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Determining the Effects of Flexibility Types on the Functional Adaptability of Municipal Service Complex During Crisis Management*

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ABSTRACT

Taking catastrophic repercussions of an earthquake into consideration, the city of Tehran suffers from some critical issues such as being located on several active faults, having critical seismic records, hosting densified population, lack of preparedness for crisis management, absence of modern technological advancements, and also the idle status of crisis management premises in normal situation. This paper tends to adapt two different functions at a single premise before and after the earthquake, by applying the flexibility principle to mitigate the immediate consequences of the disaster. The present study aims to reduce the negative impacts of the crisis and diminish the state of confusion and indecision for injured people after the earthquake by providing essential spaces in a district of Tehran. The article is applied research in terms of objective and is a mixed-method study in the descriptive-analytical category with a grounding (survey) type. The theoretical data are collected through library investigation methods and then analyzed through coding techniques and converted to codes that can be qualitatively assessed. Once the theoretical framework of conducted studies is obtained, the structured Delphi method is used based on the survey from experts to prioritize the effect of flexibility-coded indexes on the functional adaptability of municipal service complex during earthquake crisis management. Eventually, the different categories of flexibility were prioritized concerning their impact on the space of the complex. The results indicate that the most effective flexibility types are related to expandability, modular system based on the modular design networks' adaptation, multi-functionality, movable walls, flexible furniture, and movable openings and shells, respectively. Furthermore, the highest amount of the impact of various flexibility categories on the complex's space is related to structural, physical, spatial, and visual changes respectively.

Keywords: Flexible System, Modular Network, Adaptive Design, Crisis Management.

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1. INTRODUCTION

Natural disasters, especially earthquakes have been one of the most critical troubles threatening human life (Dadashpoor and Adeli 2016), which result in irrecoverable damages in the absence of required preparedness and resilience against threats (Pakru and Moosavi 2023). The earthquake belt covers 90% of the land in Iran, and Tehran is the riskiest city due to its earthquake background, numerous active faults, high population density, low resistance of buildings, etc. (Bashiri and Khajehei 2013). Therefore, the Tehran metropolis is an important city because of its special position in terms of different political, economic, and social aspects. Hence, the city must be in full preparation for crisis management and control after the incidents.

The most critical problem in crisis management is now lack of integration and cohesion between executive and decision-making centers in this field. Hence, the comprehensive crisis management plans in Iran that are reactive processes focusing on the compensation for damage without using modern technologies would lose the ability to alleviate consequences of the crisis and have the proper performance during many crises because of inattention to city preparedness and planning before crisis occurrence. Moreover, there are some crisis management centers in the city, which have been designed for crises and are left unused during the years without any operation on normal days. A necessary aspect of this study is to design a space that can be used on normal days, and individuals can use that place throughout the year and can be used during crises to decrease damages and injuries. Therefore, it is vital to design some places with proper performance in considered spatial and temporal situations.

This is a crucial study because such a municipal service complex can provide an initial performance, including cultural and sports uses during the year, and respond to crises immediately by adopting a flexible and modular system in the design of spaces based on the adaptability, variability, and versatility with the new performance during the crisis.

Accordingly, the main question of the study is as follows: 1. Which methods can be used to convert the municipal service complex to a place for post-earthquake crisis management? The secondary question of the study asks about 2. the effect of flexible and modular systems on the functional adaptability of municipal service complex regarding post-earthquake crisis management. 3. The research objective is to reduce the effects and life, financial, mental, and psychological consequences, and confusion among the injured after the earthquake crisis in a district of Tehran City.

2. THEORETICAL FOUNDATIONS

The research background and theoretical concepts about flexibility and its types are analyzed based on the research nature to achieve the theoretical framework of the study.

2.1. Background

The importance of the studied topic reveals the necessary studies that must examine this field. Table 1 reviews the research background. This study allows comparison between relevant studies.

Table 1. Background

Authors	Results	Methods used in the Study
(Eghbali and Hessari 2013)	Building a flexible housing that matches with changing needs and demands of the users and can be used for a longer duration in line with users' experience and intervention.	Modular and prefabrication system
(Shokatpour et al. 2019)	Creating a flexible space that its form and functional features can be changed by the users based on their tastes and needs	Prefabrication and modular system
(Ghafourian 2018)	Creating flexible apartment housing to meet some family needs during the needs' expansion and contraction periods	Expandability, different furniture arrangement, separability, and multifunctionality, respectively
(Jahani and Tazike Lamsaki 2016)	Creating required flexibilities in all spaces considering spatial geometry and spaces' location by providing proper access, integration, deploying suitable depth and height of space, and also a simple geometry (rectangle and square) for open and closed spaces to form relief camps and temporary complexes for emergency accommodation, etc.	Adaptability (light and furniture) Versatility (multifunctional spaces) Variability (expandability)
(Gharavi Alkhansari 2018)	Creating flexible contemporary housing to respond to the changes that occurred in the family pattern in line with their needs for expansion and contraction	Variability (separability, aggregation, and expandability)
(Seyedian and Razani 2021)	Creating flexibility and dynamism in the building and providing various needs of users in interior spaces over time	Using dynamic, expandable, and foldable movable walls in the interior space

The long-term goals have been considered in all references mentioned above, and flexibility is in line with the current and future needs of users. This study aims to alleviate the impacts of earthquake crisis on the earthquake victims; for this purpose, this paper addresses the modular system based on the adaptability of modular design network and prioritizing the effects of flexibility on the complex space to accelerate the process of converting uses to a place for accommodation, treatment, and other services for the affected people. The mentioned case is the novelty of this study compared to other studies.

2.2. Flexibility

Architectural spaces that are capable of spatial organization and indoor evolutions can meet more needs of users' needs during various times, so they provide a more desirable function compared to single-functional spaces (Ziaei, Ghoddusifar, and Bazrafkan 2022). In general, flexibility explains the building' ability to change and adapt to variable conditions (Habraken 2008, 291). The built environment indeed has various types of flexibility that require analysis. Some indicators, including variability (multifunctional space), adaptability (seasonal and daily displacement), and variability (separation and aggregation) have been designed for this purpose (Heydari, Aryan Mehr, and Karimian Shams Abadi 2018).

2.2.1. Adaptability

Adaptability means the ability to coordinate a space to be matched with the new situation (Asefi, Farrokhi, and Nesar Nobari 2017). The obtained results do not include structural changes but only provide the required adaptability using movable and semi-fixed elements (Altas and Ozsoy 1998). Table 2 reports the adaptability components extracted from various references. Figure 1 depicts the adaptability components.

Table 2. Adaptability Components

Authors	Data of Adaptability Type	Effective Components
(Lopez et al. 2017)	Creating spatial diversity is possible by using various plant species that are adaptive to various conditions of the environment and climate.	Plants
(Karimi Azeri et al. 2016)	Creating flexibility through changing the dimension of spaces, changing body form, and changing confinement degrees would create space illuminance rates with different intensities. Moreover, various senses and feelings are induced in visitors through spatial diversity using materials and color.	Light, materials, and color
(Johannes 2007)	Smart materials can match their colors, shapes, and specifications with current conditions during environmental changes.	Smart materials and color
(Seyedian and Razani 2021)	Using movable walls in three types of transitional movement (two-dimensional), rotational (three-dimensional), and rescaling for adaptability with various conditions and needs	Movable walls
(Taghizadeh, Matini, and Kakouee 2019)	Movable walls and shells	Access to a responsive architecture using movable walls and shells in three transitional, rotational, and rotational-transitional motions to be adapted to surrounding conditions.
(Mahmoodi 2018)	Use of movable openings that can be adapted to various conditions. These openings can be smart to be changed based on the environmental conditions. The flexible furniture can be matched with various conditions or be integrated with or separated from other elements.	Movable opening and furniture

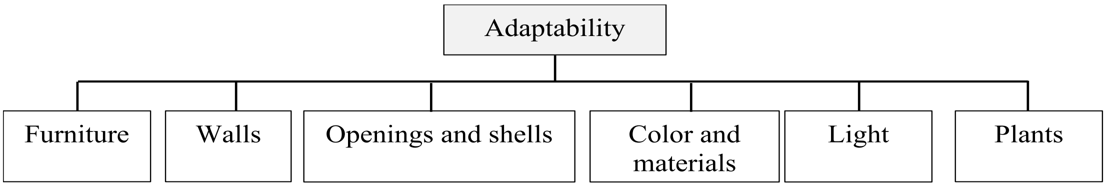

Fig. 1. Components of Adaptability

2.2.2. Versatility (Multifunctional Space)

Versatility acts as a spatial potential that provides the field for diversity in performances and different uses of space (Kharabati and Mohseni 2022). Versatility is achievable through designing a map with regular geometric patterns, adjustment of sizes, and simple and understandable access to the equipment (Einifar 2003). Table 3 reports the components of versatility extracted from various references. According to Table 2, versatility can be divided into three components.

Table 3. Components of Versatility

Authors	Data of Versatility Type	Effective Components
(Mahmoodi 2018)	- Creating a visual connection between two spaces and allowing attendance in all activities that are occurring in the complex by integrating the activity area into the complex; - Creating a single flow through the vertical connection as a central area for activities and key nodes of the building.	Transparency and Fluidity
(Karimi Azeri et al. 2016)	- Diversity is created by using natural elements such as extending open and closed spaces and creating usable joints that integrate external spaces to expand the indoor space; -Possible reuse of spaces and allocating new activities to them in the future without making physical changes in the building.	Active Joints or Articulations, Multifunctionality
(Kiaee, Soltanzadeh, and Heidari 2019)	Zoning spaces as public and private, so activity diversity is increased in more public spaces, while low diversity in activities, especially activities related to public areas is seen in the private space.	Multifunctionality
(Einifar 2003)	This kind of flexibility depends on two variables space and time, and spaces can be used simultaneously for multifunctionality and in diverse time for various performances.	Multifunctionality

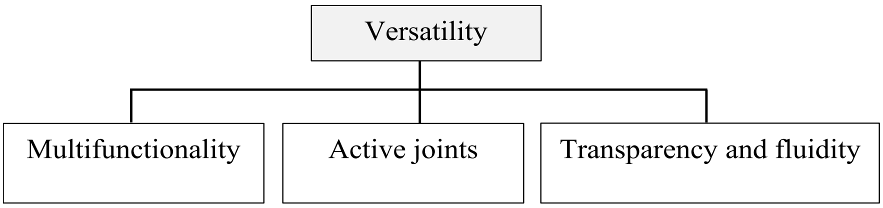

Fig. 2. Components of Versatility

2.2.3. Variability (Separation and Aggregation)

Variability indeed means the ability to respond to the development and expansion of spaces within various periods. Also, intervention in variability is higher than in adaptability, which results in a considerable evolution in a building (Heydari, Aryan Mehr, and Karimian Shams Abadi 2018). Table 4 reports the components of variability extracted from various references. Figure 3 depicts the components of variability.

Table 4. Components of Variability

Authors	Data of Variability Type	Effective Components
(Mahmoodi 2018)	Expandability is achieved indeed by using expandable structure elements, such as linear or collective organization, creating a modular rhythm, and sing gradual development techniques. Scalability also describes a feature of space for expansion or contraction.	Expandability or Developability
(Heydari, Aryan Mehr, and Karimian Shams Abadi 2018)	Variability is achievable through infrastructure expansion or separation of spaces without creating any change in the building's area.	Expandability
(Einifar 2003)	Variability makes rescale possible in line with two smaller and larger dimensions.	Expandability
(Jakupi and Istogu 2017)	A modular system makes it possible to present various alternatives in the frame of a dynamic performance based on the need.	Modular System

Authors	Data of Variability Type	Effective Components
(Shokatpour et al. 2019)	In the modular design, the components of the system are divided into smaller sections (modules), which are independent structurally but work coordinately and are properly connected to other components.	Modular System
(Till and Schneider 2007)	Modules are single units that are integrated and form a part of a complete building.	Modular System
(Von meiss 2013)	Module provides a technique in which, all dimensions and sizes of a building have a common divisor.	Modular System
(Nikravan Mofrad 2009)	Basic Module's submultiples make the activity modules smaller or larger than it and shape the Modular Design Network (MDN).	Networks for Designing Architectural Structures and Furniture
(Mir Moghtadaee et al. 2007)	In modular design, the structure is easily changed to respond to the various needs in different conditions. Therefore, this kind of flexibility is more than a threshold that cannot be achieved only by the semi-fixed space.	Structure Design Network
(Nikravan Mofrad 2009)	In the networks that are used for structure design, various modulations can be used, and all of them are derived from the basic module.	Structure Design Network
(Nikravan Mofrad and Arfaei 2005)	A construction component is placed in the reference levels' network with regular distances when its size is matched with the basic module or its coefficients and can create an architectural modular network.	Architectural Design Network
(Nikravan Mofrad 2009)	If architectural and structural designs of buildings are matched and are done based on the modular design networks, the modular furniture and appliances also can be used for the interior design of spaces, which are created from smaller divisions of architectural modular.	Furniture Design Networks
(Nikravan Mofrad and Arfaei 2005)	Modular network adaptation is obtained through adaptability or coordination between module submultiple networks.	Modular Network Adaptation

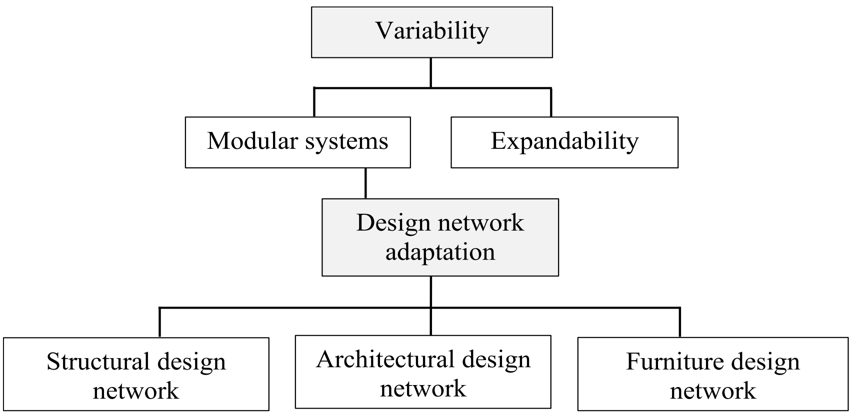

Fig. 3. Components of Variability

Figure 4 indicates the maximum data and theoretical foundations within a theoretical framework, and the purpose of using types in the research has been mentioned.

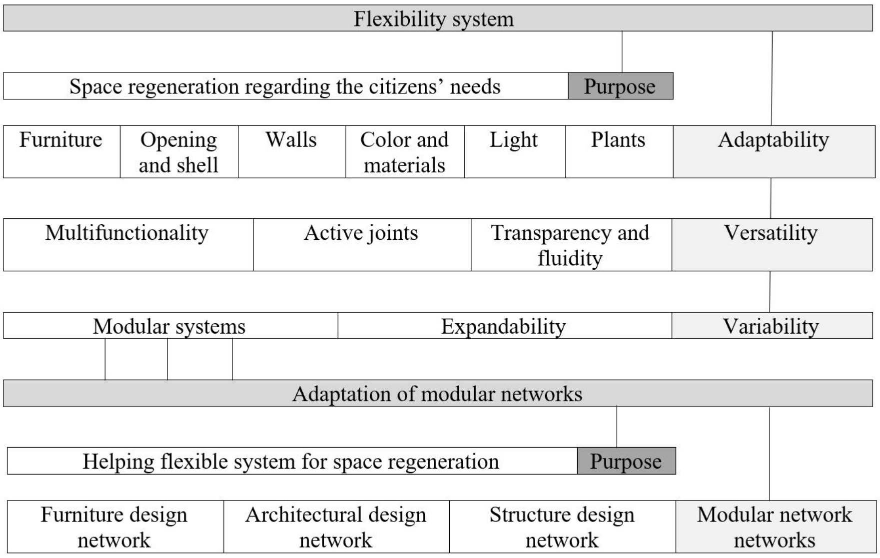

Fig. 4. Theoretical Framework

3. METHOD

This is applied research in terms of objective and is among mixed studies with descriptive-analytical method and grounding (survey) technique. The seismic conditions of Iran, particularly Tehran are addressed to pursue the research process. For this purpose, the number and situation of crisis management centers in Tehran, as well as the papers and media are reviewed to find the necessity and importance of the studied topic. In the problem statement, the main and secondary questions and the objective of the studied topic are expressed. In the second step, research background and theoretical studies are collected through library studies tools and then are analyzed based on the coding technique to be converted to codes that can be analyzed qualitatively. After a theoretical framework of the conducted study is formulated, a questionnaire is designed to determine the impact of coded types of flexibility on the functional adaptability of municipal service complex during earthquake crisis management. The questionnaire is used based on the structured Delphi technique to prioritize the effect rate of flexibility types. This is an 11-item semi-closed questionnaire with given criteria and sub-criteria, which are weighted based on the survey with experts and then analyzed through two Excel and SPSS software. To ensure the validity and reliability of the criteria, the opinions of 10 skilled architecture experts with citable experiences in flexibility have been used. The questionnaire has been implemented three times to achieve a correlation coefficient higher than 0.7, and a five-point Likert scale (from strongly low to strongly high) has been used for the ranking process in all three questionnaires. The weighted average has been used as the removal threshold. Till and Schneider (2005) express criteria for flexible design: structural systems and flexibility scale regarding the external and internal development, connection, and separability of units. Moreover, Priemus (1969) and Schroeder (1979) who are the first flexibility theorists in the world, define flexibility based on the physical, spatial, and structural features of the building. In their definitions, a physical feature of the space includes the movability of volumes or subcomponents, and also the spatial layout and development or separation potential that play a vital role in creating this ability. Accordingly, the weighted mean of all categories about the effect of flexibility on the space is measured at the end of the study after describing and analyzing the results obtained from the Delphi technique. This calculation is done to rank the flexibility types regarding the categorization in the complex space for functional adaptability of uses before and after the crisis. Table 5 indicates the classifications of flexibility effect on the space.

Table 5. Classification of Flexibility Effect on the Space

Flexibility Effect on the Space	Description
Structural Change	Change in fixed parts of the building
Physical Change	Change in demi-fixed parts of the building
Spatial Change	Different configurations of variable components and elements of the building
Visual Change	Apparent change in components and elements

Figure 5 shows the research process in each step.

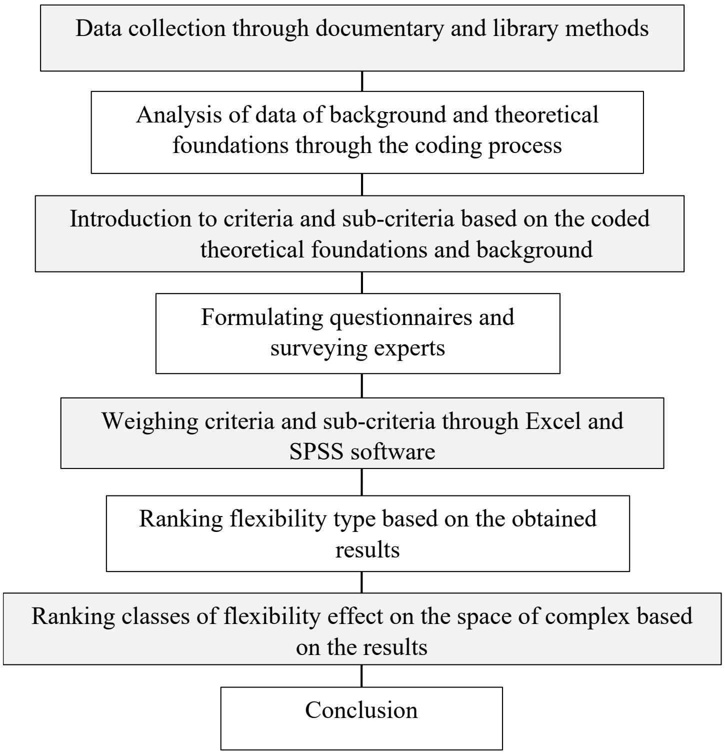

Fig. 5. Research Process

4. DATA ANALYSIS

In the first step, a questionnaire was designed to determine the effect of flexibility types on functional adaptability in the municipal service complex during earthquake crisis management. This questionnaire which comprises three criteria and 11 sub-criteria is distributed among experts to rate each index.

4.1. Results of the First Step

According to the results of the first step, three sub-criteria under the criterion of adaptability include plant, light and color, and smart materials, and two sub-criteria of versatility are transparency and fluidity, and active joints are lower than the removal threshold' mean value; hence, Kendall's W has not been measured in this step. Table 6 reports the results of the first Delphi step.

Table 6. Results of the First Step of the Delphi Technique

Criterion	Sub-Criterion	Min	Max	Weighted Mean	Standard Deviation (SD)
Adaptability	Plants	1	1	1.00	0.00
	Light	1	1	1.00	0.00
	Color and Smart Materials	1	2	1.40	0.516
	Movable Walls	3	5	4.20	0.789
	Movable Shells and Openings	2	4	3.40	0.699
	Flexible Furniture	3	4	3.40	0.516

Criterion	Sub-Criterion	Min	Max	Weighted Mean	Standard Deviation (SD)
Versatility	Transparency and Fluidity	2	3	2.80	0.422
	Active Joints	2	3	2.90	0.316
	Multifunctionality	4	5	4.40	0.516
Variability	Expandability	4	5	4.80	0.422
	Modular systems based on the adaptability of design networks of structure modular, architecture, and furniture integrated and coordination of their module submultiple networks	4	5	4.80	0.422

4.2. Results of the Second Step

In the second step of the Delphi technique, those sub-criteria that had the weighted means lower than the removal threshold are removed, and the other sub-criteria are set in the new questionnaire based on their weighted means obtained from the first step, so experts can use them to rate each index. Kandal's correlation coefficient and reliability rate equaled 0.731 and 0.716, respectively in this step. Table 7 reports the results of the second step of the Delphi technique.

Table 7. Results of the Second Step of the Delphi Technique

Criterion	Sub-Criterion	Min	Max	Weighted Mean	Standard Deviation (SD)
Adaptability	Movable Walls	3	5	4.30	0.675
	Movable Shells and Openings	3	4	3.30	0.483
	Flexible Furniture	3	4	3.20	0.422
Versatility	Multifunctionality	4	5	4.60	0.516
Variability	Expandability	4	5	4.90	0.316
	Modular systems based on the adaptability of design networks of structure modular, architecture, and furniture integrated and coordination of their module submultiple networks	4	5	4.80	0.422

4.3. Results of the Third Step

The questionnaire of the previous step has been also designed considering the weighted means of sub-criteria obtained from previous studies. The questionnaire has been distributed among experts to rate each index. The results of the third step indicate that many experts have confirmed the opinions given in the previous step. Kandal's correlation and reliability coefficients in this step equal 0.795 and 0.779, respectively. Table 8 reports the results of the third step of the Delphi technique.

Table 8. Results of the third Step of the Delphi Technique

Criterion	Sub-Criterion	Min	Max	Weighted Mean	Standard Deviation (SD)
Adaptability	Movable Walls	4	5	4.50	0.527
	Movable Shells and Openings	3	4	3.30	0.483
	Flexible Furniture	3	4	3.10	0.316

Criterion	Sub-Criterion	Min	Max	Weighted Mean	Standard Deviation (SD)
Versatility	Multifunctionality	4	5	4.70	0.483
Variability	Expandability	4	5	4.90	0.316
	Modular systems based on the adaptability of design networks of structure modular, architecture, and furniture integrated and coordination of their module submultiple networks	4	5	4.80	0.422

According to the results of the third step of the Delphis technique, the standard deviation is reduced rather than the previous step, and experts' opinions have become similar. No significant difference is seen between Kandal's correlation coefficients obtained in the second and third steps. Therefore, the survey is finished in this step. According to the final results reported in Table 8, three sub-criteria that obtained the highest weighted means were as follows based on their priorities: expandability (4.90), modular system based on the adaptation of Modular Design Networks (4.80), and multifunctionality (4.70). Movable walls (4.50), flexible furniture (3.30), and movable openings and shells (3.10) are in the next ranks. According to Table 9, the total weighted mean of each class of flexibility effect on the complex's space has been measured for functional adaptability of uses. The highest weighted mean belongs to the following variables based on their priorities: structural change (4.80), physical change (3.32), spatial change (3.30), and visual change (1.13).

Table 9. Total Mean Value of Flexibility Effects on the Complex's Space

Effect of Flexibility on Space	Types of each Classification	Weighted Mean	Total Mean Value of Class
Structural Change	Expandability	4.90	4.80
	Modular Systems based on the Adaptability of Modular Design Networks	4.80	
	Multifunctionality	4.70	
Physical Change	Movable Walls	4.50	3.32
	Movable Shells and Openings	3.10	
	Transparency and Fluidity	2.80	
	Active Joints	2.90	
Spatial Change	Flexible Furniture	3.30	3.30
Visual Change	Plants	1.00	1.13
	Light	1.00	
	Color and Smart Materials	1.40	

Figure 6 depicts the measured weighted means based on their priorities.

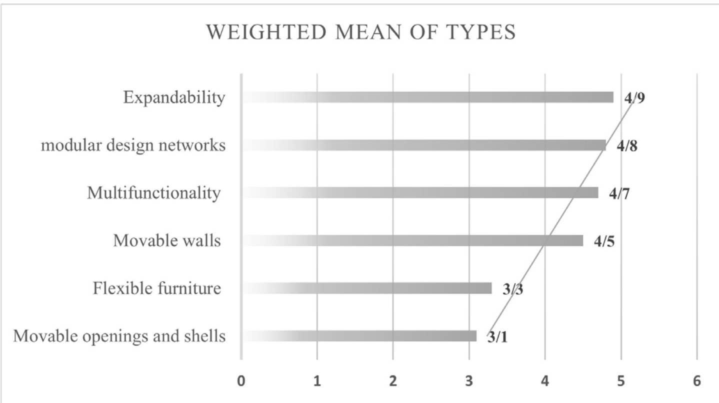

Fig. 6. Weighted Mean of Ranked Types

According to Figure 6, among other available types, the flexibility types identified in this study were among the most effective flexibility features that can affect the functional adaptability of municipal service complex. As mentioned in the research background, Ghafourian, Jahani and Tazike Lamsaki, and Gharavi Alkhansari introduced expandability and multifunctionality, and furniture, and Seyedian and Razani introduced dynamic movable walls, which are in line with the results of the present study. Matched with the results of the extant study, Ghafourian introduces expandability as the most effective flexibility component. In addition to the mentioned features, modular design networks are rated as structural changes, and movable openings and shells are considered physical changes for the functional adaptability of municipal service complex. Figure 7 depicts the weighted mean value of classes.

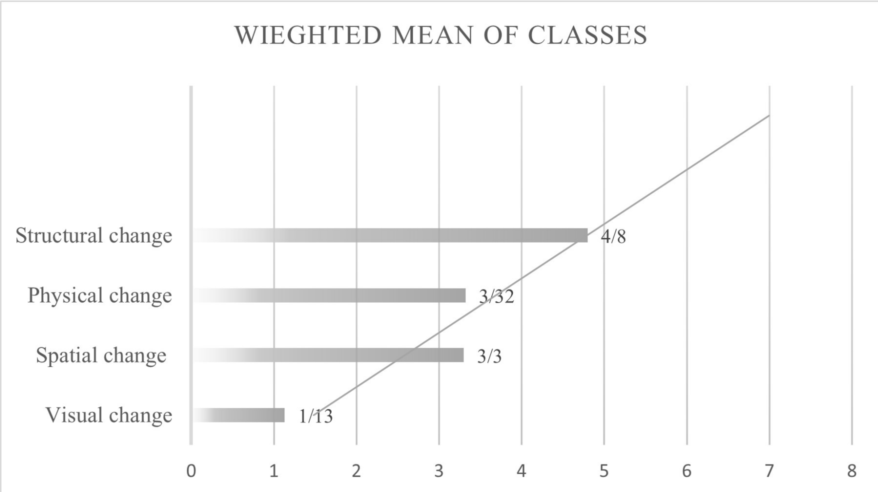

Fig. 7. Weighted Mean of Classes

Figure 7 reports the results of the survey based on the literature review. Accordingly, the structural viewpoints of Till and Schneider are matched with multifunctionality and expandability features, and the structural, physical, and spatial viewpoints of Priemus and Schroeder are in line with expandability, multifunctionality, movable walls, and flexible furniture because such potentials for structural, physical and spatial changes play a vital role in this field.

5. CONCLUSION

To realize two different uses in a complex before and after the crisis for covering the crisis management problem and meeting the needs in an area of Tehran, this study has attempted to achieve applied solutions using a flexible system approach. The following results are obtained from the conducted studies and answers given to the questions:

- Flexible systems and their different types make it possible for the municipal service complex to change the use immediately after the crisis occurrence and provide the required facilities. Flexibility serves as a proper solution for different structural, physical, spatial, and visual orders that are suitable for not only internal regulation but also for external adaptation of its areas. In this way. Flexibility is achieved through structural or physical change of building in line with the development of spaces and their separation or aggregation, as well as the movability of walls, etc.
- A modular system consisting of some networks with regular lines and certain sizes can be used to make spaces flexible deal with arbitrariness in the design, and use change within the shortest possible time. A modular system creates unity, strength, and discipline in the design making the mind look for creative relationships.
- Moreover, flexible and modular systems can be used based on the modular design networks' adaptation to create coordination between structure, architecture, furniture, and appliances. In this case, when it is required to apply changes in the architecture and furniture of spaces, the structure does not prevent such changes, avoiding disruption in architectural goals, including performance.
- Space multifunctionality, movable walls, flexible furniture, movable openings, and shells would realize the decision-making of various uses of municipal service complex before and after the crisis to create a flexible space.
- In the conducted study, the class of structural change has the highest effect on the functional adaptability of municipal service complex for use change during earthquake crisis management.
- Regarding the importance of crisis management after an earthquake occurs in Iran, it is recommended to use this study to solve the crisis management problem after the earthquake in different areas and cities. Moreover, it is suggested to provide required

spaces in the complexes with different uses.

- To create more technical orders of flexibility, mode change, and movement of the studied components, modern technologies can be considered in the design. It is recommended to integrate a flexibility system into the smart tools to create a more dynamic space.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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The authors commit to observe all the ethical principles of the publication of the scientific work based on the ethical principles of COPE. In case of any violation of the ethical principles, even after the publication of the article, they give the journal the right to delete the article and follow up on the matter.

PARTICIPATION PERCENTAGE

The authors state that they have directly participated in the stages of conducting research and writing the article.

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