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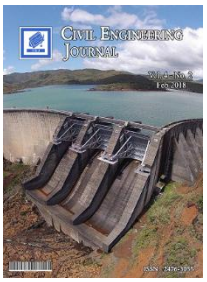

Improving Building Longevity, Adaptability, and Sustainability: Examination of Multi-Unit Residential Building Regulations in Taiwan

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Abstract

Effectively enhancing buildings' adaptability, extending their service lives, and reducing construction wastes has become a crucial issue in the construction industry. As the transformation of the socio-economic structure and diversification of user demands has grown, occupants in residence may have various needs in different stages, rethinking a sustainable and flexible living space has received substantial focus. "Open building (OB)" is an innovative method to accommodate various changeable occupant spaces, decrease the waste caused by space adjustment and reduce maintenance costs. Although the concept of OB is beneficial for sustainable built environments, the promotion of OB in Taiwan is constrained. One of the obstacles is that the OB approach is partly in conflict with the current building regulations. Without legally developed policies, developers are reluctant to supply OB housing in the market; occupants are unwilling to take the risk of implementing OB approaches in renovation. This study applied a Kano two-dimensional quality model to classify and prioritize OB regulation suggestions proposed by experts in Taiwan. A series of forums and interviews were conducted to develop OB regulations. Barriers and challenges will be discussed for further OB development that can be applied to improve building longevity, adaptability, and sustainability.

Keywords: Adaptive Use; Building Longevity; Open Building; Kano Two-Dimensional Quality Model; Building Regulations.

1. Introduction

The world is facing the significant issue of global climate change, and the Taiwanese government is endeavoring to tackle this challenge head on. The residential sector accounts for 10.9% of Taiwan's energy consumption in 2016[1]. Lowering household energy consumption to reduce damage to the environment has become an important topic today [2, 3]. Multi-unit residential building (MURB) is the main form of residential housing in metropolitan Taiwan. The recent rise in housing prices has caused public discussions; therefore, the government has declared a public housing policy to address these problems [4]. Changes in the familial structure (including aging population, declining birthrate, and the tendency for late marriage) and environmental sustainability are important factors to consider for today's housing needs [5]. Residents will have different housing requirements according to changes in their family structure, family situation, and various stages in life [6- 8]. Creating a sustainable, flexible, and effective method to satisfy the changing needs of the user and extending the service years of housing has become a continuous focal point in the industry [9-11].

Open building (OB) categorizes the design and construction of buildings in two levels: "Support" and "Infill" [12]. Many studies in the past have indicated that the OB concept is capable of being flexible and adjustable to suit a family's needs. OB can reduce wastes and damages caused by rearrangement of spaces and simultaneously cuts down the cost of

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renovation and maintenance [13, 14]. To comply with future housing policies and society trends, OB combines concepts such as diversity, flexibility, and sustainability. Thus, OB has once again attracted the public attention in Taiwan.

However, in view of the current housing-related laws in Taiwan, a majority of them regard buildings as inseparable, solid units. The traditional process of construction is different from that of OB that advocates a separable and changeable process. Furthermore, even though OB is a long term goal of the government and several experimental projects were conducted, the promotion of OB in Taiwan is constrained. One of the obstacles is that the OB approach is partly in conflict with or absent on the current building regulations [15]. For example, establishing specific piping shafts and open conduits and lines is crucial when implementing OB, current regulations related to design and construction do not accommodate these particular methods and ideas of OB. In addition, facing the numerous existing housings in the building market, there are also no clear regulations for introducing OB technologies in the building maintenance and operation stage. Unidentified regulations may easily cause the following refurbishment and renovation behaviors to be illegal while implementing OB. The government has recognized the benefits of OB and bas been planning to enact a set of policies and regulations that would revolutionize the OB development and applications in Taiwan.

Experts from the government, architects, interior designers, construction companies, manufacturers, and prefabricated-unit vendors were invited to participate in interviews and forums. Using MURB as an example and the Kano quality model, the congregation sought to assess OB regulations in the hope of solving problems related to applying OB technologies on new and existing housings under current construction regulations. The importance of this study was evaluated from the perspective of sustainability development: Economic– From the perspective of the life span of multi-unit residential building (MURB), the adaptation of OB concepts can extend a building's service life. This will have a certain level of benefit to the economy. Social− Through regulation reforms, the future of promoting OB construction is ensured. Individual residents can also improve their own living environment using OB technologies while being protected by the law. Environmental– Because of the flexibility of OB, a reduction in construction, demolition, and wastage can be achieved. Recycling and reusing of resources and components will also help to attain the goal of sustainable construction.

2. Review of Open Building

2.1. Open Building Introduction

Habraken from Netherlands proposed in the 1960s that architectural design for housing should recognize two domains of action: the action of the community and that of the individual inhabitant. Design for the community-facing functions should focus on the "support" elements (including long lasting pillars, beams, floor slabs, and vertical pipelines), where the service lives of the components are relatively longer. Conversely, design for the individual inhabitant should emphasize on the "infill" elements (including outer windows, separating walls, floorboards, ceiling, doors and windows, furniture and horizontal pipelines), where the service lives of the components are shorter. Separating construction planning into these two categories in design establishes a hierarchical concept and allows the two to be independently acted on. Secondary systems (such as the facade system, rooftop system, stairs/elevators, and interior partitioning, kitchen and bathroom, gas, electricity, and drain pipes) can be made and changed individually. This reduces wastage and damage done to the environment while simultaneously providing the resident more freedom in choice and decision making [5, 16-18]. In Japan, efforts have begun to thoroughly renovate apartments built after 1970 so as to be suitable for the demands of today's modern lifestyle [19]. From the viewpoint of environmental resources and socio-economic considerations, prolonged durability of housing is strongly required [20].

Japanese corporations have been putting forward new ideas to realize sustainable housing. One is the experimental housing utilizing Skeleton-Infill technologies, such as the NEXT21 project of the Osaka Gas Corporation. Another is concerning housing regeneration case studies, such as that on the total renovation of Mukougaoka 1st MURB by the Urban Renaissance Agency [21, 22]. Kendall published "Residential Open Building" in 2000. The book illustrated the development of OB from the 70s to recent times and presented many case studies of OBs [23]. Kendall also pointed out the strong desire for customization of the living space and environment from the residents and suggested new opportunities for personalized products and services in the construction market in the future [24]. There have also been local construction companies in Taiwan using OB technologies in MURB such as running pipes under elevated floorboards and inside ceilings, dry wall partitioning, pipeline integration systems, and prefabricated units hoping to extend the life span of buildings and to make repairs more manageable. However, under hindering Taiwanese regulations, there is a certain amount of difficulty when trying to apply some of the technologies. The question of how to introduce OB designs into Taiwan's construction regulations becomes the focal point of this study.

2.2. OB Regulations in Asia Countries

2.2.1. Long-Life Housing Technical Guidelines In Japan

In Japan, constructions that use OB concepts are called skeleton-infill (SI) construction systems. The SI housing guidelines are set by the Ministry of Land, Infrastructure and Tourism of Japan. The ministry emphasizes the need for SI housing structures to be durable for 100 years. This is to improve on the short life span of Japan's residential housings and to bring more renovation possibilities to the high-density metropolitan lifestyle. From Japan's experience of the process of designing SI housing, attention should be given to the following points: high durability, high strength, positioning of pillars and shear walls, interior surface area, ceiling height, and changeability of drainages and pipes [25].

In 2009, Japan enacted the "long-life housing policy" to extend the life of Japanese housing and increase its adaptability over time. To promote the policy, special ordinance was given including changes in construction laws, tax, and financing. The Japanese government has determined that it has more than sufficient housing for the current population and there will be very little demand for new housing constructions in the near future. Therefore, the policy emphasizes raising the efficiency and quality of existing housing [26-28].

2.2.2. The Technical Guideline for Construction of China Skeleton-infill (CSI) Housing

In 2010, "The Technical Guideline for Construction of China-Skeleton-Infill Housing" was released, in while the technological details in design and building process was formulated [29]. The long term goals of China's CSI housing include the following: expanded building life spans to over 100 years, ability to change the kitchens and bathrooms, and the participation of the residents in the design of the property. These guidelines have brought together China's current regulations and standards. Extensive opinions were sought from experts and related government units, and the guidelines have been through many discussions and amendments. The scope covers areas of design, construction, repair, maintenance, quality, and guarantee of function. There are seven main chapters in the guidelines: General principles, Explanation of terminology, CSI housing design (design principles, construction, structure, water and drainage systems, heating, ventilation and electrical), CSI infill technology, CSI housing construction and verification, CSI housing repair and maintenance management, and CSI housing functional requirements [30].

2.3. Open Building Technologies and Terminologies Used in Residential Construction

Common open building technologies can be categorized as follows: elevated floorboards, ceiling, box unit, laying pipes in piping shaft, open conduits and lines, and dry-wall partitioning system (as shown in figure 1).

- Elevated floorboards: Installing horizontal pipelines in the space between the floorboards and the floor slab and leaving a hole for easy access, examination, and repair purposes in the future.
- Ceiling: Installing horizontal pipelines in the space between the ceiling and the floor slab and leaving a hole for easy access, examination, and repair purposes in the future.
- Box units (bathroom and kitchen): Put together using prefabricated components. Components (ceiling, wall boards, floorboards, and interior bathroom components) are made in a factory and delivered to the site for assembly.

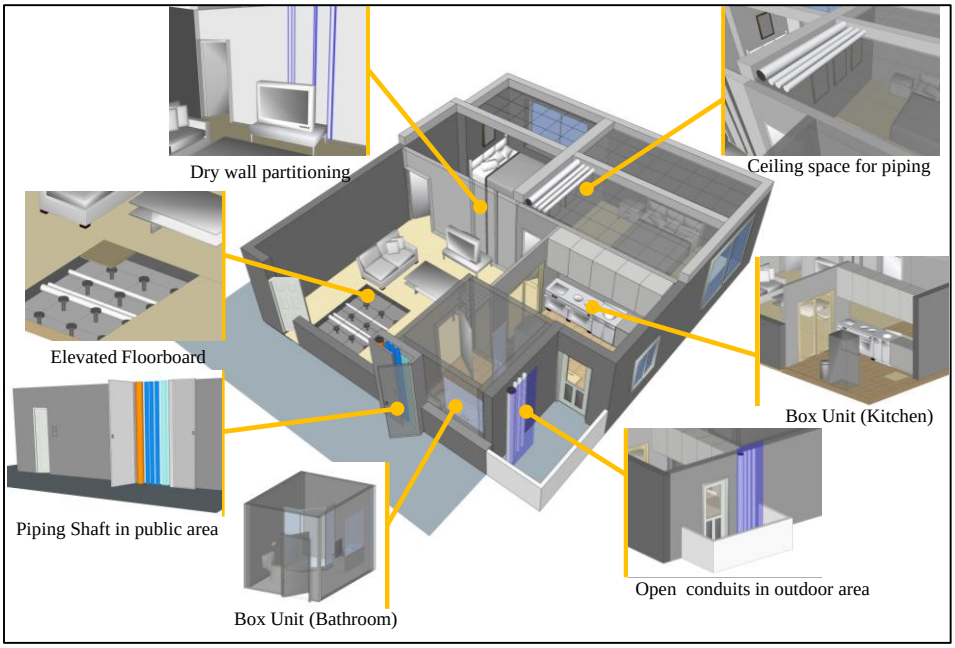

Figure 1. Common SI systems used in residential construction

- Piping shaft: Used for vertical pipes and need to be located near the areas that need water service. Shafts should be positioned in the public area to make it convenient for examinations and repairs in the future.
- Open conduits and lines: Vertical and horizontal pipelines should be exposed and visible. Wall boards and other techniques could be used to cover the pipelines so as to address the esthetic issue with this method.
- Dry-wall partitioning system: Interior partitioning can be rearranged according to the residents' needs. If piping is required, they can be installed between the dry walls.

3. Research Method: Kano Two-Dimensional Quality Model

The Kano two-dimensional quality model was applied to classify and prioritize regulation suggestions proposed by experts in this research. The Kano model is a useful tool to define the nonlinear relationship between performance-related quality attributes of a product (or service) and overall user satisfaction. These quality attributes, as shown in Figure 2, can be classified into five categories: (1) must-be attributes are expected by the users and will result in dissatisfaction when these attributes are not fulfilled; (2) one-dimensional attributes are those for which better fulfillment leads to linear increment of user satisfaction; (3) attractive attributes are usually unexpected by the users and can result in great satisfaction if they are available; (4) indifferent attributes are those that the users are not interested in the level of their performance; and (5) reverse attributes refer to a high degree of achievement resulting in dissatisfaction [31-34].

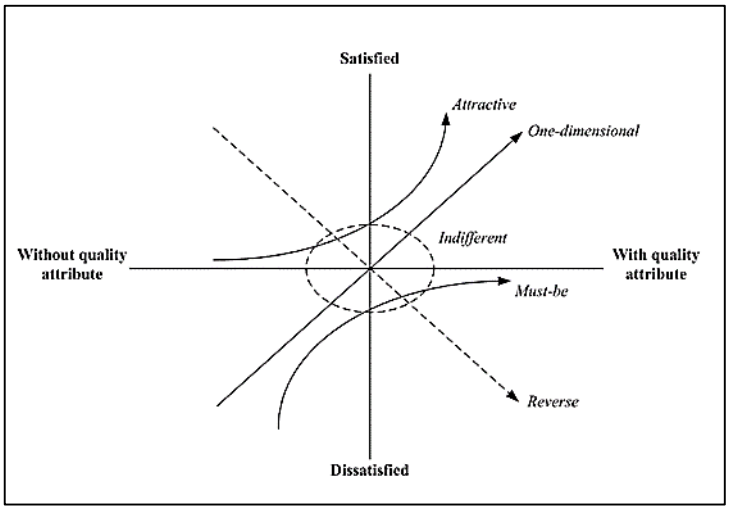

Figure 2. Kano two-dimensional quality model

The application of the Kano model in this research contains two steps. First, a questionnaire that consists of positive/functional and negative/dysfunctional is established. The expert in this research answers a pair of questions with one of five different responses—"Like," "Must-be," "Neural," "Live with," and "Dislike"—for each regulation suggestion. The first question concerns the reaction of the expert to the regulation suggestions with that attribute (functional form); the second question involves the reaction to the regulation suggestions that do not have that attribute (dysfunctional form) [33]. Second, the questionnaire is administered to various experts, and each answer pair is aligned with the Kano evaluation table [32], as shown in Table 1, which can reveal each expert's perception toward attributes of regulation suggestions [34, 35]. If the expert answers, for example, "I like it that way" as regards a specific attribute from the functional side, and answers "I am neutral" for the same attribute from the dysfunctional side, the combination of the question in the evaluation table will be in the "A" category, indicating that this attribute is attractive to this expert's needs.

Table 1. Kano evaluation table (Berger et al., 1993)

		Dysfunctional:				
		Like	Must-be	Neural	Live with	**Dislike**
Functional:	Like	Q	A	A	A	**O**
	Must-be	R	I	I	I	**M**
	Neural	R	I	I	I	**M**
	Live with	R	I	I	I	**M**
	Dislike	**R**	**R**	**R**	**R**	**Q**

Note: Q, A, R, I, O, and M denote "Questionable," "Attractive," "Reverse," "Indifferent,, "One-dimensional," and "Must-be" attributes, respectively.

4. Kano-Based Model for Examining OB Regulations for MURB in Taiwan

4.1. Interview of Experts

A total of 32 experts from industry, academia, and the government were invited to join a series of forums and interviews to examine OB regulation suggestions applied to the current building regulations. Of all participants, 4 (13%) were researchers and professors from research institutes and universities, 6 (19%) were architects, 4 (12%) were developers, 6 (19%) were professional engineers from architecture and construction companies, 3 (9%) were interior designers, 2 (6%) were representatives from prefabricated-unit vendors, and 7 (22%) were officials and representatives from the government. The investigation period was from April to September, 2014. Major regulation suggestions and modification were identified through a systematic and structured approach led by the research group.

4.2. Data Analysis

From the series of interviews and forums, the experts put together 16 regulation suggestions in four major categories and tabulated the results on the basis of the votes from the 32 participants. Among these regulation suggestions, nine were designated as "must-be attributes," two were "attractive attributes," two were "one-dimensional attributes," and three were "indifferent attributes." The results are as shown in Table 2.

Table 2. Tabulated results of OB regulation examinations for MURB

Categories	Rethinking of regulation subjects	A	O	M	I	Quality attribute
Design principles of the support (skeleton) systems	1. Enhance safety and durability of structural system.	0	2	30	0	M
	2. Improve capability of structural system.	14	6	7	5	A
	3. Building permission without partitioning system.	6	10	0	16	I
	4. Relax Indoor height rules.	12	4	14	2	M
	5. Release building height restriction.	11	4	0	17	I
Alteration principles of the infill systems	6. Ensure space rearrangement rules.	2	0	30	0	M
	7. Apply dry-wall partitioning systems.	6	14	12	0	O
	8. Establish water using spaces configuration rules.	12	2	18	0	M
Planning principles of pipeline systems	9. Piping setting rules.	3	14	15	0	M
	10. Open conduits design.	8	12	5	7	O
	11. Deduction of building's total floor area calculation.	10	5	0	17	I
	12. Centralized management for piping.	9	2	19	2	M
Application of SI technologies to existing residential buildings	13. Ensure structure strengthening rules.	0	10	22	0	M
	14. Set infill alteration design principles.	4	5	16	7	M
	15. Establish outdoor piping shelter setting rules.	15	9	4	4	A
	16. Approval for installing additional pipelines.	8	3	16	5	M

5. Discussions

Based on the results of the Table 2, there are some noticeable findings that are worth discussing. The result is highly consistent with the development experiences in Japan and China that ensuring high durability, strength, flexibility, and sustainability is key to the success of OB implementation. In addition, more design principals of skeleton and infill technologies are also required for the following OB regulations development. Compared with development experiences in above-mentioned two countries, the difference is that the present research further takes the feasibility of OB in existing residential buildings into account, which might be beneficial for a large number of existing buildings in Taiwan while implementing OB. The consensus from the experts showed that thirteen regulation suggestions should be selected for enactment because their attributes; the quality attributes of these actions were "Attractive", "One-dimensional" or "Must-be" attributes. Decisions made by experts mostly rely on their evaluations on application rationality, SI systems feasibility, and construction safety of proposed suggestions. The target of "Design principles of the support (skeleton) systems" is to ensure the structure can be stable and has suitable span and dimensions for adopting SI systems. Three regulation subjects were advanced, description is as follows.

- 'Enhance safety and durability of structural system' and 'Relax interior height rules' both are 'Must-be' attributes. Structure system design must be safe and appropriate. In Taiwan, pipes such as drainage are embedded in the concrete may cause structural damage while renovation and also reduce structural strength (holes need to be made on the facades). Thus, structural safety must not be compromised and additional space which is the factor to affect interior clear heights is required for pipes. According to this point, the portion of the height affected should be excluded from the storey heights.

- 'Improve capability of structural system' is 'Attractive' attribute. Appropriate span design will increase the flexibility of infill system and assist support system to be able to experience several times of infill system changes.
- The other two regulation subjects are deleted, explanation is as below. First, plan design without partitioning might be a flexible way for SI systems installation, but applying for a building permission in Taiwan requires the investigation of the major types of pipelines and connections, including fire extinguishing, electricity, tap water, telecommunications, and drainage. Interior partitioning will affect the pipeline settings, and piping inspection is not possible if the partitioning is not accurate. In addition, interior partitioning also influences emergency evacuation paths. Partitioning requires examination of fire emergency procedures and also the radius of fire sprinklers. Re-examination of fire emergency procedures will be required when expanding or repartitioning in the future. These will cause inconvenience during the constructions. Secondly, although restrictions relaxed of building height can encourage developers to use SI systems (avoid strict regulation examination for high-rise buildings), it is related to increase building bulk at the same time. The result will also create difficulties for examination by the construction authorities and therefore governmental departments for now are not inclined to give out such incentives to encourage developers in using SI systems.

Referring to the initiative of "Alteration principles of the infill systems" three regulation subjects were addressed. Ensuring infill system construction will not damage the structure at the situation of keeping flexible partition system is the goal of this criterion.

- 'Ensure space rearrangement rules' and 'Establish water using spaces configuration rules' are both 'Must-be' attributes. When the residents need to rearrange their layouts, they may only adjust the infill units within the housing. Actions that affect or cause the destruction of structural safety are not allowed. In addition, spatial flexibility is an important appeal of OB, but water using spaces, such as bathroom and kitchen, are interconnected to vertical water supply and drainage system. If the location of water using spaces is different from floor to floor, it may increase the difficulties of construction and renovation. Thus, the location of bathroom and kitchen should be set together to simplify water system problems in the future.
- 'Apply dry-wall partitioning systems' is 'One-dimensional' attribute. Adoption of dry-wall partition will be flexible and helpful for residence while they have various needs and changes in different stages during their family life cycle. Otherwise, without dry wall partition, there will be more damage and waste while renovation.

The aim of "Planning principles of pipeline systems" is not only enhancing convenience of renovation and maintenance, but also reducing waste caused by destroying and additional cost in the future. Under this framework, four regulation subjects were brought up, one of them is cancelled.

- 'Piping setting rules' and 'Centralized management for piping' are both 'Must-be' attributes. Piping generally are embedded in the concrete of floors or walls in Taiwan, also, water pipes and electric wires usually are separated into different place, it might cause problems and increase difficulties when renovation or maintenance in the future. Thus, in the expert's opinions, water pipes and electric wires should be centralized and disposed in the space between support system and infill system. These pipelines should not go through floorboards and is prohibited from entering other proprietary spaces. When maintaining in the future, this way can decrease the damage of structure and also without entering other proprietary spaces.
- 'Open conduits design' is 'One-dimension' attributes. Open conduits design is very helpful to maintenance in the future because staffs can easily to find and check pipes.
- The cancelled subject is 'Deduction of building's total floor area calculation'. Currently space reserved for electrical equipment (including the pipeline shaft) that occupies less than 10% of site area is not included in the area calculation in Taiwan. Most experts suggest that although an increase of the deduction ratio might be beneficial for contractors, illegal use after occupancy may easily occur with these additional floor areas. There is no need for the incentives and therefore this subject will not be considered for regulation for the time being.

The focus of "Application of SI technologies to existing residential buildings" is to assist existing residential buildings to apply OB approaches while renovation and whereby extending building life cycle. Five regulation subjects are mentioned.

- 'Ensure structure strengthening rules', 'Set infill alteration design principles' and 'Approval for installing additional pipelines' are all 'Must-be' attributes. Support system stability should be ensured and infill system modification should be conformed to interior regulations while renovation. In addition, when renovating existing buildings, the approval of the owners and construction authorities must be obtained for installing pipelines around the housing, on the exterior of the walls, rooftops, and places that are not exclusively owned. With this approval, the renovation can be legally conducted.

- 'Establish outdoor piping shelter setting rules' is 'Attractive' attribute. Considering urban environment compatibility, illegal additional building components management regulations, and protection of outdoor pipes, some rules should be further defined. First, pipes shelter should be over 50% openwork; secondly, section area of shelter should not be more than 1 square meter; third, shelter should be kept at least 3 meters from adjacent buildings or roads. The above three points are mentioned in order to keep ventilation, avoid this shelter space diverted to other use and affect safety of adjacent buildings.

6. Conclusion

It is difficult for buildings in Taiwan to be flexible with its space because of the wet construction methods that are usually applied. The use of OB technologies or SI systems can solve problems that may arise in the future caused by wet construction. Some of the SI systems conflict with Taiwan's existing construction regulations, which is a major obstacle stifling the government from promoting OB-based constructions. In view of this, the study interviewed many experts and held forums to draw out plans for specific laws that will have minimal disruption to current regulations while simultaneously raising the feasibility of applying OB construction in Taiwan and keeping up with the trend of sustainable construction. There are still needs for continuing discussions among experts to establish details of related articles, complete the process of legalization, and provide professional engineers, designers, and builders with necessary information for applying OB concepts on new and existing buildings. This is with the aim to increase the adaptation of OB and extend the life span of residential housings in Taiwan.

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