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Evaluation of functional flexibility in contemporary Japanese housing layouts: Integration of user perspective

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Abstract
In recent decades, given the indefinite identity of residents to house designers and builders, along with changes in families' lifestyles, flexibility has regained its importance in housing design. The present study aimed to develop the concept of functional flexibility, which accommodates potential responses to non-physical changes by users. Since the responsiveness and efficacy of flexible solutions in housing units largely depend on the residents' reactions to these solutions, this study integrated the user perspective to evaluate and improve functional flexibility in contemporary Japanese housing. To evaluate functional flexibility as a framework, first, its related components and indicators were identified. Next, a questionnaire survey was conducted to investigate these components in contemporary Japanese housing layouts and to evaluate the gap between the current and expected conditions based on the users' needs. Finally, some suggestions were presented to bridge this gap and optimize the housing layouts. The findings revealed that functional flexibility consists of two components of multifunctionality and convertibility. Multifunctionality was analyzed using one indicator, that is, type of combined functions. Convertibility was also evaluated using four indicators, that is, multipurpose rooms, movable partitions, movable shells, and transformable furniture. The evaluation of indicators showed that Japanese housing layouts had multifunctional spaces, multipurpose rooms, and changeable elements, leading to functional flexibility. Besides, several solutions, including the type of layouts and architectural elements, were suggested to optimize functional flexibility.

Keywords
Japanese housing, Functional flexibility, Multifunctionality, Convertibility, User participation.

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1. Introduction

1.1. Changes in housing design

Due to changes in the families' needs over time (e.g., family expansion and advancing age), a residential unit should be able to respond to the new unique lifestyles and living habits of its residents and accommodate a wide range of households over its life span (Friedman, 2002). If an architectural space cannot accommodate its users' expected functions, user dissatisfaction is inevitable. Therefore, it is important to propose appropriate design solutions to bridge the gap between expected functions (e.g., users' expectations of their living space) and current functions (e.g., a set of design strategies available in the existing housing layout). Rather than incorporating functionally predetermined spaces, flexibility allows housing units to fulfil the users' dynamic needs over time by increasing their space options (Schneider and Till, 2005); this strategy has gained increasing importance in house planning and design.

1.2. A review of flexibility

With rapid social, economic, and technological changes in today's life, flexibility has become a significant feature of contemporary house planning and design to accommodate to the transformations of human life. Flexible buildings are intended to respond to evolving conditions in form and function (Kronenburg, 2007); accordingly, in the life cycle of a building, it can maximize its production efficiency (Schmidt III and Austin, 2016). Overall, flexibility can ensure the long-term use of buildings by changing their living spaces and functions (De Paris and Lopes, 2018). Moreover, it can accommodate both temporary (e.g., combining two rooms by the use of a movable partition) and permanent (e.g., moving an external wall to expand the size of a room) changes (Schneider and Till, 2007). It can be concluded that flexibility enables buildings to meet multiple needs of users through time.

1.2.1. Typology of flexibility

Considering the potential changes in housing design, researchers have categorized the concept of flexibility (Lans and Hofland, 2005; Groak, 1992; Schneider and Till, 2005; Gilani and Türker, 2020). Dittert (1982 cited in Lans and Hofland, 2005) classified flexibility into two categories: functional flexibility (i.e., ability to change the interior space based on the residents' changing needs without structural alterations) and structural flexibility (i.e., physical and structural changes in the interior space). Moreover, Groak (1992) described two distinct aspects of flexibility, including the capacity of different physical arrangements (i.e., ability to respond to physical changes) and the capacity of different social applications (i.e., ability to respond to non-physical changes), which bear resemblances to the notions of functional and structural flexibility, respectively. Additionally, Till and Schneider (2005) classified flexibility strategies into two broad categories of use (flexibility in the spatial layout through house planning and design) and technology (flexibility through construction techniques and structural and servicing strategies).

There is a clear similarity between the abovementioned classifications. In this study, the change-based approach to flexibility was applied to classify flexibility into two categories, that is, structural-spatial flexibility and functional flexibility. Structural-spatial flexibility refers to the potential of a building to respond to physical changes by modifying the physical form of the building via joining, splitting, extending, and merging spaces. On the other hand, functional flexibility signifies the potential of a building to respond to functional changes or use of a space in different ways without making physical changes. Functional flexibility is completely dependent on the active participation of users, as well as interactions between humans and architectural space. Therefore, the present study focused on functional flexibility and evaluated it from the users' perspectives.

1.3. Japanese housing as a case study

Traditional Japanese housing, which is regarded as a valuable case study in many studies on flexibility, employs a

combination of flexible strategies, such as a wooden post-and-beam structure system (Engel, 1985), sliding doors as internal partitions and external skin, and multipurpose rooms with some furniture (Yagi, 1992). With the standardization of housing designs, the contemporary Japanese housing layout is based on a central multifunctional space and several private rooms (Daniels, 2010). The present study aimed to assess the adaptability of contemporary Japanese housing to users' expectations and to determine the criteria for improving the current condition.

1.4. Objectives and methodology

This study mainly aimed to develop the concept of functional flexibility. Besides, this explorative study aimed to identify different dimensions of functional flexibility, to investigate these dimensions in contemporary housing layouts in Japan, and to make suggestions to optimize these layouts. The research scope was limited to design strategies associated with housing layouts and did not address technical or structural strategies. Overall, the results of this study can be useful for architects, interior architects, and designers to create flexible residential spaces.

To evaluate flexibility in architecture, researchers have used various methods, including assessment based on layers and indicators (Geraedts, 2016; Kelly et al., 2011), assessment based on users' opinions (Beisi, 1995; Altaş and Özsoy, 1998), study of plan transformation over a long period (Minami, 2016), "space syntax" concerning the concept of polyvalence, and physical factors of floor plans (Femenias and Geromel, 2020; Leopen, 2006). As a common method in these studies, flexibility is divided into several sub-dimensions to appraise flexibility in buildings or to determine design strategies for achieving flexibility (Geraedts, 2016; Kelly et al., 2011; Ghafourian, 2018; Till and Schneider, 2005; Einifar, 2003; Leopen, 2006; Femenias and Geromel, 2020); however, the users' perspectives are largely ignored in the process of flexibility assessment. Therefore, user perspective is a focal point of this survey. The questionnaire survey method was employed to integrate the users' opinions for evaluating functional flexibility in contemporary Japanese housing units.

To specify the framework of this study, first, the components of functional flexibility and its related indicators were separately identified and then used as criteria to statistically evaluate the adaptability of Japanese housing layouts to the users' expectations. Next, the characteristics of contemporary Japanese housing units were discussed to collect the required data for designing the questionnaire. To understand the contemporary Japanese housing layouts, some projects designed by Japanese architectural offices, as well as a number of model houses built by major Japanese homebuilders (e.g., Misawa, Sekisui, Daiwa, and Panasonic), were visited by the authors. The questionnaire survey was conducted in 2019, and data were analyzed using SPSS Version 23.0. The collected data were used to appraise the current solutions in contemporary Japanese residential units to meet the users' changing needs over time.

2. Dimensions of functional flexibility

In this study, the concept of functional flexibility was considered as an inclusive term, covering several components related to a dimension of flexibility, without which functional flexibility could not be analyzed. Also, each component was divided into multiple sub-dimensions (i.e., indicators), which were used as the evaluation criteria for functional flexibility in housing design. In this manner, the design solutions related to these components created functional flexibility in the spatial layout. By reviewing the designers' perspectives on the concept of flexibility, the components and related indicators were extracted.

2.1. Components of functional flexibility

Designers have used several keywords for the definition of flexibility. Table 1 presents the users' perspectives of functional flexibility.

Table 1. *Keywords related to functional flexibility.*

Designers	**Keywords**
Grütter (1987)	Multi-functionality: accommodating several functions in a space
Beisi,(1995)	Multipurpose room: room function can be changed without changes to the room dimension Change in room relationships: connections between rooms of a unit Change in room quantity and size: room divisions can be changed by moveable walls Change in accessories: apartment accessories can be chosen by tenants or replaced easily
Pena & Parshall (2001)	Multi-functionality: accommodating multiple functions at the same place Convertibility: ability to respond to interior changes
Einifar (2003)	Multi-functionality: accommodating multiple functions in a space Adaptability: occurrence of various behaviors in the same place at different times
Leopen (2006)	Polyvalence: interchangeability of activities between different rooms
Ghafourian (2018)	Multi-functional: accommodating different functions at the same time in space Segregation: ability to divide a room into two separate spaces Different furniture arrangement: possibility of different arrangements of furniture, using movable and foldable furniture
Gilani & Türker (2020)	Versatility: spatial multi-use with minor structural modification Convertibility: conversion from one function to another; exchange of functions Multi-functionality: accommodating different functions at the same time, at the same place Ability to separate & re-join the rooms Flexible arrangement of furniture: ability to rearrange furniture Freedom of main space as generic space

Based on the keywords related to functional flexibility presented in Table 1, certain factors affect the flexibility of buildings. In this study, these factors, referred to as components, were as follows:

Multifunctionality (M): Multifunctionality refers to the principle of spatial integration of smaller rooms and functions into a larger room. Multifunctional spaces are open-plan spaces that can be simultaneously dedicated to multiple functions. The open-plan concept in housing architecture was more widely applied in the 1960's when the kitchen was integrated into a whole with the living room and dining room (Alfirevic and Simonović Alfirević, 2016). It seems that elimination of barriers, such as walls and doors between adjacent rooms, can save the living space owing to the reduction of circulation areas, besides enhanced accessibility due to visual and physical permeability.

Convertibility (C): Functional flexibility can be achieved through conversion of spaces (Pena and Parshall, 2001). Convertible spaces can accommodate different functions at different times according to the users' needs. Overall, places that can be used for various purposes offer their users more options than places limited to a single fixed use (Bently et al., 1985); therefore, the concept of convertibility conflicts with fixed functionalism. Also, convertibility overlaps with the concept of polyvalence, which refers to the characteristics of a fixed form that can be used in different ways without structural interventions (Leopen, 2006).

Flexibility through a polyvalent

Table 2. *Extraction of CIs based on designers' perspectives.*

Designers	**Characteristics of convertibility**	**Extracted indicator**
Schneider & Till (2007)	1.Functionally neutral rooms	Multipurpose room
	2.Connection between rooms	Movable partition
	3.Movable and sliding walls	Movable partitions, Movable shell
	4.Foldable furniture	Transformable furniture
Gilani & Türker (2020)	1.Conversion from one function to another, exchange of functions	Multipurpose room
	2.Ability to separate and rejoin rooms	Movable partition
	3.Ability to rearrange furniture	Multipurpose room
Ghafourian (2018)	1.Ability to divide a room into two separate spaces	Movable partition
	2.Various possibilities for arrangements of furniture	Multipurpose room
	3.Using movable and foldable furniture	Transformable furniture
Beisi (1995)	1.Multipurpose rooms	Multipurpose room
	2.Several possibilities for connecting rooms	Movable partition
	3.Flexible or moveable walls	Movable partition

form relies on the vague anticipation of users' various interpretations of space and possible functions. Therefore, a space with different functional capacities is considered a convertible space, which can meet the users' various functional needs (functional flexibility). Convertibility applies to both temporary and permanent changes. For example, foldable furniture can easily convert a living room into a bedroom temporarily without any structural modifications (Schneider and Till, 2007). Permanent conversion of a bedroom into a study room through different spatial arrangements is another example. Such changes can create spaces adaptable to the users' changing needs and demands.

2.2. Indicators

Multifunctionality and convertibility are the qualitative characteristics of architectural space. Therefore, to provide a simple and reliable means to measure changes in these components, it is necessary to determine related variables, namely, indicators. Each indicator provides a tool to evaluate the flexibility of housing design. In this study, indicators were extracted by reviewing the designers' perspectives of flexibility, leading to multifunctionality and convertibility in architectural space.

2.2.1. Multifunctionality indicators (MIs)

Designers have introduced specific characteristics for multifunctionality, which have been widely used to facilitate functional flexibility in architectural spaces. Gilani and Türker (2020) considered "combining different activities at the same time, at the same place" as an indicator to analyze multifunctionality. Some designers also described that multifunctionality is characterized by different integrations of housing functions (Grütter, 1987; Ghafourian, 2018; Alfirevic and Simonović Alfirević, 2016). The extracted indicator is as follows:

Type of combined activities (MI1): This indicator represents a number of activities simultaneously occurring in a single room without any fixed barriers. In practice, the type of combined activities in a multifunctional space can accommodate various layouts of a residential unit. Integration of a living room, dining room, and kitchen into one space (LDK) and integration of the dining room and kitchen into one space (DK) (Alfirevic and Simonović Alfirević, 2016) are two significant examples of housing layout.

2.2.2. Convertibility indicators (CIs)

Designers have been frequently proposing housing design solutions

to improve the characteristics of convertibility; these characteristics can be applied to determine CIs (Table 2).

Considering the characteristics of convertibility in architectural space described by the designers (Table 2), the extracted indicators were as follows:

Multipurpose room (CI1): A multipurpose room is regarded as a functionally neutral room, which can be used for various purposes at different times. The spatial plan consists of equal-sized rooms with indeterminate uses (Schneider and Till, 2007). This spatial arrangement accommodates various furniture layouts for the rooms, allowing for different modes of occupation depending on the users' demands.

Movable partition (CI2): The adjacent rooms can be connected by movable partitions and doors. For example, light sliding doors are used to join or divide the rooms in traditional Japanese housing (Schneider and Till, 2007). Different room relationships allow the users to interpret the rooms for different uses (Kim, 2013). On the other hand, the use of movable partitions, besides the ability to change the size and function of space, enables users to change the space function according to their needs.

Movable shell (CI3): A movable external shell establishes a variable relationship between indoor and outdoor spaces. It can influence the functional potential of a room by converting the indoor closed space into a semi-open space, using movable enclosure in the external walls.

Transformable furniture (CI4): Transformable or space-saving furniture can periodically change the function of space. A folding bed, for instance, can transform a living room during the day into a bedroom at night (Schneider and Till, 2007). The use of foldable furniture may be the best way to change functions in a small space.

3. An overview of contemporary Japanese housing layouts

This section includes the evolution of contemporary housing design in Japan, its layout typology, and common features.

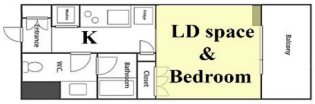
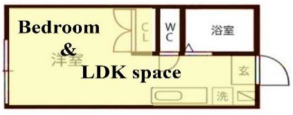
Considering the substantial war damage and housing shortage following the Second World War, the Japanese government faced a housing crisis in different cities (Ronald, 2009). In an attempt to resolve the severe housing shortage in the late 1950's and 1960's, large-scale housing complexes, called "Danchi" in Japanese, were built by the government. Generally, each unit in Danchi consists of a central dining-kitchen area, separate bedrooms, a bathroom, and a toilet (Daniels, 2012). It should be noted that in contemporary Japanese housing history, the Danchi apartment layout plays a key role in separating the dining and sleep spaces (Daniels, 2010).

Additionally, rapid urbanization, rapid population growth, and economic constraints led to the emergence of limited spatial dimensions and multifunctional spaces (e.g., dining room/kitchen). In the 1970's, the total number of housing units in Japan exceeded the number of households, leading to the greater importance of quality than quantity in housing design (Minami, 2016). This phenomenon resulted in the development of longer-lived houses by applying flexibility strategies. Movable partitioning systems in the Kodan Experimental Housing Project in 1982 (Minami, 2007), besides changeable façade systems in the Next 21 Project built in 1994 (Kendall and Teicher, 2000), are well-known case studies of flexible housing.

Post-war housing layouts, such as Danchi units, were standardized based on the "n-DK" model, where n denotes the number of rooms, except for the combined dining-kitchen (DK) area (Ronald, 2009). Later on, the "n-LDK" housing style was proposed by adding a living room (L) to the n-DK model, leading to an enlarged house size (Hinokidani, 2007). Besides, the DK and LDK styles could become an LD style, that is, a combined living room/dining room space with an adjacent kitchen. Generally, the n-DK and n-LDK styles are widely used in contemporary Japanese housing layouts.

Despite differences in construction techniques, standardization of

Table 3. *Layout typologies in Japanese contemporary house (Adapted from Real Estate Japan, 2020).*

Layout	Rooms	Example
nLDK	- A multifunctional space for Living/ Dining / Kitchen - "n" denotes the number of rooms separate from LDK (basically the number of bedrooms) - Toilet/bathroom	
nDK	- A multifunctional space for Dining / Kitchen - "n" denotes the number of rooms separate from DK - 1 room is used as a living room according to the user's perspective - Toilet/bathroom	
nSLDK	- A multifunctional space for Living / Dining / Kitchen - "n" denotes the number of rooms separate from LDK (basically the number of bedrooms) - Service room - Toilet/bathroom	
1k	- A multipurpose room as a multifunctional space for Living and Dining during the day and bedroom at night - Kitchen - Toilet/bathroom	
1R	- A multipurpose room as a multifunctional space for Living / Dining / Kitchen during the day and bedroom at night - Toilet/bathroom	

housing layouts and industrialization of construction techniques have led large construction companies in Japan to build residences with similar layouts, based on a combined space (DK or LDK style) and some private rooms (Daniels, 2010). Today, housing units in all types of Japanese styles, whether detached houses or apartment units, are classified based on a model, which determines how many rooms the housing unit has in total, excluding the bathroom and/or toilet (Real Estate Japan, 2020). These contemporary housing layouts are summarized in Table 3.

Based on the authors' observations of Japanese houses and literature review, common features related to functional flexibility were extracted:

Multifunctional space: The standardization of housing layouts after World War II (Daniels, 2010) and limited living space led to the emergence of multifunctionality in Japanese housing layouts. As mentioned earlier, multifunctional spaces are open-plan spaces that can have multiple functions at the same time. According to the housing layouts in contemporary Japan (Table 3), there are three types of multifunctional spaces based on the type of combined activities. The combination of activities, such as cooking and eating, forms a DK space in the n-DK layout. Similarly, combining activities, such as cooking, eating, and gathering together in the n-LDK, n-SLDK, and 1R layouts, as well as eating and gathering together in the n-K layout, create LDK and LD, respectively.

a b

Figure 1. *(a) Japanese-style room. (b) Western-style room (Authors, 2019).*

Multipurpose rooms: Japanese housing layouts usually consist of a multifunctional space and a number of private rooms designed in two styles, including Japanese and Western (Ronald, 2009) (Figure 1). A Japanese-style room or a tatami room is floored by tatami mats and characterized by the minimal use of furniture. On the other hand, Western-style rooms use wooden floors, and their functions are determined by the available furniture. The main distinguishing feature of these two design styles is the different lifestyles they can offer. The Japanese-style room implies floor-based living, whereas the Western-style room implies furniture-based living.

Generally, a tatami room is a multipurpose or functionally neutral room. Tatami is a traditional Japanese mat that has been used as a flooring material for sitting, sleeping, walking on, or a novel activity, such as refreshing the covers of tables, benches, and even beds (Yagi, 1992). Overall, the use of uniform-sized tatami mats as flooring enhances the functional potential of a room. The multifunctionality of tatami rooms, as well as the minimal use of furniture, provides sufficient space for various activities.

Movable partitions and shells: The analysis of housing layouts designed by major Japanese homebuilders (e.g., Misawa, Sekisui, Daiwa, and Panasonic) and architectural offices showed that two adjacent rooms may be connected by movable partitions, such as sliding doors or a door as a dividing element (Figure 2a). For example, a tatami room can be connected to its adjoining room by the means of sliding doors (Ronald, 2009), making it possible to change its size and function. By joining two small rooms, a larger architectural space can be created to adapt to the users' varying needs. Moreover, by using movable shells that provide semi-open spaces (e.g., balcony and terrace), the interior space can be converted to a semi-open space, and functional flexibility is achieved in the housing layout (Figure 2b).

Figure 2. *(a) Movable partition. (b) Movable shell in Kairo-no-iye (Cloister House) by Tezuka Architects (Authors, 2019).*

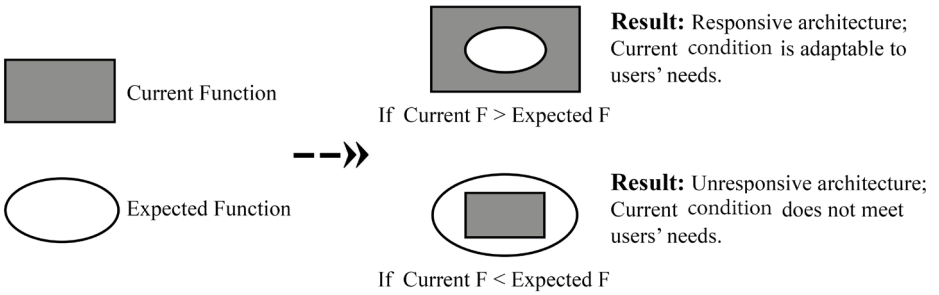


Figure 3. *Conceptual model for assessing functional flexibility (Diagram by Authors).*

4. Data collection

A questionnaire survey was conducted, targeting contemporary residents to collect the required data for this study. The users were asked if their households were responsive to their various needs. The results of the questionnaire survey were used as criteria to evaluate functional flexibility in contemporary living spaces in Japan.

4.1. Sampling technique

A survey was conducted in 2019 to collect the required primary data from the contemporary users of Japanese detached houses and apartment units. The samples were selected through simple random sampling method, which is a reliable method for collecting information when every single member of the population is chosen randomly (Rao, 2000). In this method, every population unit is given an equal chance to appear in the sample. It is worth mentioning that standardization of housing layouts in Japan (Daniels, 2010) reduced data scattering and facilitated the generalization of findings to the entire community. To collect information using this method of sampling, the questionnaires were sent to the residents' mailboxes (300 housing units including 134 detached houses and 166 apartment units) in Tokyo. Responses were received from 138 homes (51 detached houses and 87 apartment units), registering a response rate of 46%. The sample was logically assumed to represent the entire population of contemporary housing users in Japan.

4.2. Questionnaire structure

A questionnaire was used to assess the perceived gap between the users' needs and the current residential status from the users' perspectives. The current functions include a set of housing design strategies to meet the users' needs, while the expected functions comprise a set of users' expectations from their living space. If a space cannot meet these expectations, it can lead to user dissatisfaction. The conceptual analysis model of functional flexibility is therefore based on the analysis of the gap between the current and expected functions of the housing design (Figure 3).

To determine the demographic characteristics of the participants in the questionnaire, they were first asked about their sex, ownership status, and level of participation in the design and construction phases. Next, the rest of the questionnaire was structured in two parts containing 11 close-ended questions, three of which evaluated MI1, while the remaining eight evaluated CI1, CI2, CI3, and CI4 under current and expected conditions.

5. Statistical analysis

The questionnaire findings were analyzed using SPSS for Windows Version 23.0 (IBM Corp., Armonk, NY, USA). A two-sided P-value less than 0.05 indicated a significant difference. Chi-square and binomial tests were used as two valuable statistical tools to test the significance of data. Chi-square distribution test is a non-parametric test to compare the observed frequencies with the expected frequencies. Also, binomial test is a non-parametric test to determine whether the frequency distribution of nominal, dichotomous variables corresponds to the assumed distribution (Agresti, 2007).

Table 4. *Assessment results of the current and expected conditions of MI1.*

Layout type	Current condition		Expected condition				Difference (gap) between current and expected conditions (percentage)
	Descriptive statistics		Descriptive statistics		Statistical test		
	Frequency	Percentage frequency	Observed frequency	Percentage frequency	Chi-square statistic	Asymptotic Sig.	[current - expected]
Without multifunctional room	6	4.34%	18	13.04%	39.971	0.000	-8.70%
DK room	20	14.49%	52	37.68%			-23.19%
LD room	44	31.88%	14	10.14%			21.74%
LDK room	68	49.29%	54	39.14%			10.15%
With multifunctional room (DK, LD, LDK)	132	95.66%	120	86.96%	-	-	-
Sum	138	100%	138	100%	-	-	-

5.1. Description of sociodemographic characteristics

As mentioned earlier, 138 users participated in this study. The studied sample with no missing data (n=138) consisted of 53.6% males and 46.4% females. The respondents were aged between 24 and 67 years (M=37.81; SD=9.493). Moreover, 37.7% of the respondents owned their place of residence and were asked if they had participated in the design and construction of their house with designers or homemaker companies. A large majority of owners completing the questionnaire (n=46, 88.47%) had not participated in the design or construction phases.

5.2. Assessment of multifunctionality indicators (MI)

To assess the functional flexibility of housing layouts, the current and expected conditions of the multifunctionality indicator (MI1) were studied using two different categories of questions. The first category determined the frequency of multifunctional rooms and types of multifunctional spaces (LDK, DK, and LD) according to the type of combined activities under the current condition, and the second category specified the frequency of multifunctional spaces (LDK, DK, and LD) based on the respondents' preferences. Next, Chi-square test was conducted. The total scores of the questionnaires are presented in Table 4, where a P-value less than 0.05 was considered significant.

Table 4 consists of two parts. The first part presents the current conditions, and the second part depicts the respondents' expected conditions. According to the table, under the current conditions, 95.66% of dwellings had a multifunctional space (DK=14.49%, LD=31.88%, and LDK=49.29%) in their housing layouts. The second part shows the respondents' preferences for the spatial organization of living room, kitchen, and dining room ([L, D, K], [L, DK], [LD, K], and [LDK]). The results revealed that 86.96% of the respondents favored housing layouts, including a multifunctional space (DK=37.68%, LD=10.14%, and LDK=39.14%). The majority of the respondents (76.82%) chose housing layouts, including DK or LDK (DK=37.68% and LDK=39.14%) under the expected condition, while 10.14% considered LD to be consistent with their needs.

Depending on the users' preferences, data related to the expected layouts were examined by Chi-square

Table 5. *Assessment results of the current and expected conditions of CI1, CI2, CI3, and CI4.*

CI	Current condition				Expected condition				Difference (gap) between current and expected conditions (percentage)
	Descriptive statistics		Statistical test		Descriptive statistics		Statistical test		
	Frequency (Affirmative response)	Percent (Affirmative response)	Test prop.	P-value	Frequency (Affirmative response)	Percent (Affirmative response)	Test prop.	P-value	[current - expected]
CI_1	108	78.3	0.50	0.000	82	59.4	0.50	0.033	18.9
CI_2	93	67.4	0.50	0.000	33	23.9	0.50	0.000	43.5
CI_3	113	81.9	0.50	0.000	124	89.9	0.50	0.000	-8
CI_4	38	27.5	0.50	0.000	84	60.9	0.50	0.013	-33.4
Sum	138	100%	-	-	138	100%	-	-	-

test ($\chi 2$). This statistical test was used to identify whether the relationships between variables were significant. Table 7 indicates a significant relationship between different expected layouts based on the users' preferences ($\chi 2$=39.971, asymptotic Sig.=0.000, P-value<0.05). The percentage of individuals who selected spatial organizations, including multifunctional spaces (LDK, DK, and LD) (86.96%), was significantly higher than that of individuals choosing spatial layouts without a multifunctional space (13.04%).

Table 4 indicates differences (gaps) between two sets of values to compare the frequency percentage distribution of various combinations of activities in the current and expected conditions. As shown in Table 4, in the current conditions, the frequency (percentage) of housing layouts, including DK and those without multifunctional rooms, was lower compared to the expected condition. Besides, the frequency (percentage) of housing layouts, including LD (31.88%), was higher in the current condition compared to the expected condition (10.14%). Similarly, the frequency (percentage) of housing layouts including LDK (49.29%) was higher in the current condition compared to the expected condition (39.14%).

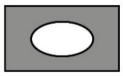
5.3. Assessment of convertibility indicators (CIs)

To assess the functional flexibility of housing layouts, the current and expected conditions of CIs were measured using two categories of questions. The first category determined whether these indicators existed in the housing units, and the second category specified whether the respondents needed these indicators. The total score of the questionnaires was a measure of functional flexibility in convertible spaces. Next, a nonparametric binomial test was conducted (as presented in Table 5). A P-value less than 0.05 was considered significant.

Table 5 consists of two parts. The first part represents the current conditions, and the second part depicts the respondents' expectations. The table shows that in the current condition, 78.3% of the respondents' residences had multipurpose rooms (CI1), and 67.4% of the respondents had either a movable partition or a door between at least two rooms in their residence (CI2). Moreover, 81.9% of the respondents' residences had movable shells in the external walls (CI3), and 27.5% of the respondents used foldable furniture at home (CI4). To examine whether the frequency distribution of CI1, CI2, CI3, and CI4 is significant under the current condition, a binomial test was applied. The results showed that the P-value was less than 0.05 (P-value=0.000 for CI1, CI2, CI3, and CI4); in other words, the result was significant, and the frequency (percentage) of affirmative responses differed significantly from the test proportion (0.50).

Under expected conditions, 59.4%,

Table 6. *Conceptual model for assessing MI in contemporary Japanese housing.*

Indicators		Conceptual assessment model		
		Comparison of current and expected functions	Current function / Expected function	Result
MI_1	Types of combined activities	Expected condition < current condition (responsive architecture)		Current condition is adaptable to users' needs

23.9%, 89.9%, and 60.9% of the respondents evaluated CI1, CI2, CI3, and CI4 to be consistent with their needs, respectively. To determine whether the frequency distribution of CI1, CI2, CI3, and CI4 was significant under the expected conditions, a binomial test was performed. The results showed that the P-value was less than 0.05 (P-value for CI1=0.033; P-value for CI2 and CI3=0.000; and P-value for CI4=0.013), meaning that the result was significant, and the observed frequency (percentage) of affirmative responses differed significantly from the test proportion (0.50).

For comparison of the frequency percentage distribution of CIs under the current and expected conditions, Table 5 presents the difference (gap) between the two sets of values. As shown in Table 5, under the current condition, the frequency (percentage) of CI1 and CI2 was higher than expected. However, the frequency (percentage) of CI3 and CI4 was lower than expected under the current condition.

6. Discussion

Identification of the components of functional flexibility (i.e., multifunctionality and convertibility) and their indicators makes the concept of functional flexibility comprehensible and provides a tool to evaluate it in housing layouts. Also, since the residents' reaction to the available flexible solutions has been investigated insufficiently, this study used a questionnaire survey to integrate the users' perspective for evaluating functional flexibility. For this purpose, users involved in this questionnaire survey were asked about the current and expected conditions of the indicators (Tables 4 and 5).

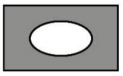
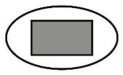
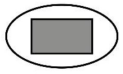
For each indicator, the frequencies related to the current and expected conditions were compared to determine whether the available solutions could be responsive to the users' expectations. The current condition can be helpful in functional flexibility if it covers the users' expectations; otherwise, it requires changes for adaptation to their needs. In the following section, functional flexibility in Japanese housing layouts was evaluated in two sections, that is, multifunctionality and convertibility, and then, some suggestions were made to optimize these spatial layouts.

6.1. Evaluation of multifunctionality indicator (MI) in Japanese housing layouts

In this study, multifunctionality was evaluated in Japanese housing layouts, using the indicator of "type of combined activities". This study investigated the users' perspectives of spatial organizations, including multifunctional spaces (DK, LD, and LDK), and organizations without multifunctional space under the current and expected conditions (Table 4). Overall, 95.66% of users involved in this survey had a multifunctional space in their housing unit, and only 4.34% used separate rooms for the kitchen, dining room, and living room. Also, 86.96% of the users considered a multifunctional space to be suitable to their needs. According to the conceptual analysis model described earlier, the current condition could meet the expectations (Table 6). Consequently, Japanese housing units can be considered flexible in terms of multifunctionality.

As previously mentioned, in the contemporary Japanese housing layouts (Table 4), there are three types of

Table 7. *Conceptual model for assessing CIs in contemporary Japanese housing.*

Indicators		Conceptual assessment model		
		Comparison of current and expected functions	Current conditions / Expected conditions	Result
CI_1	Multipurpose room	Expected condition < current condition (responsive architecture)		Current condition is adaptable to users' needs
CI_2	Movable partition	Expected condition < current condition (responsive architecture)		Current condition is adaptable to users' needs
CI_3	Movable shell	Expected condition > current condition (unresponsive architecture)		Current condition does not meet users' needs
CI_4	Transformable furniture	Expected condition > current condition (unresponsive architecture)		Current condition does not meet users' needs

multifunctional spaces based on the type of combined activities: DK, LD, and LDK. The present study also explored the users' points of view about these spaces under the current and expected conditions and then measured differences in their frequencies (Table 4). The frequency distribution of layouts under the expected conditions revealed that the users preferred layouts, including DK and LDK to those with LD or without multifunctional rooms. In the current condition, the frequency of LDK layouts exceeded the users' expectations, while the frequency of housing layouts including DK did not match the users' expected conditions. Therefore, more attention should be paid to layouts involving a DK space; moreover, a movable partition (such as a sliding door) can be installed in LDK between DK and living spaces so that LDK can be converted to DK and a separate living room when needed. Moreover, since the frequency of Japanese housing layouts including an LD room was higher than the users' expectation, it can be suitable to use a movable partition between the LD room and kitchen, which makes the alteration of LD to LDK possible when needed.

Generally, it is suggested to design the living room, dining room, and kitchen adjacent to each other. Also, it is recommended to anticipate requirements for movable partitions (e.g., installing frames on the ceiling and floor) between these three spaces in the design stage. In this manner, users can choose which activities to combine to form LDK, DK, and LD or three separate rooms according to their needs at any time.

6.2. Evaluation of convertibility indicators (CIs) in Japanese housing layouts

Convertibility was evaluated in Japanese housing layouts using the indicators of "multipurpose room", "movable partition", "movable shell", and "transformable furniture". To this end, this study explored the frequency distribution of CIs in Japanese housing layouts under the current conditions. Also, it indicated the users' views about the adaptability of these indicators to their needs under the expected condition and then measured the differences between their frequencies (Table 5).

In this study, a conceptual analysis model was applied to determine whether the frequency distribution of CIs responded to the users' expectations under the current condition. Table 7 presents the conceptual models related to CI1, CI2, CI3, and CI4 for evaluating the gap between the current and expected conditions in the contemporary Japanese housing.

The results showed that in the case of multipurpose room (CI1) and movable partitions (CI2), the current condition of Japanese housing layouts had a greater potential than the expected condition to meet the users' needs. In case of movable shells (CI3) and transformable furniture (CI4), the ex-

isting condition did not match the users' expectations. Therefore, it can be recommended to add external movable and sliding skins to increase the functional flexibility of interior space. Moreover, it is suggested that industrial designers, interior designers, and architects pay more attention to this indicator.

7. Conclusion

This study evaluated functional flexibility in the contemporary Japanese housing layouts with the integration of users' perspectives. Although the functional flexibility of housing units depends on their ability to accommodate non-structural changes by users, the users' perspectives have been rarely considered in the assessment of flexibility. To evaluate the functional flexibility of contemporary Japanese housing, the present study compared the users' opinions about the current and expected conditions of functional flexibility. The results first identified the components and indicators of functional flexibility to provide assessment criteria. The findings showed that functional flexibility comprised two components of multifunctionality and convertibility. Multifunctionality was evaluated using the indicator of type of combined functions. Convertibility was assessed by indicators, including a multipurpose room, movable partition, movable shell, and transformable furniture. Next, a questionnaire survey was conducted to assess the gap between the current and expected conditions based on the users' perspectives.

The results revealed that the spatial layouts of contemporary Japanese houses have some characteristics associated with functional flexibility: 1) multifunctional spaces (LDK, DK, or LD) with various combinations of living, dining, and kitchen areas; 2) multipurpose rooms which accommodate various activities at different times; 3) movable partitions (sliding doors) between rooms which enable users to change the size and function of rooms. Regarding the mentioned indicators, the current conditions were adaptable to the users' needs, while the current conditions of indicators, including the movable shell and transformable furniture, did not entirely meet the users' expectations. Moreover, this study presented some suggestions to fill the gap between the current and expected conditions to optimize the adaptability of Japanese housing layouts to the users' changing needs. These suggestions are as follows:

Creating housing layouts with LDK or DK.

Designing the living room, dining room, and kitchen adjacent to each other and installing frames on the ceiling and floor between them to facilitate adding movable partitions in the future.

Creating a movable shell between the interior and exterior spaces.

Using transformable furniture (e.g., foldable furniture) for altering the function of a room.

Overall, this study focused on the development of functional flexibility from the users' perspectives by identifying its dimensions. It is suggested to conduct a study targeting the development of structural-spatial flexibility and to evaluate it based on the opinions of home builders and designers in Japan.

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