, 2004)

Lifespan (Years)	Type of Change	Term of Change	Aesthetic Upgrade	Functional Change	Spatial Upgrade	Functional Upgrade	Technical Upgrade
0	Trend	everyday					
1	Changes in spatial purpose	≥ 1 year					
5	Adaptation for functional use	≥ 5 years					
5	Upgrade of interior finishing	≥ 5 years					
10	Change of function	≥ 10 years					
15	Upgrade the level of comfort	≥ 15 years					
15	Functional upgrade	≥ 15 years					
30	Technical upgrade	≥ 30 years					

SUSTAINABLE INNOVATE SOLUTION FOR ADAPTABILITY

Adoption and adaptation of innovative solutions is necessary for construction industry to improve its performance to the socio-economic situation in Malaysia. The innovation of IBS can be seen as having five (5) distinct stages – Knowledge, Persuasion, Decision, Implementation, and Confirmation. According to Roger (2003), construction players must learn and be persuaded with such innovation before adoption. Basically, different innovations will produce different communication networks within the same system. This network of communication as a prescribed, formal, or mechanistic structure (Anumba, 2003) may flow in numerous directions (Zakari, 2006) based upon positions, title or role. The structure can provide the required flexibility and adaptability and described integrally.

Design Rules

Construction industry in Malaysia shows a fractionated process by different parties achieving their own aims on the same building. Different cultures and different traditions, many times conflict with the common aim of completing the building. It is necessary to break some of the barriers between the different disciplines during the design process as the first step to a better built environment.

The design rules in relationship to architectural design have to deal with different scale-levels and different 'kind' of aspects. It can be described as the interweaving mechanism between the several aspects and the different design disciplines. The key-aspect is the flexibility and bandwidth in the design process to be reached by application of design methodology. The approach will guide, control and correct the specific solution during design process towards sustainability (Brand et al, 2001). This can be achieved by providing methods to communicate the consequences of design steps between the different disciplines on areas such as construction, costs, life cycle and Internal Environmental Quality (IEQ) at early design stages. The aim is to support all disciplines with information about the tasks and decisions of the other disciplines. Supplying explanation of this information will improve effectiveness of adaptable design and green building (den Hartog, 2003).

Architectural Programming

Effective design and effective construction are both necessary in Architectural Programming to produce adaptable buildings and are therefore closely related. Making a programme of requirements for a building pre-supposes a model of the future (de Jong & van der Voordt, 2008). The study among present and future users, functional analyses, norms and characteristic values, lessons learned from evaluative study and statistical prognoses are important sources to formulate requirement for architectural programming.

Usually, the conceptual design stage is especially vague. As for adaptability, it should start with rough initial ideas about the function that the building should have (Aliakseyeu, 2003). As the design proceeds, more information about user requirements and detail are developed. Though there is little information at the early stages of design nearly all the important decisions have to be made at this time. There is either information contradiction or design process paradox (Zeiler, 2006). After the functional and spatial design concept, the construction concept is made and developed towards a mature composition which is the construction of the building, as a totality of systems, sub-systems and building parts, components and elements (de Jong & van der Voordt, 2008).

RESEARCH METHODOLOGY

The modular housing of Raines Court in London and adaptable housing of NEXT21 in Osaka was selected as a case study to assess the stage of modularization and adaptation of the building. The cross-sectional case study covers the information which drawn from multiple sources based on triangulation method (Yin, 2003). To categorize the different methods and levels of modularization and adaptation in the house, a general overview of the building components was set. The overview also shows the related coordination to the modularization and adaptation. Brand (1994) mentioned various categories of residential building are used in the past research, however as for this research, the categorization is based on the prefabricated components. Next to the categorization of the housing, the criteria for architectural design such as concept, organization, function, design rules and modular coordination, green features etc were investigate. The different levels of adaptability were used as a tool in evaluating such criteria of architectural design. The case studies will be analyzed according to the levels of adaptability and concluded in a table. The table gives an overview on the application of adaptability for the both cases. Finally, the criteria of instrument for the next case study of teachers' quarters in Malaysia will base on the result from this case study.

INTERVIEWS AND OBSERVATION

Raines Court and NEXT21 demonstrating new concepts of multi-family housing units that incorporates sustainable design methods and advanced technologies expected to be used in the near future. The design of these buildings were conceived with a hypothesis that the highly technological and individualized lifestyle is expected in the new century, and addresses issues relating to high-density urban housing and resource conservation in building. In contrast to conventional cookie-cutter design, Raines Court and NEXT21 experiments a new collective housing that accommodate innovation in construction, and the preferences and lifestyle of individual occupants, respectively. At the same time, it aims at showcasing an environmentally friendly building incorporating varies energy and resource conserving design strategies and building systems. As a way of achieving these goals, the concept of two-stage housing was adopted, and design and construction of building infrastructure and individual housing units were carried out in two stages.

General Overview

Raines Court located at Stoke Newington in London while NEXT21 located at Osaka. The area surrounding of the both site contains a number of residential buildings and schools. The site of the both housing is approximately 1,500 square meters in area. Both six-storey housing were won many awards in architectural practice and building construction in the past years. A typical two-bedroom apartment in zinc-clad development of Raines Court comprises of two modules, one with living/dining kitchen and the other with bedrooms and a generous bathroom.

The Raines Court which are the first multi-storey modular housing development in the United Kingdom was completed in 2003, aimed to drive forward the impetus for innovation and demonstrate improvements in speed and efficiency. The housing features 53 shared ownership flats aimed at local people in Hackney on moderate incomes and key workers, as well as eight live/work units for sale on the open market. Raines Court was an extended experiment for Peabody into the potential for delivering high quality housing through off-site volumetric construction methods. As Peabody's second modular housing development, it followed on from award-winning Murray Grove in 1999, and hailed by the government and the construction industry as a breakthrough for innovative house building. Much of what was achieved with Raines Court was an industry first and it was the largest factory-assembled, affordable housing project in the country at the time.

The NEXT21 project was sponsored by the Osaka Gas Company and completed in October 1993. The building consists of 18 individual housing units, which were designed by 13 different architects. The construction period lasted from May 1992 to September 1993, and the design of the units continued until December 1993. Following a period of six months in which the building was open to the public, the five-year experiment in occupancy began in April 1994. Employees of the Osaka Gas Company and their families became the occupants of the building, participating in the project by beginning the five-year process of compiling data related to their living experience.

An innovative architectural system has been put into practice at Raines Court and NEXT21. Basically, the component systems are divided into five (5) groups according to the required life of each component and production path as follows:

- **Structure**, such as construction, connections and foundation
- **Infill**, such as floors, walls and windows
- **Interior**, such as wallpaper, curtains and chairs
- **Environment**, such as experience, sound and light intensity
- **Outfit**, such as roofing, balconies and facade

In order for these subsystems to be compatible and to harmoniously produce a well integrated building, three (3) types of coordination are required:

- Geometric coordination in terms of the size and shape of the building components.
- Performance coordination of building equipment.
- Job coordination in the process of construction

Design Concept

The Raines Court and NEXT21 project incorporates two principal concepts in its design: the systems building and the two-stage building. Together, these two concepts provide a framework from which specific design strategies emanated.

Systems Building

Systems building contribute to reducing initial construction and lifecycle costs in various ways. The key design task was to synthesize a number of building subsystems and their component parts into one integrated building. Raines Court which involved processes adopted to understand and meet client needs, supported team working throughout, and maintained continuous improvement, was won the award for architectural best practise in 2004. The project which wanted to prove that modular housing could be built to a high enough standard for people to want to buy them. Total success was achieved in that every flat was sold as soon as the project was complete. However, the systems were not allows for a technologically-flexible of adaptability.

Nonetheless the NEXT21 offered the adaptability by decomposition of the integration system assembled from a series of multiple independent subsystems. The decomposition of the building into a collection of subsystems allows for a building system which enables easy disassembly of each part as its life expires. In addition, this division increases the flexibility for technological and occupant lifestyle churns. The components can be easily replaced, and the adaptive reuse of individual units in response to changes in the lifestyle and occupancy pattern is built in its design. With the approach, building products from an independent manufacturer could be easily incorporated without disrupting the integrity of other subsystems.

Prefabricated products are used in the both housing during construction. By using prefabricated building components, the job site waste during construction can be avoided. However, during occupancy and use, the only NEXT21 offers independent subsystems make it easy and economical to replace component parts. After a building's life, the disassembly of its component part is convenient, and useful parts could be easily recycled or reused. For these reasons, systems building could be regarded as a strategy for disassembly and sustainable design. The systems building of Raines Court and NEXT21 are illustrate in Figure 3 as follows:

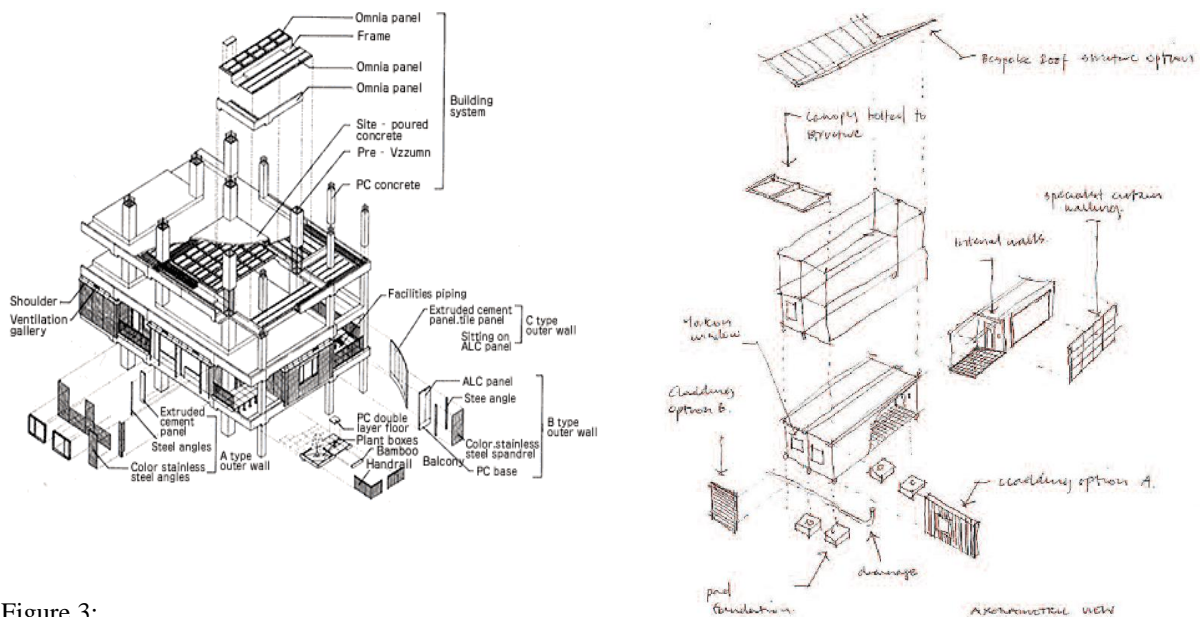


Figure 3:
Systems Building of Raines Court and NEXT21

Two-Stage Building

Both housing were designed using modular coordination to meet the need and lifestyle of initial occupants. Raines Court demonstrate the flexibility of modular construction, which offered architectural variety to relate the building to its context and to maximize the available space on site to the benefit of the tenants and the developer. A typical two-bedroom apartment in zinc-clad development of Raines Court comprises of two modules, one with living/dining kitchen and the other with bedrooms and a generous bathroom. Alike Raines Court, NEXT21 was designed to consider the future adaptively. It is also intended to flexibly accommodate future building technologies as they continue to innovate.

The systems of both housing are classified into two groups; the support and the infill, which provides the principal guideline for implementing the two-stage system as follows:

- **The Support** such as structure and are installed outside individual units are regarded as a shared property and designed to be permanent in NEXT21. However, the stability of Raines Court is provided by the group of modules acting together and supplemented by bracing.
- **The infill** such as partitions, fittings, interior finishes, doors and windows of the individual units, and the mechanical equipment within the individual units are regarded as personal property of the individual owners which has a shorter life and is designed to be easily replaceable in NEXT21. However, in Raines Court, the module that consist of all such infill was constructed in the factory to form a volumetric component which limiting its adaptability.

The concept of two different modes of fabrication that could be brought together such as support and infill – concrete frame and sequence of prefabricated components to be hauled into position and assembled dry within the frame or like stacking bottles in a rack was embarked by Le Corbusier in 1946 are illustrate in Figure 4 as follows:

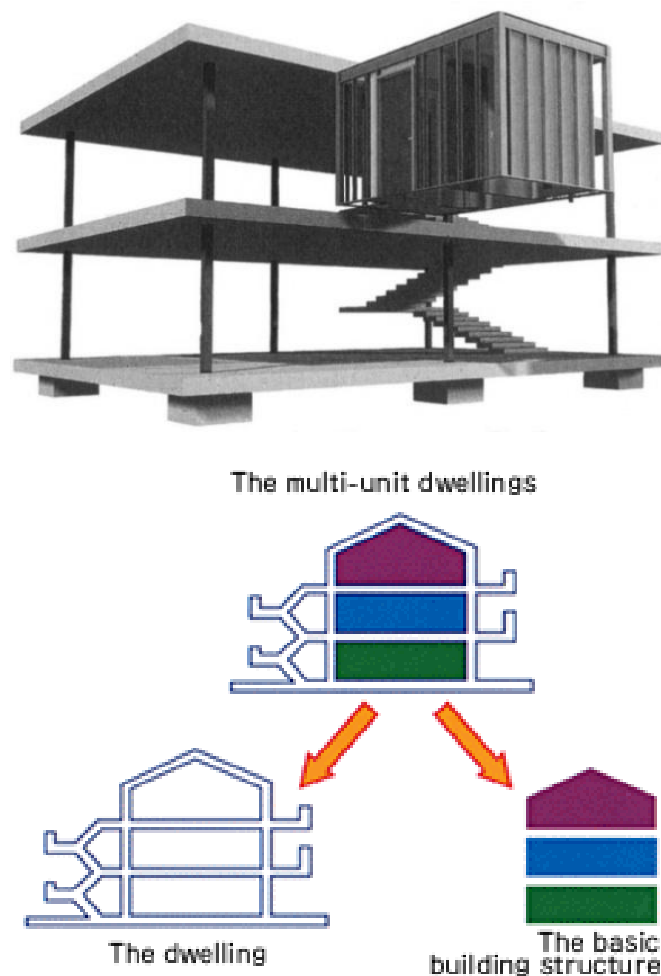


Figure 4. The Concept of Support and Infill

The Architectural Organization

The architectural organizations for both housing are organized into three (3) zone types as follows:

House Zones

The house zone defines the organization of the building framework. These zones are organized into six layers in the both housing, with six (6) units and eight (8) units on each floor for NEXT21 and Raines Court, respectively.

In NEXT21, the columns of 60 centimeters square in plan and are spaced 6.6 meters apart, surface-to-surface, or 7.2 meters apart, center-to-center. Spaces for ducts and pipes are provided in both the floor and ceiling plenums so that rooms, including wet areas, can be freely located. The zones include three different sizes of modules as follows:

- 7.2 meters x 7.2 meters (main modules) face north or south,
- 7.2 meters x 3.6 meters (sub-modules) face east or west, and
- 7.2 meters x 1.8 meters (sub-modules) face east or west.

The house zones have floor-to-floor are higher than the heights typically found in collective housing buildings heights anticipating future expansions of building mechanical, electrical or plumbing systems in floor and ceiling plenums.

In Raines Court, the 127 room-sized modules are arranged in pairs to create a single apartment. The length of the 3.8 meter wide modules varied from 9.6 meter to 11.6 meter, and alternate modules incorporated an integral balcony. The modules are only 3 meter high, allowing for a 600 mm floor-to-ceiling space.

Street Zones

The street zones are formed by the spaces between the house zones in NEXT21, and are 3.6 meters wide, from surface-to-surface. Similar to the house zones, the floor and ceiling have plenums to accommodate the shared ducts and pipes for the building. Unlike spaces in the house zones, however, these spaces are deeper and can accommodate more pipes. The floor panels are removable to provide access for maintenance or system replacement. The street zones of NEXT21 include stairs, corridors, and voids and are 3.6 meters wide are shows in Figure 5 as follows:

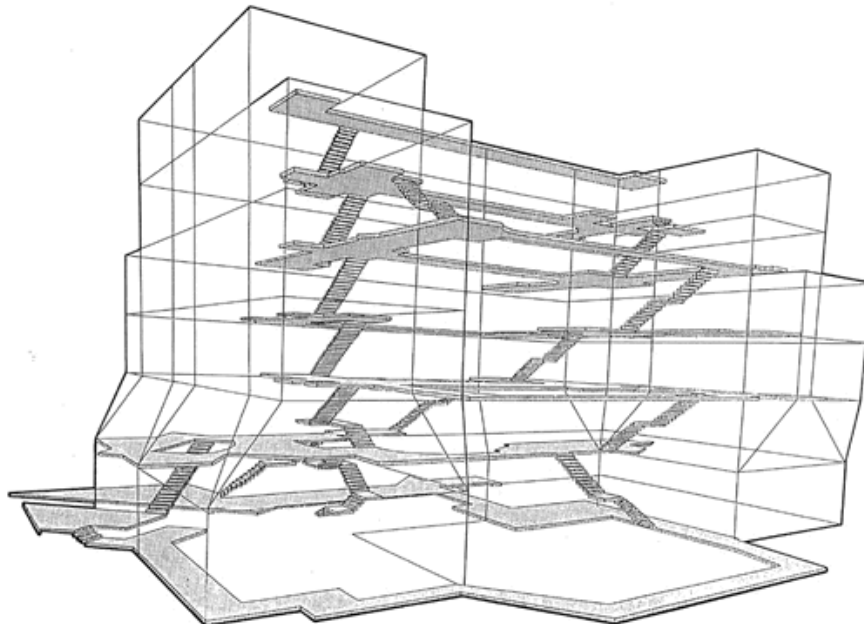
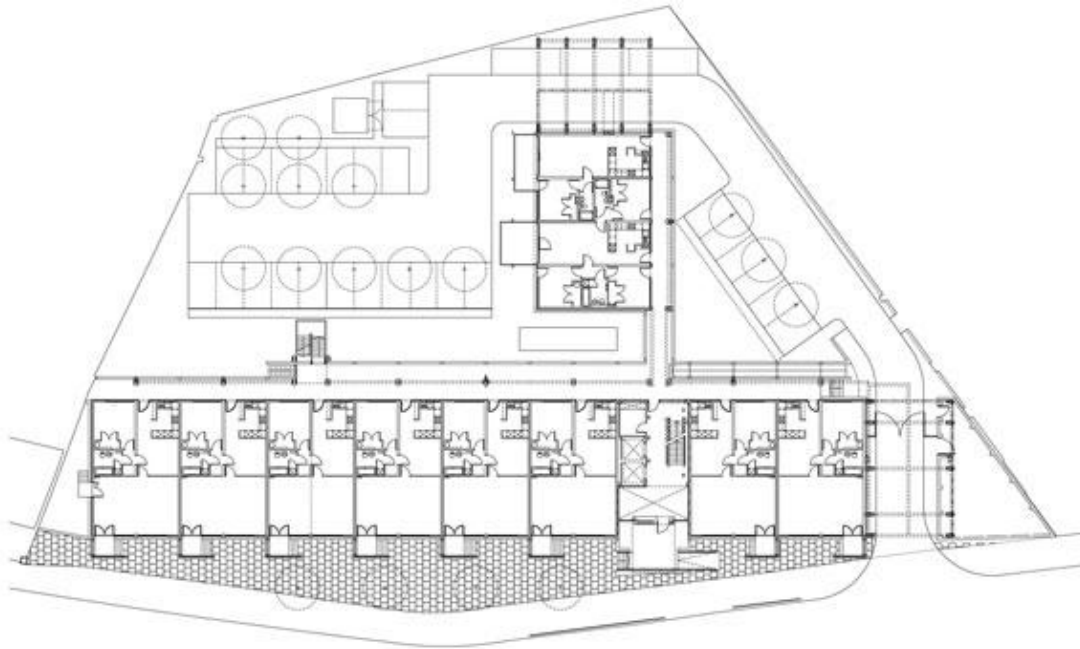


Figure 5. The 3D Street Zone of NEXT21

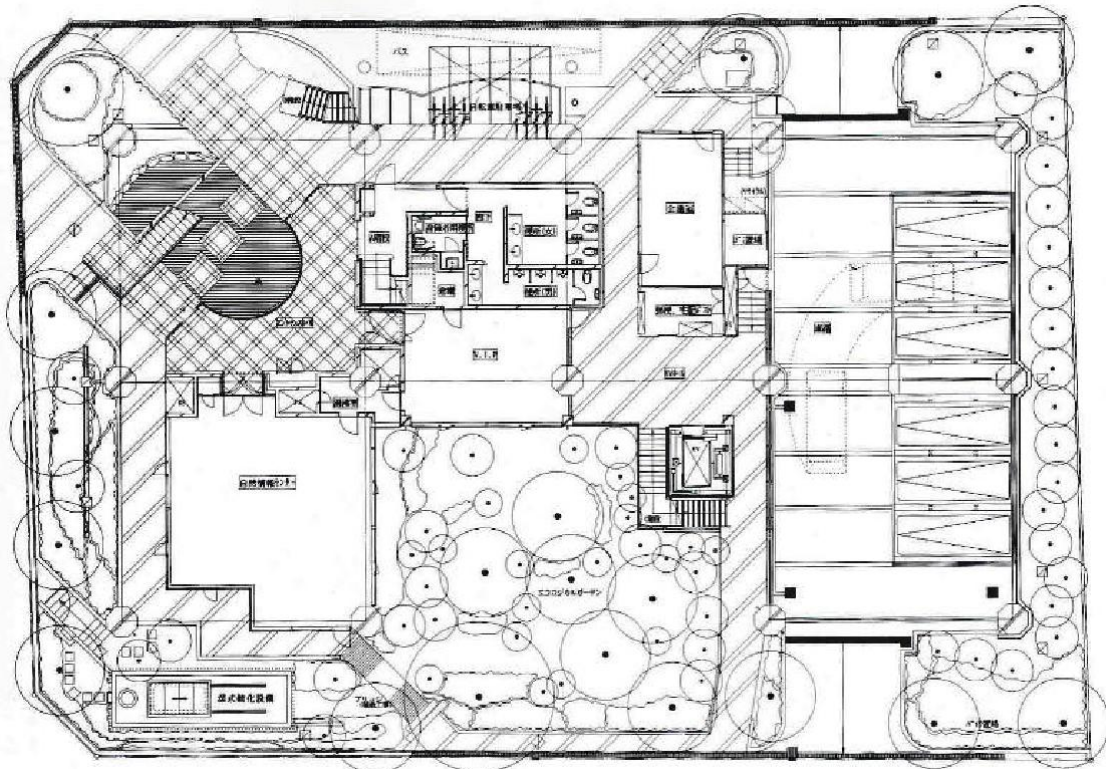
However, for Raines Court, a single corridor of 1.5 meter wide was provided as a connection between units of houses.

Public Zones

Large spaces were required on the lower levels of the building in order to accommodate public facilities such as a conference room, parking, and a mechanical room. Consequently, a larger bay size was necessary. This was accomplished in NEXT21 by consolidating every four columns on the upper floors into one column on the lower floors. The public zones consist of 10.8 meters x 10.8 meters or 10.8 meters x 9.6 meters. However, there are no public zones provided in Raines Court.



i) Raines Court



ii) NEXT21

Figure 6. Lower Level Plans

The Functional Design

The functional design of both housing consists of four subsystems: structure, cladding, infill and mechanical systems. This division is based on the different life spans and production methods of the subsystem components.

Structure

The structure is the only part of the building that is fixated permanently. Consequently, it must have a longer life span than the other subsystems. It was agreed that the life span of NEXT21 should be at least 60 years. To achieve this, the concrete structure was clad to protect from rain, wind, and other corrosive elements. However in Raines Court, the modules are designed to be self-supported by their corner columns. Stability of the six-storey housing is provided by the group of modules acting together and supplemented by bracing.

Alike Raines Court, the building frame of adaptable housing such NEXT21 consists of columns and beams of cast in-situ concrete. However, a thin factory-produced precast concrete panels and boxes were used as a formwork during the construction of columns and beams. The columns were built by the Pre-column method and the beams by the Oroform method. Both methods are very durable and do not require the wasteful use of temporary materials. The floors were also constructed using thin precast concrete panels as formworks.

From the third floor up, there are six independent structures which are single-span towers of columns and beams, each 7.2 meters square in span, as shows in Figure 7 as follows:

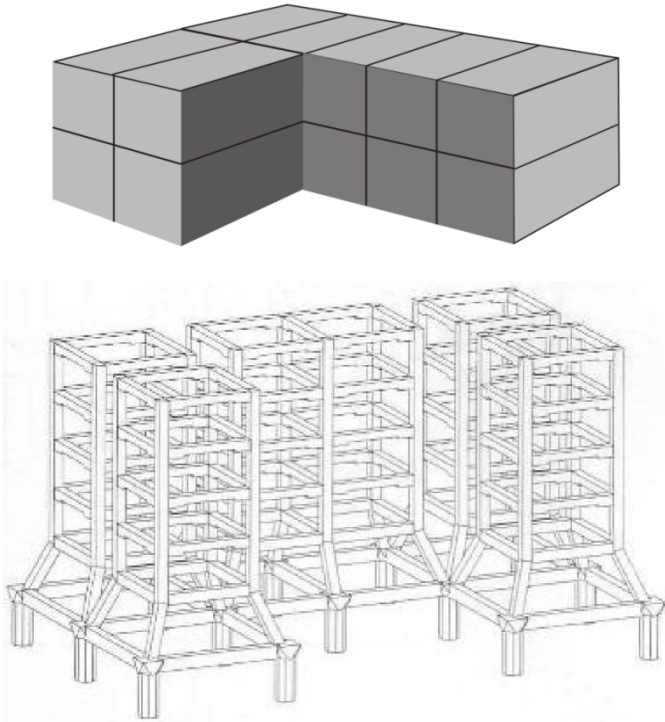


Figure 7. Structure Frame of Raines Court and NEXT21

These areas are the common corridor spaces (the 3D street), and the extra space provided allows for pipes and wiring underneath the finished floor. The floor-top-floor height of the upper levels is 3.6 meters. Every four columns on the upper floors are consolidated into one column on the lower floors. This creates larger bays (10.8 meters x 10.8 meters and 10.8 meters x 9.6 meters) on the lower floors in order to accommodate the public facilities. The result is a tree-shape structure in which the columns branch off from a trunk below.

Cladding

The facade of Raines Court to the main street is clad with lightweight ship-lap profiles zinc panels, with zinc cover strips to mask jointing. The panels were clipped onto a sub-frame directly attached to the modules in manufacture. The courtyard elevations were finished with vertical larch timber cladding to add a degree of warmth to the finish of the external envelope. Each apartment has its own unique colour to form a striking composition within the front and the rear facades of each block. A patent glazed roof overhang on the sixth floor provides shelter from the weather for the access decks. Square glass screens along the walkway provide further protection outside the entrance to each apartment. Such facades of Raines Court are shown in Figure 8 as follows:



Figure 8. Front and Rear Facade of Raines Court

While in NEXT21, the exterior walls are located at the tip of a cantilever to allow for the changing of the panels to be accomplished from the inside, without the need for scaffolding. The perimeter walls fit into a 150 millimetre wide band, and heat insulation material and a stainless exterior finish are affixed to the outside of the walls. By making them easily replaceable, the designers treat the exterior walls as an independent system. The geometric variation of individual unit facades was coordinated through the incorporation of design rules for the exterior walls and the modular arrangement of the windows. The stainless finish of the exterior walls was arranged in coordination with the window components to give the building a unified appearance from the street. Several cladding materials were incorporated as shown in Figure 9 as follows:



Figure 9. Facade of NEXT21

Infill

The infill consists of partitions, fittings, and the interior finishes of the floors, ceilings, and walls. The ceilings and the floors in each unit have hung ceilings and raised floors respectively. Even with these plenum spaces, a sufficient floor-to-ceiling height was provided through the building.

In Raines Court, infill is a uniform and factory manufactured volumetric component of each house. It has integrated services installed in the factory, such as plumbing, electrical wiring, floor and ceiling components including finishes. The size of the unit is varied from 9.6 meter to 11.6 meter in length of 3.8 meter wide modules, and alternate modules incorporated an integral balcony. Each module was completely functional units that are assembled in the factory. It complies with the project specifications and is delivered to site as a fully finished cubicle unit (door, window, all sanitary wares, fittings, accessories, electrical, etc). The modules are only 3 meter high, allowing for a 600 mm floor-to-ceiling space.

As for NEXT21, all prefabricated components of infill were in the panel system and have been assembled on-site during construction. The floor is constructed by a method that improves sound insulation. The architects were allowed to choose the floor finishes of individual units, and many chose wood flooring. A standard floor level is set at 240 millimetres above the slab of the building frame.

The plenum space under the floor of NEXT21 accommodates wiring and plumbing. The accessibility of this space allows for the easy replacement of components. The structural plan and the plan of the mechanical systems are coordinated so that pipes and ducts do not need to pass through the walls, floors, and beams of the building frame. Each unit is equipped with hung ceilings that provide a space for air conditioning ducts and equipment. Large beams have stepped shapes cut out of the middle so that, at the exterior wall, for supply and exhaust ducts have easy access to the outdoors. The incorporation of these features of the infill subsystem allows for flexibility in the location of interior partitions and facilitates easy maintenance and renovation of mechanical components.

The Mechanical Systems

The aging of the pipes and duct components of mechanical systems has a major impact on the life span of the building. The advancement of automated electric home appliances has increased the demand for flexible wiring infrastructure in NEXT21 compare to Raines Court. Therefore in NEXT21, the spaces and pathways that accommodate mechanical systems were designed to be easily accessible, and the components of mechanical systems were assembled in modular elements arranged in grids. These interrelated grids occur on several levels and organize the design of all building subsystems. The ducts, pipes, and wiring of mechanical systems are housed in floor or ceiling plenum spaces, which allows for flexibility for the location of kitchens and bathrooms.

However, in Raines Court, the structural zone between the roof of one module and the floor of the upper module provides the one hour fire resistance and is not available for use as a horizontal service distribution zone. Services can pass vertically through the zone. Care is required when designing the module layout to ensure that all sections of roof can drain to the perimeter.

The clear separation of the mechanical systems and the building frame was accomplished in NEXT21 by the concentration of the vertical shafts for the mechanical systems, as opposed to the typical method in which vertical shafts are located inside the individual units. The latter approach makes the repair of old pipes difficult and increases the amount of debris that must be disposed of after repair work. In NEXT21, large vertical shafts are located in two places in the building. Pipes and wiring are led from these shafts, underneath the common corridors (the street zones) to each unit. This concentration of the vertical shafts in easily accessible locations facilitates the maintenance of pipes and wiring.

DESIGN RULES

The application of design rules ensure a unified formal composition of the building projects and promote rationality in construction. It is very important especially for on-site assembling technique of construction. Therefore, a main feature of the design rules for NEXT21 is the arrangement of the perimeter walls in the individual units. The perimeter walls are confined to a 30 centimetre thickness. They can be arranged with their outer lines on a grid created by lines that are spaced alternately 1,200 millimetres and 600 millimetres apart. In other words, it is a 90 centimetre grid that incorporates a double grid of walls that are 30 centimetre thick. When the arrangement of the perimeter walls for the units has been determined, the enclosed spaces become the house zones and the exterior spaces become the street zones. When the position of a perimeter wall differs from the already established boundary between the street zone and the house zone, the rule for the mutual extension of the house zone and the street zone was applied. This rule was established to allow the greatest latitude in the design of the relationship between units and the streets. According to this rule, it was possible for a part of the street zone to extend into a house or part of the house zone to protrude into the street. However, excessive use of this rule would result in a disorderly streetscape, and thus, was discouraged.

As for Raines Court, the principal constraint of design rules is the structural grid which is different to traditional grids – it is based on a standard 3.3 meter wide module of varying lengths, which allows delivery by road from the factory to the site. The clear spans along the length of the module, up to 12 meter, means the number of structural columns in Raines Court is similar to traditional steel or concrete framed building although the arrangement differs.

The design team of NEXT21 introduced a more sophisticated series of grids of 3,600mm for structural components. The centreline of reinforced concrete columns was fitted with the grid line, and the size of columns was 750mm. Architects designed the houses based on the predesigned structural skeleton, determining the position of their own external walls. The grid for external walls was a tartan grid with a 150mm band whose center corresponded to the structural grid. Figure 10 shows the relation of the superimposed grids. Using these superimposed grids, the surface of external wall is uninterrupted by the structural columns.

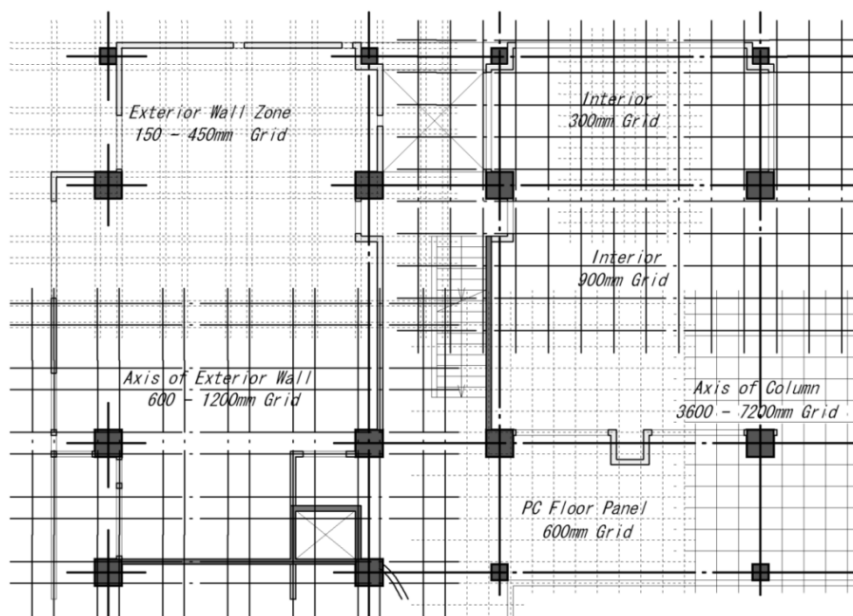


Figure 10. Grid Pattern for NEXT 21

The grid of 30 centimetres is the basis for modular coordination throughout the both housing of Raines Court and NEXT21. The partitions, floors, ceilings, windows, and components such as prefabricated units, fittings, and electric home appliances must all adhere to this module.

GREEN FEATURES

One of the objectives of the NEXT21 project was the incorporation of nature in the design of collective housing. A theme of the project was the creation of an inner-city oasis. Grass and trees were planted on the roof, and small atria were created in the balconies. In addition, a courtyard, called an ecological garden, is located on the ground level and is stocked with plants that attract wild birds and insects. This infusion of nature in the building made the occupants become more conscious of seasonal changes in an urban setting.

Another concept which is intended to create a more natural environment was the theme of a 3D neighborhood with a 3D network of streets. This network of streets allows one to come from the urban street and walk a public path through the entire structure, from floor to floor, crossing the bridge halfway over the common garden below, until one ends up at the roof garden. As in a typical neighborhood, one can walk through the 3D neighborhood of NEXT21 in a number of different ways. This organization enhances the integration between the building and nature, a characteristic of traditional Japanese dwellings, while providing several approaches to individual housing units.

The floor slabs of the streets are lowered to provide not only common zones for pipes and wiring, but also zones for plants. In most buildings that attempt to accommodate spaces for plants in their corridors, raised plant boxes are incorporated. However, the method used in this building creates a space for plants where the soil is on the same level as the floor, resulting in a more natural setting.

Recycling and Reuse

Waste from the kitchens is ground in a disposer and sent by a special pipe to waste treatment equipment in the basement machine room. This device works through the catalytic wet oxidation process in which the waste is slowly oxidized in a long tube, changed into clean exhaust gas, and reclaimed as water. The heat generated during this process is used as a heat source for the heating system and the recycled water is reused for flushing toilets and watering plants. In addition, organic matter in the drainage from such sources as baths is treated by the contact aerating treatment system. Recycling and the centralized treatment of waste within the building increase building's environmental responsibility. The recycling of natural resources are more economical and feasible in collective living than single family dwelling, another environmental benefit of collective housing in high-density urban areas.

Energy Efficiency

The concept of an "energy-producing" building was applied to conserving energy consumption. Technologies for on-site electricity generation by means of solar and fuel cells were incorporated. In addition, the project features a cogeneration system that uses wasted heat produced from water heating and air conditioning. Although Osaka has a relatively mild climate, exterior walls and windows have high insulation values and are airtight. In addition, it has a small window area compared with typical Japanese homes, which further increases the heat insulation and air-tightness of the building. Energy efficient ventilation and air-conditioning systems run 24-hour a day. To recover heat contained in exhausted air, heat recovery ventilators were incorporated in the ventilation systems.

EVALUATION

	COMPONENTS	ELEMENTS	LEVEL OF ADAPTATION												METHOD OF ADAPTATION	
			RAINES COURT						NEXT 21						RAINES COURT	NEXT 21
			1	2	3	4	5	6	1	2	3	4	5	6		
1	Structure	Construction	■						■						▪ Changeable modular structure.	
		Connections	■						■							
		Foundation														
2	Infill	Floors						■						▪ Manually changed windows	▪ Manually changed windows and walls. ▪ Free floor plan for flexible furnishing.	
		Walls						■								
		Windows	■					■								
3	Interior	Wall Paper	■					■					▪ Manually movable units.	▪ Electronic driven elements, like doors, drawers. ▪ Manually movable units.		
		Curtains	■					■								
		Chairs	■					■								
4	Environment	Experience			■					■			▪ Suspended ceiling.	▪ Suspended ceiling. ▪ Adjustable colour of façade		
		Sound			■					■						
		Light Intensity			■					■						
5	Outfit	Roofing	■							■			▪ Manually configurable sliding shutters and windows.	▪ Adjustable translucency of façade. ▪ Image of façade can be changed. ▪ Curtain wall.		
		Balconies	■							■						
		Facade	■							■						

LEVEL OF ADAPTATION (1) Flexible (2) Active (3) Dynamic (4) Interactive (5) Intelligent (6) Smart

DISCUSSION

Even though the only two housing were select represent modular and adaptable buildings, it could be explain that the housing are very outstanding in terms of flexible and adaptation. This is logically in-line with technological developments. The integration of new technologies with old elements of the building is interesting. What can be seen in NEXT21 is that elements of the building are integrated with existing technologies to get to the level of adaptation.

Next to the fact that Open Building has its basics in building processes and systems, flexibility and variation are a common result of the involvement of the user in the building process (Kendall et al., 2000). Therefore IBS housing have the possibility to be renewed more easily compared to conventional houses, but this needs considerable effort. In some aspects the definition of IBS is differ from those used by United Kingdom and Japan. Therefore, a framework for adaptability of housing in Malaysia will be refined to fulfil the Malaysian need and purpose.

For the decision on the level of adaptability in Malaysia, only the components of the building will be considered. Interior aspects as well as environmental aspects were not being considered. This was an attempt to narrow the subject of analysis. The technical possibility to achieve a specific level of adaptability depends on the specific definitions of IBS in Malaysia. If the definition would be different this would possibly influence the level of adaptability. Furthermore the assumption that the named techniques are mainly responsible for the possibility to create a certain level of adaptability could be discussed. Then it would meet the requirement of new techniques and a new level of adaptability for Malaysia as can be concluded from this research as Architectural Programming.

LESSON LEARNT

The design of collective housing is typically proceed based on assumed user preference. However, in Raines Court and NEXT21, user participation in design was integral part of design decision making processes. In order to attain adaptability in architecture, the project organizers and designers have to conduct some interviews with prospective occupants to identify their needs and wants in living in a collective housing. Designer should consider the factor to produce home that accommodates individual lifestyle, high-tech and comfortable, and allows for social gatherings and interaction and communal living. Such house that grows and capable to accommodate the three-generations have to be multifunctional, such as home office, workshop, studio, fitness room. Also, the home have to tranquil indoors and suitable for both a young family as well as the elderly. Therefore, designers in Malaysia have to establish a general design objective for the IBS housing project as follows:

- A flexible building that allows for the provision of diverse housing units and that responds to changes in the lifestyles of occupants within individual units.
- A building that conserves energy and utilizes natural resources efficiently.
- A building that minimizes the deleterious environmental impact.
- A building that is flexible in adapting innovation in building technology.
- A building that provide spaces in contact with nature.

In order to achieve these objectives, a series of specific design strategies are suggested to be study further for a next case study to be carried out in Malaysia, as follows:

- **Integrated Building Design:** A structural system that provides flexibility in locating exterior walls and interior layouts, and that is organized in module so that various individual units can be harmonized to form an integrated building. Both standard and nonstandard building components are to be incorporated to enhance the diversity of the individual units. To test the ability of the building system to accommodate diverse residential units, each unit should be designed by different architect.
- **Concept of Recyclability:** Waste treatment systems and methods that encourage the reuse and recycling of resources produced from the building including solid wastes and gray water. In addition, the construction method that avoid or reduce the use of wooden formworks.
- **Adaptability:** A building assembly method that delineates building systems into distinct subsystems. This creates a building that has the flexibility to adapt to future technological changes by providing for the easy replacement of subsystems as they become outdated. In addition, this resources more effectively by allowing for only necessary components are replaced as their life expires.
- **Green Effect:** The creation of an open and three-dimensional street. It further enhances the green effect by enabling occupants to experience nature as they move through the building. People will feel livelier in such three-dimensional spaces. The space under the streets is used as conduits for the supply and discharge of resources such as energy and water.

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