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Using change modes and effects analysis tool for explaining the ratio of flexibility and spatial organization in housing

Usando la herramienta de análisis de modos y efectos de cambio para explicar la proporción de flexibilidad y organización espacial en la vivienda

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ABSTRACT

Architectural spaces with the capability of spatial organization and internal transformations can respond to a greater number of their users' needs at different times. The necessity to access this ability is one of the subcategories of flexibility in housing as a contemplative subject. The purpose of this research is to provide an analytical model in relation to understanding change modes and effects analysis tool and using its indicators to assess flexibility in housing. The research method in the present study will be of mixed type, and its performance method will be based on estimation and evaluation. The obtained results show that the spatial organization in residential complexes in Tehran city is based on applying possible changes in the spaces. This has led to the increased flexibility of spaces in relation to various activities.

Keywords: housing; flexibility; spatial organization; change modes and effects analysis.

RESUMEN

Los espacios arquitectónicos con capacidad de organización espacial y transformaciones internas pueden responder a un mayor número de necesidades de sus usuarios en diferentes momentos. La necesidad de acceder a esta capacidad es una de las subcategorías de la flexibilidad en la vivienda como sujeto contemplativo. El propósito de esta investigación es proporcionar un modelo analítico en relación con la comprensión de la herramienta de análisis de modos y efectos de cambio y el uso de sus indicadores para evaluar la flexibilidad en la vivienda. El método de investigación del presente estudio será de tipo mixto, y su método de desempeño se basará en la estimación y evaluación. Los resultados obtenidos muestran que la organización espacial en los complejos residenciales de la ciudad de Teherán se basa en la aplicación de posibles cambios en los espacios. Esto ha llevado a una mayor flexibilidad de espacios en relación a diversas actividades.

***Palabras clave**: alojamiento; flexibilidad; organización espacial; análisis de modos y efectos de cambio.*

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1. INTRODUCTION

Nowadays, on the one hand, it can be seen that designers' connection with users has decreased over time, which reduces their knowledge of basic needs and wants. On the other hand, also living difficulties, rising prices, and the ever-changing situations of families have been cited as leading to flexibility and spatial organization in housing. But most of the projects have lacked the necessary productivity by ignoring or less attention to the living needs of the residents, and their inability to respond optimally to the needs of users is clear. Housing is one of the vital elements of human life and supplier of his or her various needs, which is called the place of rest or stop, and its role and importance as a convenient accommodation are sensitive and key. The importance of housing stems from the fact that many of each person's basic needs are met there. Considering the increase in the rate of migration, the expansion of urbanization, the technical advances in construction, the greater awareness of individual rights, and the need to meet social demands, the housing issue and the need to access it is taking on new dimensions day by day (1). Today houses in the world and Iran have not been able to succeed in meeting the needs of users. Because the changes in them have not been derived from changes in needs but only correspond with a particular style at a specific time that they are predictable in a short time in the economy. Therefore, the main concern is the limitation of various choices in housing species according to their type and also the inability to regulate users' residence over time based on their wants and needs or in accordance with demographic changes (2). The great cities of the world in the new age have become the place of the density of population and the place of exchange of goods, objects, and information. The collection of these factors has led to problems such as increasing domain of inequalities, expanding degradation of criteria, and even changes in norms, values, and behaviors of individuals and has led to humans living more time in a more limited context of society whole. On the other hand, Iran has also faced a sudden population growth in recent years. The economic downturn, social problems, and the lack of specialized personnel in the fields of civil, architecture, and urbanism with a clear rationale led to hasty decisions that put housing supply solutions in an unsuitable cycle. Today, housings are being developed without the provision of complementary elements. In other words, services, facilities, and also qualities of different spaces are ignored. Meanwhile, public and private investors have begun to build by seemingly emulating the experiences of countries and importing new technologies, regardless of the conditions that this type of housing brings. Development and urbanization in Iran are leading to the gradual replacement of individual housings with multi-family residential complexes. These new dwellings were largely designed by foreign companies and Iranian architects educated abroad with minimum knowledge of Iranians' lifestyles. In the first comprehensive plan of Tehran city, it was explained that one-floor housings are the consequence of poor construction techniques and central courtyards are the reflection of old social conventions. The need for introverted areas is eliminated and life in residential complexes is created. Balconies will substitute for courtyards, and elevators will increase the number of floors (3).

Discussion about flexibility in architectural spaces is among the topics that have received a lot of attention in recent years. Satisfying a variety of needs of different users at different times is one of the reasons for this attention. However, most researches in this field have attempted to provide general definitions and also, in some cases, introduced strategies and tools to make human living spaces flexible, especially housing. Among them, we can mention the modular approach and prefabrication in flexible housing (4), flexibility criteria for design of apartment housing in Iran (5), and such cases. Analyzing them, this important can be achieved that the conceptual dimensions and the way of demonstration of such a subject in various spatial patterns have been less studied. In some ways, it can be mentioned that there is no research on housing based on this content in the country. In addition, change modes and effects analysis as a method to evaluate products flexibility has so far been used only in industrial design and not in architectural design. Among them, we can mention do's and don'ts of computerized manufacturing (6), classification of flexible manufacturing systems (7), postindustrial manufacturing (8), an agenda for research on the flexibility of manufacturing processes (9), economic measure of productivity, quality, and flexibility in advanced manufacturing systems (10), flexibility in manufacturing: a survey (11), and such cases. Using this tool for housing as another form of product, in addition to the field of design in the industry, we also adapt it to the field of design in architecture. Although in some researches flexibility has been used and in others change modes and effects analysis has been considered, this research affects study by using them simultaneously with each other. On the other hand, it seeks to provide an analytical model in relation to understanding change modes and effects analysis tool and using its indicators to assess flexibility in housing. In order to better express the problem, this research attempts to answer the question:

How to use the indicators of change modes and effects analysis tool to assess flexibility in housing?

2. STATE OF THE ART

2.1. Background

In the field of flexibility and spatial organization in housing, various theories and experiences with different orientations have emerged, especially in recent times. This multiplicity and diversity of opinions point out the importance and urgent need for the issue. Reviewing the body of knowledge, some of the research achievements in this field have been categorized and presented based on the time of publication.

Howe (1990), in an article entitled "The flexible house designing for changing needs," concludes that this mode of design will facilitate the adaptation of the house to changing household needs and dampen the demand for new housing in developing areas (12). Gosling et al. (2008), in an article entitled "Flexible buildings for an adaptable and sustainable future," conclude that a flexible and adaptable approach to construction may contribute to the sustainable construction agenda (13). Shabani et al. (2010), in an article entitled "Achieving privacy in the Iranian contemporary compact apartment through flexible design," conclude that the flexibility will be described to get applied in today's compact apartment that is to create spaces with the ability to combine and separate from each other to have more privacy (14). Rian and Sassone (2012), in an article entitled "Flexible housing, a healthy housing: a brief discussion about the merits of flex-

ibility in designing healthy accommodation," conclude that flexibility can offer a better, adaptable, customizable, affordable, and accessible domestic setting in every aspect that brings comfort to the occupants' physical, mental, and socio-emotional health (15). Abbaszadeh et al. (2013), in an article entitled "Analyzing a proper flexible and adaptable pattern for promoting the housing quality in Iran," conclude that a flexible and adaptable home designing on the basis of the residents' requirements changes in their different lifecycles is one of the strategies to satisfy the residents and prevent them from changing their homes (16). Seo and Kim (2013), in an article entitled "Interpretable housing for freedom of the body: the next generation of flexible homes," conclude that more precisely designed houses can guarantee the freedom of the body and thus alternatives for the flexible domestic life (17). Cellucci and Di Sivo (2015), in an article entitled "The flexible housing: criteria and strategies for implementation of the flexibility," conclude that flexibility can be considered as the antidote to obsolescence or the characteristic of the system that guarantees slippage over time (18). Estaji (2017), in an article entitled "A review of flexibility and adaptability in housing design," concludes that flexibility is the ability and the potential of a building to change, adapt, and reorganize itself in response to the changes (19). Ghafourian (2018), in an article entitled "Identification of flexible types in designing Iranian apartment housing," concludes that the four types of flexibility are introduced in order of priority, including extensibility, the capability of different furniture arrangements, segregation, and multi-functionality in housing space (20).

Examining the mentioned items, it appears that flexibility is an issue related to spatial relations and current activities in them. But what is less considered are the conceptual dimensions and the way of demonstration of it in various spatial patterns. Accordingly, the present research tries to use change modes and effects analysis tool for explaining the ratio of flexibility and spatial organization in housing.

2.2. Flexibility

Flexibility is an essential concept in the field of housing due to changes in the needs and wants of users. Flexible housing can be defined as housing that is designed to change in its lifespan. Therefore, flexible housing is suitable for users with different and changing lifestyles. Accordingly, the ability of housing to meet the needs of users from the very beginning and during its use can be considered as one of the main fields of flexibility measurement in the field of architecture (21).

Generally, flexibility is referred to as the capability to change objects and things. In architecture and environmental design and particular housing design, this word refers to the spatial flexibility and the organization of human-made space and change in it to achieve new conditions, needs, and applications. Some spaces provide many activities without the need for reorganization, and some other spaces can be modified to meet different needs (22).

The artificial environment has some kinds of flexibility that require analysis. In this regard, the indicators of variability (multi-functional space), adaptability (seasonal and daily displacement), and changeability (segregation and aggregation) have been defined. Variability is the capability to provide different uses of space. This kind of flexibility deals with the two variables of space and time. Space of housing will be able to be used for several functions simultaneously and for different functions at different times. Variability can be achieved by designing a plan with a regular geometric structure, readable access to building equipment, and adjusting the size of spaces. Adaptability is the ability of a space to adapt to new conditions required. The most effective method to achieve this in architectural programming is fixing the internal components and the possibility of creating various combinations of them. In housing, it is the capability to meet the new needs by changing the interior walls and installing the components, provided that these changes do not make a change in the area of the building. Generally, adaptability includes all internal changes such as structural change, micro-elements, and spaces composition. Changeability refers to the decrease and increase of quantity or the segregation and aggregation of spaces and the possibility of returning to the original design after the conversion or expansion of its area. In this case, flexibility means the capability to respond to population growth at different stages of life. In other words, this ability makes it possible to change the size of housing in order to make it smaller or larger. The concept of changeability is related to the study of infrastructural changes, spatial needs, and its shape (23).

2.3. Spatial organization

Spatial organization is a basic pattern for creating a composition in architecture that brings together different spaces and provides a coherent structure for design (24). In general, there are conditions for different types of spaces in a house which are:

- Spaces have special functions or require special forms,
- Spaces should be functionally flexible and freely adjustable,
- Spaces must be easily accessible and adjacent to other spaces,
- Spaces have similar functions and can be placed together as a functional set or repeated in a linear order,
- Spaces must be open to the outside to provide light, ventilation, visibility, or access to open spaces,
- Spaces should be distinct and separated from each other for being private,
- Spaces have a unique and the only function or degree of importance.

The arrangement technique of these spaces can clarify their relative importance and functional role in the organization of one building (25). There are several methods for analyzing it, that each of them has its own quantitative and qualitative tools that the executive results of all of these somehow lead to a description of the function of space.

2.3.1. Change modes and effects analysis

Change modes and effects analysis is a tool for measuring a product's flexibility towards change and thereby diminishing the cost of redesign and shortening time to market. This method facilitates the evaluation of products for flexibility for future evolution and comparisons of the flexibility of different products for users. Accordingly, it can be used to help identify characteristics of a design that inherently aid or hinder the flexibility of a product. The goal of it is to aid designers in minimizing the costs associated with redesigning and producing one space when it evolves. Using this tool, each of the possible changes is evaluated by the indicators of design flexibility, readiness, and occurrence (26).

Design flexibility reflects how difficult and costly it is to start producing the product with the change. This measure is assessed by users based on the potential effects of change and the extent of changes in one space. The effects of these changes are rated on an interval scale of 1 to 10, that 1 means minimum design flexibility and 10 means maximum design flexibility. Readiness reflects how easily the designer can begin to implement the change in its producing chain. This measure is assessed by users based on the potential modes of change and the extent of changes in one space. The modes of these changes are rated on an interval scale of 1 to 10, that 1 means minimum readiness and 10 means maximum readiness. Occurrence reflects the probability of a particular change occurring. This measure is assessed by users based on the potential causes of change and the extent of changes in one space. The causes of these changes are rated on an interval scale of 1 to 10, that 1 means minimum occurrence and 10 means maximum occurrence (27).

The tool of change modes and effects analysis analyzes the different features of samples through one component of change potential number, and they are appeared according to the indicators of design flexibility, readiness, and occurrence [1]. Change potential number gives an indication of how easily a change can be incorporated into a product and the overall flexibility for a given change for users. Forming the table in a systematic manner is the main step in this process so that change potential number of one space for its possible changes can be assessed. The inherent flexibility of a design for a given change, the readiness of the designer to react, and the probability of occurrence are the main factors that are considered in this evaluation (28).

$$[1] \quad \mathrm{CPN} = 1/N \sum_{i=1}^{i=N} [(R_i + F_i) - O_i + 8]/27$$

Where F is design flexibility, R is readiness, and O is occurrence and N corresponds to the maximum of the number of potential modes of change, the number of potential effects of change, or the number of potential causes of change. The minimum change potential number is 0, which means that the product is completely inflexible for any future change, and the maximum change potential number is 1, which means that the product is completely flexible to any future change. Accordingly, it is called a completely inflexible space, in which redesign is done at a cost incurred, and it is called a completely flexible space, in which redesign is done at no cost incurred.

The formula from change potential number has been created, such that the change potential number is linearly related to the three indicators of design flexibility, readiness, and occurrence and normalized between 0 and 1. If a product is ideally flexible for a change, the values and the signs of these indicators should be assigned as explained. The number 8 in the numerator and the number 27 in the denominator are added to bound the change potential number from 0 to 1 (Table 1).

3. METHODOLOGY

The work method of this research will be done in combination and with mixed nature. Initially, information is collected through the library study, and the field survey includes using available information, observation, interview, and questionnaire. On the one hand, various demonstrations of flexibility including variability, adaptability, and changeability are categorized, in which the focus is on providing the qualitative components needed to design the desired spatial organization. On the other hand, indicators of change modes and effects analysis are identified. Then the possibility of a relationship between the components of flexibility and change modes and effects analysis is determined that this relationship is analyzed with the help of logical reasoning. In order to implement this result in real case samples, users of residential complexes in Tehran city are evaluated as a research society because it is the capital, the largest, and the most populous city of Iran and the existing restrictions in Tehran city have led to the expansion of the construction of residential complexes in contemporary architecture. The main strategy for sampling is to select the stratified random method proportional to the volume [2] that sample volume can be extracted through Cochran's formula [3]. Using the change potential number formula in change modes and effects analysis tool for estimation and evaluation, the indicators of design flexibility, readiness, and occurrence are ranked. Finally, inductive reasoning will be used to draw a conclusion about the subject.

$$[2] \quad n_h = (N_h/N)n$$

$$[3] \quad n = z^2 pq/e^2$$

Where n_h is the sample size for each stratum, N_h is the population size for each stratum, N is the population size, n is the sample size, z is the desired level of confidence (z = 1.96), e is the desired level of precision (e = 0.05), p is the estimated proportion of an attribute that is present in the population (p = 0.5), and q is the estimated proportion of an attribute that is not present in the population (q = 0.5) (29).

3.1. Analysis

Flexibility is a two-dimensional concept that is related on the one hand to physical structures and, on the other hand, to behavioral patterns, although it can be formed in response to changes of climatic and structural types. Accordingly, in order to understand the various fields of its formation, it is necessary to study spatial relations and current activities in them. Demonstrating the concepts of flexibility and change modes and effects analysis and investigating the case study samples are introduced below.

Table 1. Conditions for an ideally flexible product for a change.

Indicators	Description	Value	Sign
Readiness	The designer should be completely ready for this change	10	+
Design flexibility	It should cause a minimum effect or redesign to other functions, parts, or modules in the design	10	+
Occurrence	This change should have a low probability of occurrence	1	-

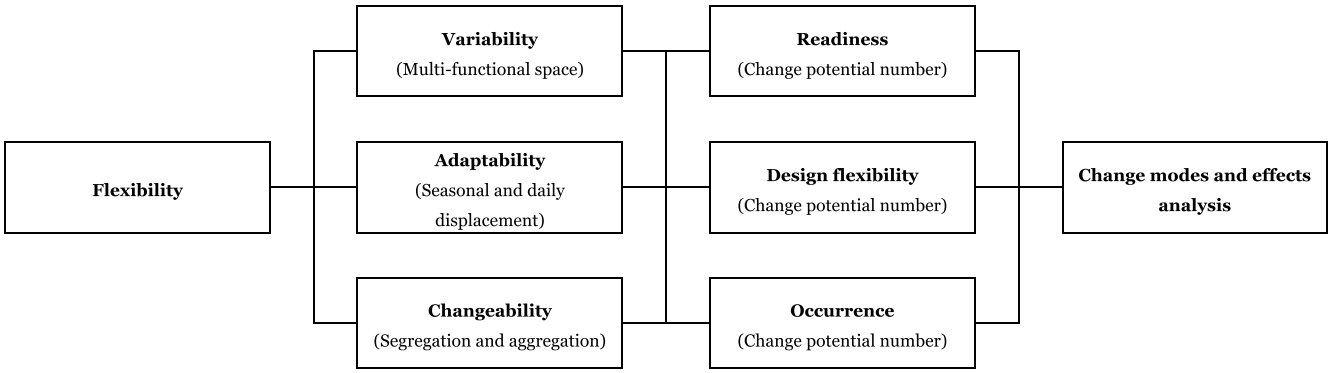


Figure 1. Demonstrating the concepts of flexibility and change modes and effects analysis.

3.1.1. Demonstrating the concepts of flexibility and change modes and effects analysis

Variability is a concept related to current functions in a spatial organization and means the capability to perform different activities of users in it. Adaptability is also another demonstration of flexibility that depends on the user and the type of his or her desires more than on the space and the existing activities in it. Changeability means the capability to make a change in the spatial organization of a set in order to perform the desired activities of users in it. Therefore, one space is considered more flexible from the point of view of users in which the inherent flexibility of a design for a given change is maximal, the readiness of the designer to react is maximal, and the probability of occurrence is minimal, which in turn leads to a lower redesign cost. These factors in change modes and effects analysis are obtained by the concepts of design flexibility, readiness, and occurrence, which can be evaluated using the component of change potential number. Thus, the indicators of variability, adaptability, and changeability in flexibility are related to the indicators of design flexibility, readiness, and occurrence in change modes and effects analysis tool to analyze the spatial organization, and thus affect the spatial organization in housing (Figure 1).

3.1.2. Investigating the case study samples

Based on the available statistics, the second district of Tehran municipality was selected with the highest number of residential complexes. Then based on the collected informa-

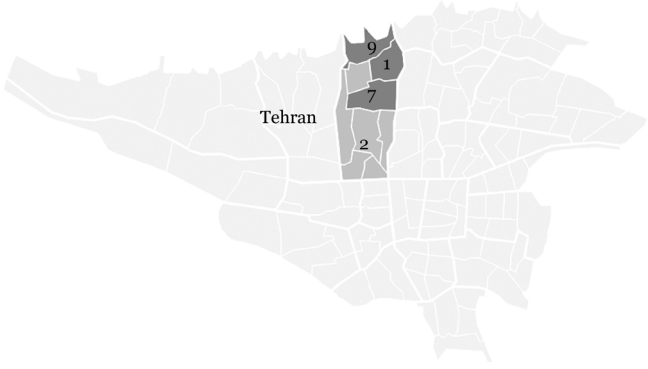


Figure 2. Tehran city, District two, Regions one, nine, and seven.

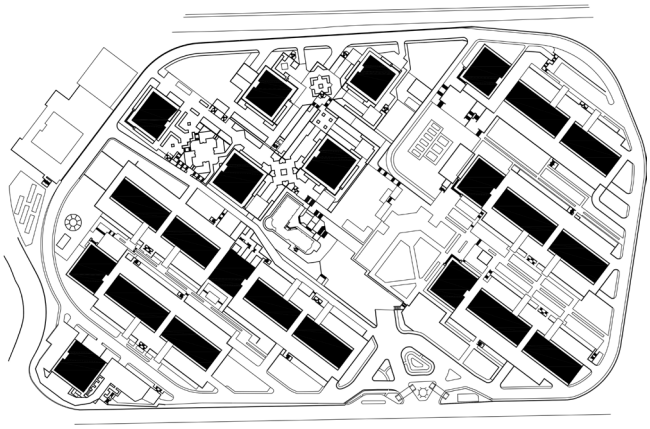


Figure 3. Atisaz residential complex site plan.

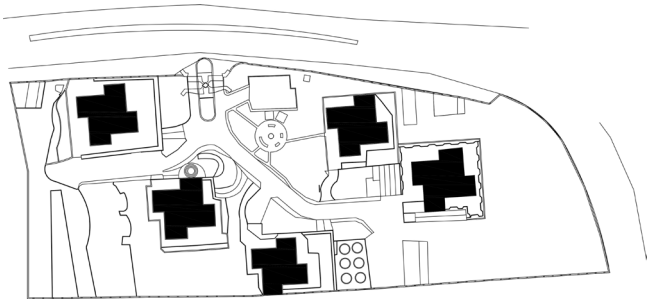


Figure 4. Mahan residential complex site plan.

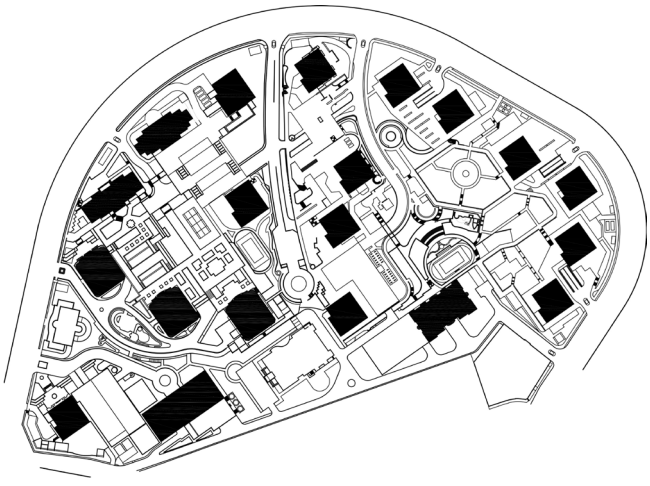
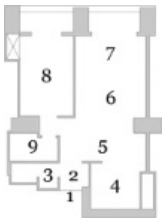
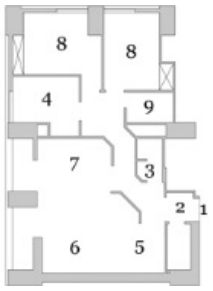
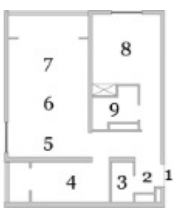
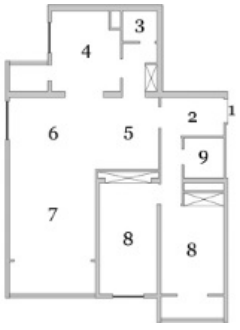
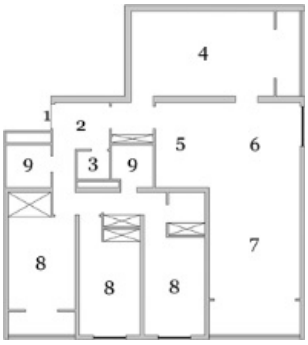


Figure 5. Hormozan residential complex site plan.

Figure 6. Similar blocks in Atisaz, Mahan, and Hormozan residential complexes.

Table 2. 1, 2, and 3 bedroom plans from similar blocks in Atisaz, Mahan, and Hormozan residential complexes, 1. Entrance, 2. Hall, 3. Toilet service, 4. Kitchen, 5. Living, 6. Dining, 7. Catering, 8. Bedroom, 9. Bathroom service.

Residential complexes	1 bedroom	2 bedroom	3 bedroom
Atisaz			
Mahan			
Hormozan			

tion, matching the data, and comparing them, common factors such as the number of units, height, and shape of open space were extracted and three residential complexes of Atisaz, Mahan, and Hormozan were eligible for the most species to build were identified. Atisaz with 23 blocks, 12 to 31 floors, and 2290 units, Mahan with 5 blocks, 19 floors, and 320 units, and Hormozan with 20 blocks, 16 to 33 floors, and 1433 units are located in regions one, nine, and seven respectively (Figures 2, 3, 4, and 5).

The 1, 2, and 3 bedroom plans were selected from similar blocks in each one, and their spaces were decomposed in some rational manner, so that the functions, parts, or modules of one space could be assessed for its possible changes. Analysis in terms of functions, parts, or modules shows the degree of complexity of the space under study (Figure 6) (Table 2).

A number of 384 people of their users that do not belong to the same dwelling were selected with a stratified random method proportional to the volume, and their needs in the spaces were identified as the potential causes of change, based on the importance and number of times that occurred, as a result of which the potential modes of change and the potential effects of change were classified. Based on the above, design flexibility, readiness, and occurrence were ranked and evaluated with the component of change potential number in its formula. All techniques used in the data collection were intended to ensure that all elicited data within all categories are completely based on the perceptions of the respondents (Tables 3 and 4).

4. ANALYSIS OF RESULTS

4.1. Findings

Based on the above contents, an analysis of the relationship between demonstrating the concepts of flexibility and change modes and effects analysis has been done by investigating the case study samples that have led to the adjustment of their factors with each other versus change potential number. Modifiability of furniture action hereunder the potential modes of change, which falls into the category of variability, is influenced by hedonism hereunder the potential causes of change and leads to spatial improvement hereunder the potential effects of change. Ranking of readiness for modifiability of furniture action as 3, design flexibility for spatial improvement as 10, and occurrence for hedonism as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.40. Adding a room without changing plan hereunder the potential modes of change, which falls into the category of variability, is influenced by hedonism hereunder the potential causes of change and leads to spatial improvement hereunder the potential effects of change. Ranking of readiness for add-

Table 3. Users of Atisaz, Mahan, and Hormozan residential complexes.

Users	Variable	Frequency	Percentage
Age group	20-40	329	86
	40-60	55	14
Gender	Male	188	49
	Female	196	51
Marital status	Single	213	55
	Married	171	45

Table 4. Change modes and effects analysis for 1, 2, and 3 bedroom plans from similar blocks in Atisaz, Mahan, and Hormozan residential complexes.

Spaces	Potential modes of change	Readiness	Potential effects of change	Design flexibility	Potential causes of change	Occurrence	Change potential number
Kitchen	Possibility to renovate equipment	3	Better ventilation	3	Security	9	0.18
Living	Adding a room without changing plan	5	Spatial improvement	4	Hedonism	10	0.25
Dining	Enlarging a room area	6	Preferred aesthetic	10	Hedonism	10	0.51
	Adding a room without changing plan	5	Spatial improvement	4	Hedonism	10	0.25
Catering	Adding a room without changing plan	5	Spatial improvement	4	Hedonism	10	0.25
Bedroom	Enlarging a room area	6	Preferred aesthetic	10	Hedonism	10	0.51
	Modifiability of wall color	5	Preferred aesthetic	3	Self-direction	10	0.22
	Modifiability of floor covering	2	Visual effect	6	Self-direction	10	0.22
Whole housing	Adding a room with changing plan	5	Everyday activity	1	Self-direction	10	0.14
	Modifiability of furniture action	3	Spatial improvement	10	Hedonism	10	0.40
	Modifiability of window size	2	Better ventilation	4	Security	9	0.18

ing a room without changing plan as 5, design flexibility for spatial improvement as 4, and occurrence for hedonism as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.25. Modifiability of floor covering hereunder the potential modes of change, which falls into the category of adaptability, is influenced by self-direction hereunder the potential causes of change and leads to visual effect hereunder the potential effects of change. Ranking of readiness for modifiability of floor covering as 2, design flexibility for visual effect as 6, and occurrence for self-direction as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.22. Modifiability of wall color hereunder the potential modes of change, which falls into the category of adaptability, is influenced by self-direction hereunder the potential causes of change and leads to preferred aesthetic hereunder the potential effects of change. Ranking of readiness for modifiability of wall color as 5, design flexibility for preferred aesthetic as 3, and occurrence for self-direction as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.22. Modifiability of window size hereunder the potential modes of change, which falls into the category of adaptability, is influenced by security hereunder the potential causes of change and leads to better ventilation hereunder the potential effects of change. Ranking of readiness for modifiability of window size as 2, design flexibility for better ventilation as 4, and occurrence for security as 9 are assessed. Finally, the change potential number is calculated using its formula to be 0.18. Possibility to renovate equipment hereunder the potential modes of change, which falls into the category of adaptability, is influenced by security hereunder the potential causes of change and leads to better ventilation hereunder the potential effects of change. Ranking of readiness for possibility to renovate equipment as 3, design flexibility for better ventilation as 3, and occurrence for security as 9 are assessed. Finally, the change potential number is calculated using its formula to be 0.18. Enlarging a room area hereunder the potential modes of change, which falls into the category of changeability, is influenced by hedonism hereunder the potential causes of change and leads to preferred aesthetic hereunder the potential effects of change. Ranking of readiness for enlarging a room area as 6, design flexibility for preferred aesthetic as 10, and occurrence for hedonism as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.51. Adding a room with changing plan hereunder the potential modes of change, which falls into the category of changeability, is influenced by self-direction hereunder the potential causes of change and leads to everyday activity hereunder the potential effects of change. Ranking of readiness for adding a room with changing plan as 5, design flexibility for everyday activity as 1, and occurrence for self-direction as 10 are assessed. Finally, the change potential number is calculated using its formula to be 0.14 (Table 5).

Adjustment of flexibility and change modes and effects analysis factors with each other versus change potential number shows that respectively by enlarging a room area, modifiability of furniture action, adding a room without changing plan, modifiability of floor covering, modifiability of wall color, modifiability of window size, possibility to renovate equipment, and adding a room with changing plan and consequently increasing functions, parts, or modules, the spatial organization in housing becomes more flexible (Figures 7, 8, and 9).

The adjustment chart of potential modes of change versus change potential number with a goodness of fit of 0.1383 and a sparse pattern shows a weak correlation between the observed values and the expected values, as a result of which the degree

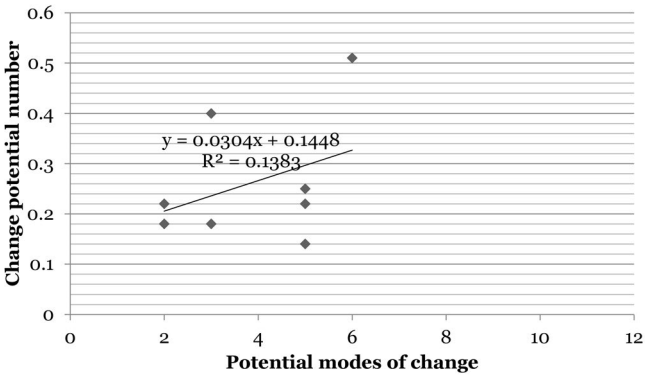


Figure 7. Adjustment chart of potential modes of change (horizontal axis) versus change potential number (vertical axis).

Table 5. Analysis of demonstrating the concepts of flexibility and change modes and effects analysis by investigating the case study samples.

		Change modes and effects analysis			CPN
		Readiness	**Design flexibility**	**Occurrence**	
Flexibility	**Variability**	Modifiability of furniture action (3)	Spatial improvement (10)	Hedonism (10)	0.40
		Adding a room without changing plan (5)	Spatial improvement (4)	Hedonism (10)	0.25
	Adaptability	Modifiability of floor covering (2)	Visual effect (6)	Self-direction (10)	0.22
		Modifiability of wall color (5)	Preferred aesthetic (3)	Self-direction (10)	0.22
		Modifiability of window size (2)	Better ventilation (4)	Security (9)	0.18
		Possibility to renovate quipment (3)	Better ventilation (3)	Security (9)	0.18
	Changeability	Enlarging a room area (6)	Preferred aesthetic (10)	Hedonism (10)	0.51
		Adding a room with changing plan (5)	Everyday activity (1)	Self-direction (10)	0.14

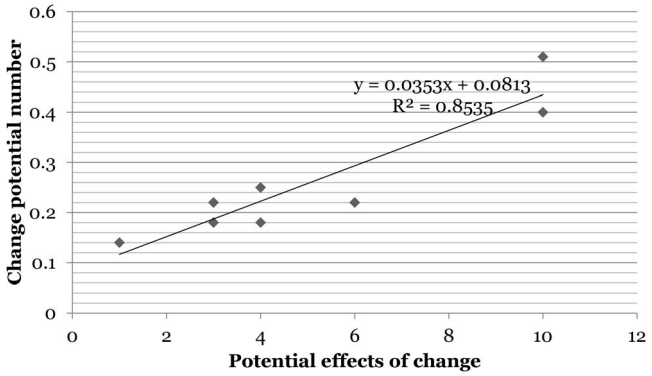


Figure 8. Adjustment chart of potential effects of change (horizontal axis) versus change potential number (vertical axis).

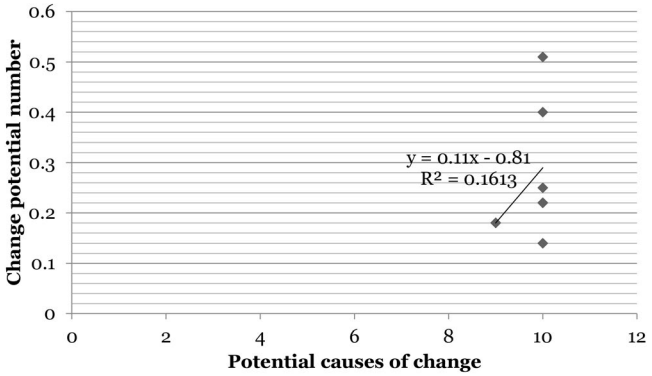


Figure 9. Adjustment chart of potential causes of change (horizontal axis) versus change potential number (vertical axis).

of readiness and the indicators of flexibility vary. The adjustment chart of potential effects of change versus change potential number with a goodness of fit of 0.8535 and an ascending pattern shows a strong correlation between the observed values and the expected values, as a result of which the degree of design flexibility and the indicators of flexibility increase. The adjustment chart of potential causes of change versus change potential number with a goodness of fit of 0.1613 and a sparse pattern shows a weak correlation between the observed values and the expected values, as a result of which the degree of occurrence and the indicators of flexibility vary.

5. CONCLUSIONS

According to the analysis that has been done on using change modes and effects analysis tool for explaining the ratio of flexibility and spatial organization in housing and in answering the proposed question, the results were obtained as follows:

Architectural spaces with the capability of spatial organization and internal transformations can respond to a greater number of their users' needs at different times. The necessity to access this ability is one of the subcategories of flexibility in housing as a contemplative subject. The purpose of this research is to provide an analytical model in relation to understanding change modes and effects analysis tool and using its indicators to assess flexibility in housing.

Change modes and effects analysis is a tool for measuring a product's flexibility towards change and thereby diminishing the cost of redesign and shortening time to market. This method facilitates the evaluation of products for flexibility for future evolution and comparisons of the flexibility of different products for users. Accordingly, it can be used to help identify characteristics of a design that inherently aid or hinder the flexibility of a product. The goal of it is to aid designers in minimizing the costs associated with redesigning and producing one space when it evolves. Using this tool, each of the possible changes is evaluated by the indicators of design flexibility, readiness, and occurrence.

The indicators of variability, adaptability, and changeability in flexibility are related to the indicators of design flexibility, readiness, and occurrence in change modes and effects analysis tool to analyze the spatial organization, and thus affect the spatial organization in housing.

Spatial organization in residential complexes in Tehran city is based on applying possible changes in the spaces of kitchen, living, dining, catering, and bedroom. Accordingly, the most potential modes of change, potential effects of change, and potential causes of change take place between them, which has led to the increased flexibility of spaces in relation to various activities. However, other spaces are just a place to do a specific activity, which confirms the reduction of their flexibility.

Adjustment of flexibility and change modes and effects analysis factors with each other versus change potential number shows that respectively by enlarging a room area, modifiability of furniture action, adding a room without changing plan, modifiability of floor covering, modifiability of wall color, modifiability of window size, possibility to renovate equipment, and adding a room with changing plan and consequently increasing functions, parts, or modules, the spatial organization in housing becomes more flexible.

Due to the practical constraints and the need for a significant level of interaction in addressing all three factors of design flexibility, readiness, and occurrence, it is suggested that products be evaluated with design flexibility alone. One of the significant future extensions of this work would be to develop a comprehensive methodology to design flexibility. This would be an important contribution to design theory in general. Such a methodology will focus on a systematic step-by-step procedure of designing the product to a desired level of flexibility. Given the complexity of this problem and based on the understanding of

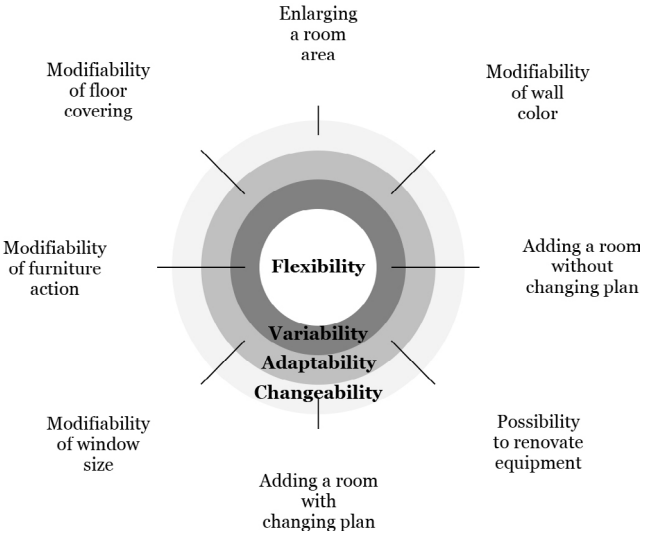


Figure 10. Analytical model.

flexibility in this research, this will require a significant effort. Although an initial effort is taken towards this direction, an extensive empirical study on numerous products across different domains could be done. While this effort will be more time and cost consuming.

The achievements of this research could help researchers provide an analytical model in relation to understanding change modes and effects analysis tool and using its indicators to assess flexibility in housing (Figure 10).

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