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Structural Analysis of Key Drivers Affecting Resilience against Earthquakes in District 20 of Tehran

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Original Article

Abstract

INTRODUCTION: Informal settlements in cities are one of the most vulnerable regions to natural disasters, including earthquakes. The investigation of the vulnerability of Tehran's 20th District to earthquakes revealed that the plans and measures taken to make this area more resilient were unsuccessful. This research was conducted to systematically identify and analyze the key drivers effective on the resilience of District 20 of Tehran against earthquakes.

METHODS: The present study was mixed (quantitative-qualitative) with an analytical-exploratory nature, and the statistical population consisted of a group of 35 experts in the two fields of "futuristic approach" and "resilience". The Delphi technique was utilized in this research, and the obtained data were analyzed in MicMac software using structural analysis.

FINDINGS: The findings obtained from the distribution of variables in the axes of influence and dependence of factors in MicMac software indicated the instability of the system within the scope of the study, based on which, five categories of variables were identified.

CONCLUSION: According to the high score of direct and indirect influences of the factors, 11 main factors were identified as the key drivers affecting the resilience of District 20 of the Tehran metropolis against the earthquake.

Keywords: Earthquake; District 20 of Tehran; Informal settlements; Resilience

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Introduction

The world's population has reached 2.7 billion after doubling in size during the last 50 years. According to the current growth rate of 1.2% per year, in less than 60 years, the world population will have reached 14.4 billion people (1). In general, by 2070, 60% of the world's population will be living in cities (2). The current trend of population growth as well as the increase in urbanization have led to numerous challenges in cities. This trend of increasing urbanization has brought various consequences in the world, the most important of which is the problem of informal settlements (3-5).

Informal settlements are home to about one billion people of the world's population. In other words, about one-seventh of the world's population and one-third of its urban population live in the suburbs (2). Informal settlements, as the main symbol of less developed urban areas, are a physical manifestation of economic-social inequality in an urban area (6). They are considered one of the biggest challenges of the 21st century due to the fact that the rapid growth of the population leads to environmental degradation, high levels of poverty in cities, and insufficient access to basic services, such as water, sanitation, and garbage collection (7).

Residents of informal settlements are highly exposed to possible risks. Residential land insecurity, high population density, violence, lack of economic resistance, and unsanitary living conditions in informal settlements (e.g., insufficient bathrooms, lack of safe drinking

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water, and poor health services) have made the residents, especially children, women, and the elderly, prone to more dangerous challenges, such as various natural and human hazards (8).

One of the natural disasters that threaten urban communities, especially informal settlements, is the earthquake. Earthquake is a destructive and unpredictable natural disaster (9). From 2000 to 2019, earthquakes have caused an estimated loss of about 721,318 deaths and damage to the global economy of about 636 billion dollars (10). The enormous costs and damages caused by earthquakes have created new risks for human societies and limited social and economic development, especially in informal settlements (11).

Earthquakes have minimal destructive effects on regions where buildings have enough strength and resistance. However, in regions where strong materials have not been used or are less used in the construction of buildings, there is a lot of destruction and casualties. The amount of damages and injuries caused by such incidents in vulnerable urban areas and informal settlements is doubled because these tissues are more vulnerable due to the non-observance of technical and engineering standards in building construction, location in sloping lands, inefficient communication networks, lack of open and green spaces, and lack of urban facilities and equipment (12).

In this regard, Tehran, as one of the important cities of Iran, has a high risk of earthquakes due to the location of several active faults around and inside it. According to experts, the only city that may be severely damaged (70% destruction) by an earthquake on an engineering scale (moderate earthquake) is Tehran. District 20 of Tehran is located in the northern region of central Iran (Tehran-Rey Plain). The operation of several faults in this area makes it the most hazardous part of the city compared to other areas.

It is predicted that, in the event of an earthquake, severe irreparable human and financial losses will be caused to District 20 since a large part of the residential areas of this region are made up of fine-grained, impervious slabs with the use of non-durable and unstable materials. In addition to the issues raised, it is worth noting that what has been considered so far in the management of incidents and urban management is confrontation and risk reduction. This view should be improved considering the developments in cities and the existence of logical models and methods to deal with urban risks because the lower the capacity of cities to withstand the pressures of urban expansion, the more adverse effects it will have on the earth. Therefore, reducing the risk of accidents is of particular importance, and it is necessary to find a suitable position in the national policies of each country so that favorable conditions can be created for effective and efficient risk reduction at different levels (13).

In a situation where risk and uncertainty are growing, resilience is introduced as the concept of facing disruptions, surprises, and changes. Therefore, in this research, in order to manage the crisis against the earthquake crisis, the most important factors affecting the resilience of District 20 of Tehran are identified and analyzed with the futuristic approach. In line with the above goal, the main question of the research is raised as follows: "What are the key driving forces affecting the resilience of District 20 of Tehran against the earthquake crisis?"

Due to the characteristics of the construction and formation of informal settlements, these areas are exposed to several risks and disasters. Following various disasters, the concept of resilience has emerged globally as a model of urban risk management and new emergency management (14, 15). As a result, the global attitude towards risks and changes has turned from reducing vulnerability to increasing resilience, and urban societies should seek to create and strengthen resilience and pay attention to its concept against crises (16).

Urban planning today places great emphasis on resilience, with many countries investing heavily. In general, increasing urban resilience to deal with risks and epidemics is highly important (17) and is a new path for the sustainable development of cities in the future (18). Due to the growing trend of risk and uncertainties, resilience is introduced as a concept of facing disturbances, surprises, and changes (19).

According to Doorn, resilience is not necessarily a way to return to the pre-crisis state and can be an opportunity to improve and reach a more favorable situation (20). Ross et al. defined resilience as a new engineering-based approach designed to recover efficiently and effectively as the system's ability to cope (the ability to resist or

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adapt to external shocks), along with pre-disaster preparedness and adaptation measures that can be taken immediately after disasters (21). Nagenborg defines resilience as a tool to establish fairness and believes that it does not always mean leaping back (pre-crisis state) and can in many cases mean leaping forward (reaching a new, more favorable state) (22).

So far, no specific set of indicators or organized frameworks have been created to quantify disaster resilience. Despite this, there is a consensus in the scientific community that resilience is a multifaceted concept with social, economic, institutional, and physical dimensions.

According to Rose, resilience includes three categories, namely physical, social, and environmental factors. He holds the opinion that social infrastructures and effective criteria should be mentioned as influencing factors on resilience. However, in contrast to natural disasters, he mentioned environmental factors as the most important factors affecting urban resilience. Davies believes that society must return to its original state immediately after the occurrence of disasters, which is done with the help of public and government institutions. His belief is focused on two institutional and social components, and he considers the institutional component more important because he believes that before a disaster, society must be resilient so that it does not suffer from huge damage.

A variety of theorists, including Kanz, Lynch, and Radwin have focused on the characteristics of the physical environment and its role in urban resilience. Considering the stability and resilience of urban areas, as well as the division of different layers of the urban form, it seems that the division of factors affecting urban resilience includes social, economic, institutional, and physical-spatial dimensions (23).

This study, according to the research question, examined physical-spatial components of resilience in District 20 of Tehran. Due to the exploratory nature of the research, some of the indicators used in this research were extracted using the environmental survey method, which is the same as theoretical foundation studies and previous pieces of research, and the rest of the indicators were obtained through the formation of a Delphi panel and the opinion of experts.

Lotfi and Rahimi (2019), in research entitled "Analysis of the factors effective in reducing the vulnerability of informal settlements against earthquakes under study: Farahzad neighborhood, District 2 of Tehran metropolis", reported that the quality of the building was the most important factor to reduce the vulnerability to earthquakes (31). Arasteh et al (2021) identified key factors affecting urban resilience with a futuristic approach in the Mashhad metropolis. Based on the results of the research, six key variables of slum dwelling, migration, population density, and urbanization percentage from the social index group, and income level and housing price variables from the economic index group were obtained as key drivers (32).

In research by Bader Azar et al. (2022), among 40 factors affecting the resilience of Tabriz city against earthquakes, these 12 factors were among the key and important factors for the resilience of Tabriz city against earthquakes: fault activity, slum dwelling, population density, building resistance, damage rate, poverty, risk zoning map, income, access to open space, crisis budget, temporary accommodation, and security (33).

Asadi (2021) evaluated the socio-economic components explaining resilience in informal settlements (a case study: Tabriz city) and reported that the most influential economic indicators were related to the variables of employment status, income, and home ownership among social indicators, while among the social indicators, the most influential indicators were related to the variables of education level and sense of belonging to the neighborhood (34).

Latifi et al. (2022) analyzed and leveled the key drivers effective in increasing the physical resilience of Tehran city with a focus on District 10 against earthquakes. The results of the research showed that the driver "density class" with the highest penetration force was the main infrastructure and the main stimulus of urban physical resilience, and any action to increase the physical resilience of the studied region against earthquakes required modifications in this driver (35).

In their research, Abunyewah et al. (2018) investigated informal settlements against the risk of disasters and concluded that planning, environmental communication, and land use influenced the characteristics of informal settlements, which are the keys to the management of dealing with risks in informal settlements (36).

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In a research, Joyner and Sasani (2020) investigated the factors affecting the resilience of buildings against earthquakes. Based on the results of this research, the seismic performance of the building played an important role in strengthening and resilience against earthquakes. The seismic performance of the building can also be improved by increasing the strength of the building through strengthening and using resistant materials (37).

Li and Zhou (2020), in their research examining the factors affecting resilience against earthquakes, pointed out the importance of the role of the road network and believed that the road network was one of the most important ways of urban life, the flexibility of which is highly important after an earthquake for rapid and safe relief and rescue (38).

Cheng and Zhang (2021), in their research, evaluated the indicators affecting regional resilience against earthquakes. Based on the results of this research conducted in Nepal, the type of building foundation, the type of internal wall, and population density were the most sensitive factors that played a role in earthquake resilience (39). Niazi et al. (2021), in their research, while pointing out that Iran is located in one of the most earthquake-prone regions of the world, believed that among the factors affecting resilience against earthquakes, special attention should be paid to the performance of health care centers after an earthquake to identify patients and ways to provide services to them (40).

Bothara et al. (2022), in their research, investigated the factors affecting the resilience of indigenous buildings along the Himalayan arc against earthquakes. They concluded that the buildings that were built with traditional and indigenous methods but observed all the requirements of strengthening were highly resistant to earthquakes. Moreover, a proper balance needs to be observed in construction between traditional and modern construction materials and methods (41).

The literature review shows that despite the importance of informal settlements in urban management and considering the special characteristics of these settlements that make them vulnerable to disasters, especially earthquakes, and that earthquakes in these areas may have irreparable financial loss and death tolls, this issue has not been addressed with a systematic and comprehensive futuristic approach. Therefore, this research for the first time investigated the key drivers affecting resilience against earthquakes in District 20 of the Tehran metropolis.

Methods

The current research, with a futuristic approach, was conducted to identify the most important factors affecting resilience against the earthquake crisis in District 20 of Tehran. In this research, due to its exploratory nature, the environmental scanning technique was used, and since the dominant approach of this research was prospective, the Delphi technique was adopted. The sample population of this research consisted of a group of 35 experts specializing in two fields: "futuristic approach" and "resilience". In the first stage of Delphi, an 83-item questionnaire was distributed among the experts, who filled out the questionnaire completely. At this stage, Kendall's coefficient of concordance among panel members was low and equal to 0.293. The average of answers given in the first round of Delphi was between 3 and 5. Due to the large number of indicators and items in the questionnaire, which most of the panel members mentioned and sometimes complained about, all the indicators whose average was less than 3 (according to experts' opinion) were removed for the second stage of Delphi.

In the second stage of Delphi, 35 items were distributed and collected among the group members, for which, Kendall's coefficient of concordance was obtained at 0.495. Considering that compared to the first stage, the coefficient of concordance among the panel members increased significantly for the items of the questionnaire, the Delphi was not continued. At this stage, 44 factors were called the final indices for structural analysis in MicMac software.

Findings

District 20 is located in the land subsidence area of North Central Iran (Tehran-Rey Plain). Due to the operation of several faults, the extent of subsidence in the North of Central Iran has been divided into 4 physiographic parts: Tehran Plain, Rey subsidence, South Rey subsidence, and Kahrizak subsidence. District 20 is located in the maximum length of the South Rey fault and a major part of the North Rey fault, and the activation of these faults is possible. A large

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percentage of the land uses in the studied area are part of deteriorated and irregular urban fabrics and informal settlements, and the formation of high building and population densities in some parts of the region will increase the vulnerability of the region in case of an earthquake. According to the results of some studies, District 20 is more vulnerable compared to other regions of Tehran when an earthquake occurs. Therefore, it is highly imperative to identify the drivers that affect the resilience of this region in times of crisis, emphasizing the earthquake crisis.

Due to the fact that Kendall's coefficient of concordance for the members' replies about the order of the factors in the second stage indicated a strong and, in some cases, very strong consensus among the panel members, the Delphi rounds were stopped at this stage. At the end of this stage, 44 influencing factors that were obtained by asking experts in resilience were processed and analyzed in the MicMac software; based on the output of which, the key drivers effective on the resilience of informal settlements were identified, with an emphasis on the District 20 of Tehran. These 44 factors were determined in four dimensions (Table 2).

According to the identified 44 initial factors, a 44×44 cross-impact matrix was formed and entered into MicMac software for data processing. Table 3 presents the dimensions of the matrix and its characteristics.

Table 1. Dimensions and effective components in resilience

Definitions	Components	Criteria
Social resilience includes conditions under which individuals and social groups adapt to environmental changes, and it actually expresses the ability of society to respond to crises (24). This dimension is the result of the difference in social capacity among societies. In other words, it is the capacity of social groups and societies to recover themselves after a crisis or to respond positively to accidents	**Social**	Age and gender structure of the population (24). Education level, health coverage, and population density (25). Driving forces of social change, changing economic growth and social transformation, trends in civil society (26). Social capital: public participation, social network, attachment to place, social support, safety and security, awareness, justice, and equality (24).
Economic resilience is evaluated based on the severity and amount of damage, the capacity or ability to compensate for damages and the ability to return to suitable employment and income conditions, the amount of household capital and income that can be converted into capital and employment, the housing situation, the level of access to financial services, insurance, allowances and the ability to revive the economic activities of households after an accident. This dimension of resilience increases or decreases economic stability, especially livelihood stability at the community level (27).	**Economic**	Business type, business scale, employment (25). Engines of economic growth, labor force, and economic production (26).
Resilience in the institutional component is defined as the capacity of societies to reduce risk and create organizational links within the society in such a way that includes features related to risk reduction, planning, and experience of previous accidents. This dimension assesses the physical characteristics of organizations, including the number of local institutions, access to information, forces, and trained volunteers, adherence to crisis management guidelines, the timeliness of laws and regulations that are preventive and encouraging, especially in the matter of housing construction, interaction of local institutions with people and government institutions, satisfaction with the performance of institutions, accountability of institutions, and how to manage or respond to accidents such as organizational structure (28).	**Institutional**	Institutional platform (volunteer groups, system support, system strength). Institutional performance (system effectiveness, design and decision-making by managers and executives, coordination and evaluation). Institutional relations (citizens' relations with institutions - cooperation of institutions - necessary training) (25).
According to Zahm Edgar (2000), the emphasis of all ecological definitions is on the amount of destruction that a system can withstand without changing conditions or falling apart. Moreover, in his opinion, more focus is on stability and resilience in the face of destruction and the speed of returning to the initial equilibrium point (29).	**Physical-spatial**	Road network, open spaces, density of buildings, relief centers (30), critical lines and infrastructures, type of materials, quality of buildings, and urban equipment (emergency and fire stations) (25). The ratio of the height of the wall to the width of the passages, the type and length of the passages, the slope of the passages, the arc of the passages, the quality of the floor of the passageway, the texture pattern of the passages to prevent natural hazards, environmental design and development, attention to the climate in construction, damage caused by hazards, natural, ecosystem, environmental cleanliness and health, geology, fault, soil type, vegetation, landslide (30).

Table 2. Factors affecting the future resilience of informal settlements against the earthquake crisis with an emphasis on District 20 of Tehran metropolis

Dimension	Variable
Structural-physical	(x1): building density, (x2): composition of mass and space (ratio of built to unbuilt spaces), (x3): percentage of checkered to organic texture in the area, (x4): ratio of regular subdivisions to the irregular ones in the area, (x5): the number of building floors, (x6): the quality of residential units (ratio of renovative and destructive structures to the total built area), (x7): the quality of construction and execution of structures, (x8): the age of the building, (x9): construction materials (frame materials and foundation materials), (x10): occupation level of residential units, (x11): building density, (x12): distance from the fault, (x13): distance from hazardous centers (x14): neighborhood with incompatible land uses, (x15): development and expansion of population centers on seismic zones, (x16): attention to the improvement and renovation of buildings, (x17): geological and lithological condition of the District 20
Road network and access hierarchy	(x18): the ratio of the average width of the roads to the population density, (x19): the density of the urban fabric (x20): the existence of numerous suitable access points to different parts of the city, (x21): the materials and condition of the road floor, (x22): the reliability of network components (roads and bridges), (x23): the percentage of dead-end roads in the area compared to the total area of the roads in the region, (x24): the slope of the roads, (x25): the security of the roads
Status of services and infrastructure facilities	(x26): location of specific areas for temporary accommodation, (x27): correct location of service centers in times of crisis, (x28): balanced distribution of relief centers, (x29): access to fire stations, (x30): access to medical centers and hospitals, (x31): access to law enforcement centers, (x32): access to the Red Crescent Center, (x33): access to emergency services, (x34): access to open and safe space, (x35): securing the city's infrastructure networks (gas, water, electricity, and sewage) against natural disasters with an emphasis on the earthquake crisis, (x36): the existence of communication infrastructure, including messenger lines, (x37): the existence of earthquake warning devices.
Socio-economic	(x38): population density, (x39): training of forces in the operational and management department, (x40): people's ability to use the correct methods to deal with crisis, (x41): training people to deal with possible risks, (x42) government resources for risk management (x43): the existence of an institutional and collaborative culture for self-organization, (x44): preventing the spread of poverty and housing low-income people in high-risk areas

Table 3. General characteristics of the matrix

Indicator	Value
Matrix dimensions	44
Number of repetitions	2
Number of zeros (no effect)	80
Number of ones (low impact)	712
Number of twos (medium effect)	746
Number of threes (high impact)	398
Number of p	0
Total	1,856
Degree of completion	95.86%

As can be seen, the degree of the matrix completion was 95.86%. The high share of matrix completion can explain the existence of a relationship between the selected drivers and matching binary relationships between drivers. This problem reveals the difficulty of making decisions about the resilience of District 20 of the Tehran metropolis in the face of an earthquake crisis. That is because the existence of a lot of relationships between drivers indicates the necessity of adopting accurate and optimal solutions for different drivers, while failure to provide an optimal solution for each driver, considering the relationship between the drivers, would inevitably cause a decline in the status of other drivers.

Concerning the rest of the relationships, based on the results of the structural analysis in MicMac software, the score of 80 relationships was zero from the total number of relationships. This indicated that the factors neither influenced each other nor were influenced by each other; this percentage accounted for nearly 4.31% of the total volume of the matrix. Moreover, from the total of 1,856 possible relationships in this matrix, the scores of 712 relationships were number one (38.36%), 746 relationships were number two (40.19%), and 398 relationships were number three (21.44%).

The obtained results demonstrated that relationships with medium intensity had the highest frequency, while relationships with high intensity had the lowest frequency in the system. Furthermore, based on statistical indicators, the matrix with 5 times data rotation had 100% desirability and optimization, which indicated the high validity of the questionnaire and its answers. After analyzing the spatial organization and the characteristics of the study area, the analysis of the degree of direct influence and effectiveness of the factors was done. Based on the analytical results of the matrix of influence and dependence of factors, variables (x6): quality of residential units (ratio of renovative and destructive structures to the total built area), (x12): distance from the fault, (x7): quality of construction and implementation of the structure, (x8): the age of the building, and (x9): construction materials (frame materials and foundation materials) had the greatest impact on the future resilience of District 20 of Tehran against the earthquake crisis, while the variables (x36): the existence of communication infrastructures (e.g., massaging lines) and (x37): the existence of earthquake warning devices had the lowest degree of influence.

In the next step, the key factors were analyzed based on the location in the influence/dependence map. The dependence of drivers, along with their influence, determines the nature of a driver. Drivers that have a great influence on other drivers, but are less dependent, are considered environmental or system input drivers, as opposed to drivers that are the most dependent and the least influenced, which are the target drivers or the output of the system. As mentioned in the methodology section of structural analysis and MicMac software, system variables after evaluating their effects on each other by experts and based on mathematical relationships between them, were located on an x-y grid with the title influence/dependence map. Their position on the grid indicated the status of the drivers in the system and their role in the dynamics and evolution of the system in the future. Based on the position of the drivers on the grid, the drivers were divided into influential, two-way (risk target), dependent, independent, and regulatory and intermediate.

What can be understood from the scatter plot of the variables affecting the resilience of District 20 of Tehran against the earthquake crisis is the instability of the system. Based on this, five types of variables can be identified according to Table 4.

At this stage, the causal loop diagram of influence was examined. The causal loop diagram of influence shows the intensity and direction of influence and dependence of drivers. Based on the results of the analysis, drivers (x6): the quality of residential units (ratio of renovative and destructive structures to the total built area) and (x12): the distance from the fault were the origin and the destination of the highest and the most intense impacts and played a crucial role in the center of the causal loop of drivers. Furthermore, driver (x10): the occupancy ratio of residential units was the target of numerous arrows of drivers, which indicated the strong effectiveness of this driver over other ones. The way how direct and indirect relationships of each of the variables identified in the MicMac software were analyzed in five coverages: 5%, 25%, 50%, 75%, and 100%. Each of these coverages shows weak, medium, and strong relationships between variables. Because 100% coverage represents all the effects of variables from very strong to very weak, in this part, the graph of the influence of factors with 100% coverage is displayed (Figure 2).

In the next step, to extract the key factors, the displacement and the ranking of the desired variables in terms of influence and dependence (direct and indirect) were conducted (Table 4). Due to the fact that the software multiplies the matrix several times to calculate the indirect effects, the sum of the indirect influences and dependences was obtained as a multi-digit number, making it difficult to compare them with the direct influences. To alleviate this problem, the software provided a table of the contribution of factors based on direct and indirect influences on a scale of 10,000. Based on this, the total influence and dependence were calculated as 10,000, and the contribution of each factor from this number was indicative of its contribution to the whole system.

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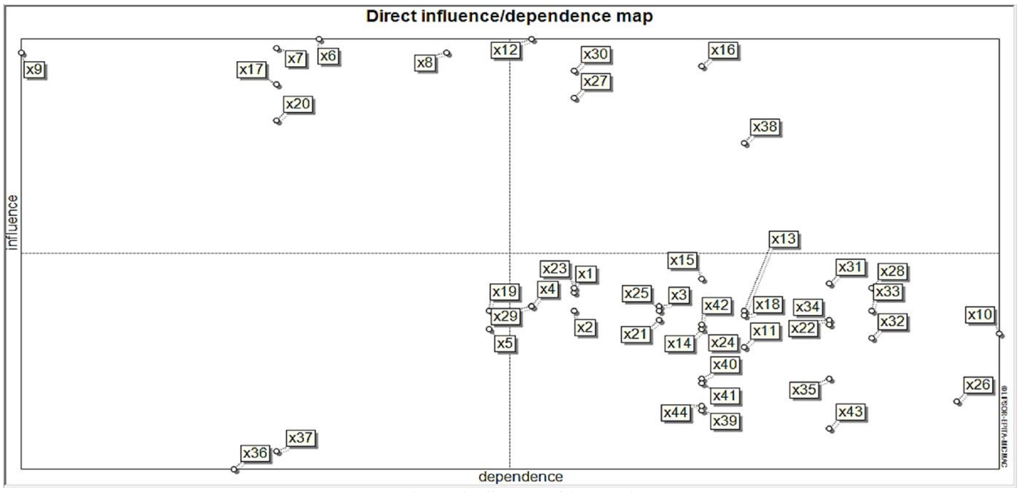

Figure 1. Direct influence/dependence map

Table 4. Distribution of variables based on their classification

Classification	Variable
Determining or influencing variables	(x6): the quality of residential units (ratio of renovative and destructive structures to the total built area), (x7): the quality of construction and execution of structures, (x8): the age of the building, (x9): building materials (frame materials and foundation materials), (x17): the geological and lithological conditions of District 20, (x20): the presence of various and numerous accesses with suitable quality to different parts of the city.
Bivariate variables	(x12): distance from the fault, (x16): paying attention to the improvement and renovation of buildings, (x30): access to medical centers and hospitals, (x27): correct location of service centers in times of crisis, (x28): balanced distribution of relief centers.
Regulatory variables	(x29): access to fire stations, (x4): the ratio of regular to irregular subdivisions of the area, (x5): the number of building floors, (x19): the urban fabric density, (x23): the percentage of dead-end roads in the area relative to the total area of the roads in the region, (x1): building density, (x2): mass and space composition (ratio of built to unbuilt spaces)
Influential variables	(x3): the percentage of checkered to organic texture in the area, (x10): the occupancy level of residential units, (x11): the density of buildings, (x13): the distance from hazardous centers, (x14): neighborhood with incompatible land uses, (x15): the development and expansion of population centers on seismic zones, (x18): the ratio of the average width of roads to the population density, (x21): the materials and condition of the road floor, (x22): the reliability of network components (roads and bridges), (x24): slope of roads, (x25): security of roads, (x26): location of special areas for temporary accommodation, (x31): access to law enforcement centers, (x32): access to Red Crescent Center, (x33): access to emergencies, (x34): access to open and safe space, (x35): securing city infrastructure networks (gas, water, electricity, and sewage) against natural disasters with an emphasis on the earthquake crisis, (x38): population density, (x39): training of forces in the operational and management sector, (x40): people's ability to use the correct methods to deal with crisis, (x41): training people to deal with possible risks, (x42): government resources for risk management (x43): the existence of an institutional and collaborative culture for self-organization, (x44): preventing the spread of poverty and housing low-income people in high-risk areas.
Independent variables	(x45): the existence of communication infrastructure, including messaging lines, (x37): the existence of earthquake warning devices

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According to Table 5, 11 variables were obtained as key drivers effective on the resilience of informal settlements against the earthquake crisis, with an emphasis on District 20 of the Tehran metropolis. These variables included: (x6): the quality of residential units (ratio of renovative and demolition parts to the total built area), (x12): the distance from the fault, (x7): the quality of construction and implementation of the structure, (x8): age of buildings, (x9), construction materials (frame materials and foundation materials), (x16): attention to improvement and renovation of (x30): access to medical centers and hospitals, (x17), the geological and

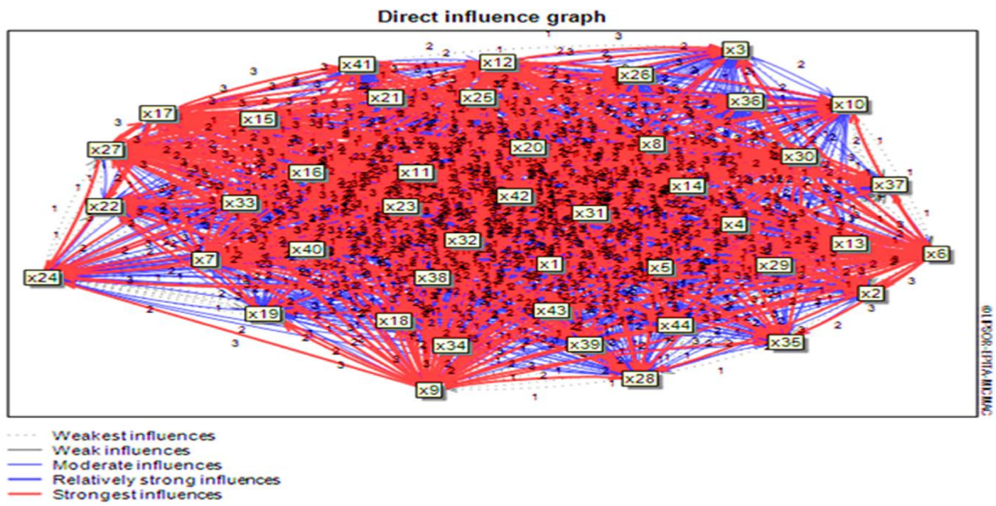

Figure 2. Cycle loop graph of direct influence with 100% coverage

Table 5. Key factors affecting the resilience of informal settlements against the earthquake crisis with an emphasis on District 20 of Tehran Metropolis

	Direct		indirect	
Rank	**Variable**	**Influence**	**Variable**	**Influence**
1	x6	379	x6	377
2	x12	379	x12	377
3	x7	373	x7	368
4	x8	370	x8	363
5	x9	370	x9	363
6	x16	361	x16	353
7	x30	359	x30	349
8	x17	350	x17	341
9	x27	341	x27	330
10	x20	326	x20	321
11	x38	311	x38	316

lithological condition of District 20, (x27): the correct location of service centers in times of crisis, (x20): the existence of various and numerous access points with suitable quality to different parts of the city, and (x38): population density. The variables mentioned in indirect influence without displacement were also repeated in indirect influence.

Discussion and Conclusion

District 20 is located in the land subsidence area of North Central Iran (Tehran-Rey Plain). Due to the operation of several faults, the extent of subsidence in the North of Central Iran has been divided into 4 physiographic parts: Tehran Plain, Rey subsidence, South Rey subsidence, and Kahrizak subsidence. District 20 is located in the maximum length of the South Rey fault and a major part of the North Rey fault, and the activation of these faults is possible. According to the study conducted by the Japan International Cooperation Agency, the possibility of the

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activation of three faults in Tehran has been identified, one of which is the South Rey fault. If activated, this fault would be the most fatal in the country and maybe the world.

Therefore, this research was dedicated to the identification of the most important factors affecting resilience against the earthquake crisis with an emphasis on District 20 of the Tehran metropolis. In addition to the mentioned cases, a large percentage of the land uses in the studied area belong to the urban deteriorated and abnormal fabrics, and the formation of high building and population densities in some spots of the region will increase the vulnerability of the region in case of an earthquake. According to the investigations, District 20 is more vulnerable than the other Districts of Tehran when an earthquake occurs.

For this purpose, firstly, using the environmental scanning technique and the Delphi method, 44 primary factors were extracted in 4 different areas, and with structural analysis in the MicMac software, the degree of influence and dependence of the factors, the stability and instability of the system, and finally the driving factors affecting the resilience of informal settlements against the earthquake crisis were determined by emphasizing District 20 of the Tehran metropolis. The results of the research demonstrated that the structural-physical factors had the highest impact on the future of these settlements.

Moreover, based on the results obtained from the structural analysis in MicMac software, 11 factors were selected as the key drivers effective on the resilience of informal settlements against the earthquake crisis, with an emphasis on District 20 of the Tehran metropolis. These drivers were as follows in descending order: (x6): the quality of residential units (ratio of renovative and destructive structures to the total built area), (x12): the distance from the fault, (x7): quality of construction and implementation of the structure, (x8): the age of the building, (x9): building materials (frame materials and foundation materials), (x16), attention to the improvement and renovation of buildings, (x30): access to medical centers and hospitals, (x17): geological and lithological condition of District 20, (x27): the correct location of service centers in times of crisis, (x20): the presence of diverse and numerous accesses with suitable quality to different parts of the city, and (x38): population density.

The comparison of the results of this research with those of other studies presented in the Introduction Section shows that the findings of this research are in line with those of the research conducted by Lotfi and Rahimi (2017). In the current study, the driver of the quality of residential units (ratio of renovative and destructive structures to the total built area) obtained the highest score, and therefore, was identified as the most key driver for the resilience of District 20 in the face of the earthquake crisis. Likewise, in the mentioned study, the quality of the building was reported to be the most important factor in reducing the vulnerability to a possible earthquake in the Farahzad neighborhood. Additionally, considering the last driver obtained in the current research, (x38), population density was also identified as one of the effective factors, which was in agreement with the findings of the research by Arasteh et al. (2021).

The results of the examination of the obtained drivers were consistent with those reported in the research by Bader Azar et al. (2022). In the above-mentioned study, 4 factors of access to open space, population density, building resistance, and fault activity were among the key and important factors for the resilience of Tabriz city against earthquakes, which were also reported in the present research. Furthermore, the results of this research were in line with those of the study by Joyner and Sasani (2020) in terms of the driver of construction materials (frame materials and foundation materials), with those of the research by Li and Zhou (2020) in terms of the driver of the existence of diverse and numerous suitable access points to different parts of the city, with those of the research by Cheng and Zhang (2021) in terms of the driver of construction materials (frame materials and foundation materials), and with those of the research by Niazi et al. (2021) in terms of access to medical centers and hospitals.

In the end, it should be mentioned that the issues and problems of informal settlements are multi-faceted and multi-dimensional by their nature and appear in a different way in each case. The functional and physical disorders of these urban fabrics along with the occurrence of numerous crises and loss of life and money are among the reasons that have forced the policymakers and urban planners to present new strategies and solutions in facing such crises.

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Therefore, according to the obtained key drivers, it is necessary to examine all driving factors at different levels and make necessary plans in line with each of these influential forces.

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Conflict of Interests

Authors have no conflict of interests.

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