A holistic approach for evaluating the contribution of system performance on resilience against earthquake in historic-commercial urban fabrics

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Abstract

The occurrence of earthquakes in historical urban fabrics with commercial value, such as traditional bazaars may have far-reaching cultural and socio-economic consequences. However, few comprehensive studies have been conducted so far on assessing their risk and resilience to earthquakes. Among the parameters affecting the resilience of such urban fabrics, system performance plays a key role, which has been addressed in this paper to evaluate its contribution on resilience of historical bazaars to earthquakes. To this end, a novel index-based model is developed by integrating resilience-related dimensions, indicators and sub-indicators. For this purpose, the cultural, historical, physical, socio-economic and organizational dimensions of resilience have been considered. Then, the effective indicators and sub-indicators amongst these five dimensions are determined and their importance is calculated by using Analytic Hierarchy Process (AHP). Moreover, the qualitative parameters are quantified using fuzzy logic and included in the model. The proposed model can be used to estimate the system performance in traditional bazaars based on 5 dimensions, 17 indicators and 50 sub-indicators. In addition, by utilizing this model, the effective interventions to improve the resilience of different parts of bazaars can be assessed. The proposed model is applied in Tabriz traditional bazaar, as a world heritage, to determine the system performance and its impacts on seismic resilience. The results depicted the applicability of the model for assessment the system performance in traditional bazaars. This approach can be used in similar urban fabrics worldwide, by calibrating relevant parameters based on local conditions.

1- Introduction

During the recent decade, the conventional approach of disaster management has been shifted from focusing solely on reducing risks and vulnerability to enhancing resilience. This novel approach has higher capacity to deal with uncertain hazards such as earthquakes. Resilience is defined as the system's ability to withstand emerging hazards, so that it can quickly return to its original state (Adger, 2000). According to UNDRR, resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management (UNDRR, 2022).

Up to now, various models have been proposed in order to determine the resilience of urban fabrics and communities such as "Climate Disaster Resilience Index (CDRI)" model (Shaw & TEAM, 2009), "Baseline Resilience Index Conditions (BRIC)" model (Cutter, Burton, & Emrich, 2010), "PEOPLES" model (Renschler, et al., 2010) and "Disaster Resilience Index (DRI)" (Khazai, et al., 2015). These models used a combination of physical, economic, social and organizational dimensions as well as other indicators for assessment of resilience, some of which were previously reported by Bruneau (Tierney & Bruneau, 2007).

All the above-mentioned models have been developed for assessing the resilience in ordinary cities and communities. However, the consequences of earthquakes such as Bam (Iran, 2003), Sumatra (Indonesia, 2006), Tohoku (Japan, 2010), etc. have shown that the occurrence of natural disasters can destroy valuable old urban fabrics, museums and historical monuments and objects. This highlights the necessity of improving resilience as well as preventing and managing crises in the cultural and historical fabrics of cities. Therefore, in recent years, the issue of reducing the effects of natural disasters on historical sites has attracted the attention of many countries as well as relevant official authorities such as UNESCO[1], ICCROM[2], ICORP[3] and ICOMOS[4], and various studies have been conducted in this regard.

Traditional bazaars, which are of great cultural and economic values, are the most vulnerable areas to earthquakes. The occurrence of natural disasters in such areas may destroy historical and cultural heritage, disrupt the business of many people and cause significant casualties and losses. Traditional bazaars are different from ordinary urban fabrics in several aspects; for example, economically, such bazaars are often the center of trade and commerce in historical cities. Physically, most of the buildings in the traditional bazaars are vulnerable to disasters such as earthquakes, due to their age, materials and lack of retrofitting measures. Socially, diversity in communications, sociopolitical movements and overcrowding at certain times of the day and some seasons make these areas unique. The cultural-historical value of these places for local people as well as their importance in the tourism industry are among the other factors indicating the difference between the traditional bazaars and other urban fabrics. Thus, applying conventional risk and resilience assessment models for measuring the resilience of traditional bazaars may not provide accurate results.

Few studies have been conducted so far to identify the risk and resilience of historical bazaars. Amini et al. examined vulnerability of Tehran Bazaar to earthquake and fire and addressed the inappropriate accessibility and shortages in emergency response measures (Hosseini, 2014). Razavi et al. evaluated the role of open spaces in preparing seismic risk reduction programs in Qazvin Historical Bazaar (Razavi, 2012). Yücel et al. studied the evacuation plan in case of emergency in Istanbul Grand Bazaar (Yücel & Arun, 2010). Alighadr et al. (2012) investigated the emergency evacuation at the time of the accident in Timcheh Mozaffariyeh, Tabriz Historical Bazaar. Most of these studies have focused on how to improve the emergency response capacities in historical bazaars, especially with an emphasis on how to improve accessibility and evacuation plans. However, the issue of reducing seismic risk has not been comprehensively addressed.

Among the studies related to earthquake risk management measures in bazaars, Asadzadeh and Amini Hosseini evaluated seismic risk of Ardabil Traditional Bazaar considering three indicators of hazards, vulnerability and response capacities. They identified and prioritized the most vulnerable points and proposed applicable interventions for reducing the effects of earthquakes (Asadzadeh Tarebari & Amini Hosseini, 2020).

In this study a new model to estimate the system performance in urban fabrics with historic-commercial value against earthquakes is introduced. The proposed model provides a comprehensive view of the system performance to be used in earthquake resilience assessment of traditional bazaars. Moreover, the effect of different interventions on improving resilience can be evaluated by using this model. Thus, the model can be considered as a

decision-making support measure for disaster risk management officials and urban planners to determine the most effective interventions for enhancing resilience to earthquakes, considering available (normally limited) resources. The model could be used in different historical bazaars worldwide by adapting its parameters to the conditions of each region.

- [1] United Nations Educational, Scientific and Cultural Organization
- [2] International Centre for the Conservation and Restoration of Monuments
- [3] International Cooperative Research Project
- [4] International Council On Monuments and Sites

2- Methodology

2-1- Effective indicators in resilience of historic-commercial urban fabrics

In this paper, indicators related to different dimensions of resilience against earthquakes were classified into physical, economic, social and organizational dimensions, based on the scholarly articles mentioned in the previous section (Tierney & Bruneau, 2007). However, since in those studies, cultural-historical dimension, which is very important in traditional bazaars, has not been considered, indicators related to this dimension were also added to the framework. In addition, the existence of religious, educational and cultural centers in traditional bazaars has turned these urban fabrics into places where trade, cultural affairs and social activities interact distinctively (Zangi Abadi et al., 2012) (Pourjafar et al., 2013). Accordingly, following the occurrence of natural hazards, the tangible and intangible values of bazaars (such as authenticity, identity, performance and dynamism) may be severely damaged (Razeghi & Derakhshani, 2017). Therefore, in order to improve the resilience of traditional bazaars against earthquakes, in addition to the dimensions mentioned in previous studies, it is necessary to pay sufficient attention to these unique features and functions of such bazaars. These indicators and sub-indicators are illustrated in Table 1.

2-2- Determining weights of selected indicators in evaluating resilience of bazaars

In this research, a questionnaire-based survey was conducted for assessing the weights of resilience-related parameters. For this purpose, after preparing the final list of indicators and sub-indicators, interviews with 55 relevant experts (including professors and graduate students of universities in the field of earthquake risk management, urban planners, disaster management experts and cultural heritage officials) were conducted to get their opinions about the importance weight of the selected parameters. Then, the Analytical Hierarchy Process (AHP) method was applied to determine the weight of each dimension, indicator and sub-indicator. In addition, in this study, a special vector method was employed to calculate the relative weight of incompatible matrices. Accordingly, inconsistency ratio was calculated for all the paired comparison matrices; if necessary. Furthermore, to correct the incompatible answers, the relevant questions were resubmitted to the survey participants. Results related to the relative weight of dimensions, indicators and sub-indices are shown in Table 1.

2-3- Quantification of qualitative parameters, fuzzy logic and difuzzification

In order to estimate the resilience index, it is necessary to quantify all the indicators and sub-indicators. For this purpose, the qualitative sub-indicators should be converted to quantitative values by using uniform approaches. On the other hand, the received answers about qualitative parameters normally have significant uncertainty, because the understanding and definition of the questionnaire designer and each respondent can be different. Therefore, in this study the fuzzy logic was used to reduce the uncertainty caused by this subject. The word fuzzy means inaccurate, vague and ambiguous. Fuzzy model or set is a mathematical way of representing and expressing vague and inaccurate information; the theory of these collections was developed by Zadeh (Zadeh, 1988). To determine the membership function of each qualitative parameter in questionnaire, the answers for each parameter were categorized and, finally, a bar chart was drawn for each one. In these graphs, it was specified how many respondents are within each range. Then, according to the type of bar charts, the membership function form can be selected. A quantitative equivalent value to each qualitative response was also obtained by calculating the horizontal axis coordinates of the center of each membership function, in order to center of area method for difuzzification. In the following, for example, the membership function and the upper and lower bounds (u and l) for the sub-indicator of "sense of belonging and satisfaction" as well as the coordinates of the center of the area ($\bar{x}$) for 5 degrees very low, low, medium, high and very high are given.

2-4- Evaluating the system performance for historic-commercial urban fabrics

The system performance is a key parameter to evaluate the resilience against earthquake. In order to calculate system performance in traditional bazaars, the contribution of indicators and sub-indicators should be assessed, as shown in Eq. 1:

$$P_j = \sum_{i=1}^n W_{ij} \times indicatorvalue(k_j) \quad (1)$$

where P_j represents the system performance in the desired indicator or dimension, n is the number of relevant indicators or sub-indicators and W is the weight of each indicator or sub-indicator, as already presented in Table 1. After assigning the criteria for each sub-indicator, relevant values should be normalized, which means that the answers may vary from 0 to 10 (the value of 10 shows the highest system performance). To evaluate system performance in each segment of the historical bazaar, a combination of 5 main physical, economic, social, organizational (institutional) and cultural-historical dimensions should be evaluated. Then, the overall system performance (PT) against earthquakes is calculated as follows:

$$PT = 0.3 \times PHS + 0.23 \times ECM + 0.32 \times SCL + 0.09 \times STU + 0.06 \times CH \quad (2)$$

PHS, ECM, SCL, STU and *CH* are system performance in physical, economic, social, organizational and cultural-historical dimensions, with weights of 0.3, 0.23, 0.32, 0.09 and 0.06, respectively (Table 1).

2-5- Non-dimensionalization of quantitative parameters

In the previous section, quantification and scoring criteria for qualitative parameters and sub-indicators were discussed. Some other parameters are quantitative in nature and can be calculated directly. However, these parameters also need to be standardized, so that they can be used in the model. In the following, some of these quantitative parameters and standardization methods to be used in evaluation of system performance are discussed.

- Secondary hazards (fire and leakage of hazardous materials) (*FL*)

$$FL = \frac{FLa_{max} - FLa}{FLa_{max} - FLa_{min}} \times 10 \times a \times b \times c \quad (3)$$

a, *b* and *c* are the coefficients of toxic substances, gas and electricity network, respectively. *FLa* is fire load caused by goods and fuel storage per unit area (Mj/m²).

- Population density (*Dep*):

$$Depa = \frac{average (Pop_1 + Pop_2)}{Sc}$$

$$Dep = \frac{Depa_{max} - Depa}{Depa_{max} - Depa_{min}} \times 10 \quad (4)$$

Pop₁ is total number of people in the bazaar at the peak hours (in Iran around 12:30 pm), *Pop₂* is the total number of people in less crowded hours (in Iran around 10:30 am), *Sc* is the area of internal routes and public spaces inside the Bazaar, and *Depa_{max}* and *Depa_{min}* are maximum and minimum population density across all the sectors.

- Resources (emergency water and electricity supply, fire extinguishing system) (*Ers*)

$$Ers = 10 \times average \left[ems, \frac{feu - feu_{min}}{feu_{max} - feu_{min}}, fed, fec, max(fh, fha), fes \right] \quad (5)$$

Where *ems* is the existence of emergency water and electricity source, *fed* is the merchant's willingness to pay for purchase and maintenance of fire extinguisher inside their units in bazaar, *fec* is the compatibility of existing fire extinguisher type with stored goods and materials, *fh* and *fha* are the presence of fire hydrants in or around each sections and *fes* is the presence of other fire extinguishing systems or sensors, respectively. *feu*, *feu_{max}* and *feu_{min}*, also refer to the ratio of the number of fire extinguishers to the number of units and the maximum and minimum ratios among all the sections, respectively.

- Emergency routes and evacuation places (*Aev*)

$$Aev = Acc + 10 \times \frac{dod_{max} - dod}{dod_{max} - dod_{min}} + 10 \times Qee$$

$$Acc = 10 \times \frac{vac + rmp + blk}{3} \quad (6)$$

Acc is the situation of emergency routes, *vac*, *rmp*, *blk* and *Qee* are the accessibility of relief and firefighting machineries to each site, the availability of suitable ramps (in case of difference in elevation), the status of obstacles and barriers for the movement of rescue and relief teams, and the potential of road blockage after the earthquake, respectively. *dod*, *dod_{max}* and *dod_{min}* are also the distance to the nearest open space (parking, yards, and streets) and the maximum and minimum distance between all the sections (meters) to these spaces, respectively.

3- Case Study: System Performance Of Tabriz Historical Bazaar Against Earthquake

Tabriz Historical Bazaar is one of the oldest bazaars in the Middle East and known as the largest covered bazaar in the world, which is located in the center of Tabriz, Iran. This bazaar was registered as the UNESCO World Heritage in August, 2010. There are some documents of tourists mentioning the Bazaar was active in the 10th century, along the Silk Road. However, it was destroyed in 1780 by Tabriz earthquake, but soon after it was rebuilt (Adelzadeh, 2016). Considering the high risk of earthquake, existing vulnerable buildings and infrastructures, high population density in some hours along the day, improper land-use and insufficient response infrastructures, the potential consequences of a strong earthquake in the bazaar can be a tragedy.

On the other hand, Tabriz Bazaar is a place for commercial as well as socio-cultural and political activities. Therefore, an earthquake may have different physical, social and economic consequences in Tabriz, due to damage in the Bazaar. In order to evaluate the resilience of Tabriz bazaar against earthquake, in this paper, the system performance was evaluated based on the introduced approach into 125 sections (Fig. 1).

Accordingly, all the sub-indicators and indicators (Table 1) were calculated for these sections. Then, system performance in 5 dimensions was obtained by integration of the indicators using Eq. 1. Finally, the overall performance of the system against earthquakes was obtained, based on Eq. 2. In the following sections, some of the results are presented.

3-1- Physical dimension

Earthquake Hazard

The scenario considered for this study is an earthquake with the return period of 2475 years. Iso-acceleration map for Peak Ground Acceleration (PGA) of this earthquake (probability of 2% in 50 years) in city of Tabriz and the location of Tabriz Bazaar in the city are shown in Fig. 2. As depicted, in city of Tabriz, PGA varies between 0.44g and 0.66 g, while in the study area, it is between 0.585 and 0.625 g, which is a high amount.

Soil type and geological conditions

Ground water level in different parts of bazaar varies from 6.5 to 9 m. The soil is mainly of sand type, but based on the geological studies, liquefaction risk is relatively low. In addition, due to smooth slope of this area, the potential of landslide is also very low (Tehran Padir, 2009). There is also an old qanat (underground irrigation channel) under Tabriz Bazaar in the east-west direction, which increases the risk of land subsidence. Accordingly, except for those area built above the qanat; Tabriz Bazaar has a relatively good condition under the sub-indicators of geological hazards.

Risk of fire and leakage of toxic substances

Another hazard in the study area (due to the presence of stocks of flammable goods and chemical products) is fire. Fire outbreaks cause every year serious damages to Tabriz bazaar, some of them due to vulnerability of the electricity network. In addition, shopkeepers and merchants also use petroleum, electric heating appliances and gas cylinders to cook or keeping their workplaces warm in the winters. This can be also sometimes the roots of fire (Fig. 3). There are also some chemical and poisonous material (such as pesticides, adhesive, paint, solvents, etc.) shops that at the time of earthquake might be damaged and cause additional problems. One of the basic strategies to reduce the risk of fire and leakage of hazardous materials is to monitor and limit the depot of such materials, and move them to out of the bazaar. In this study, by field survey, the amount of flammable goods and fuel, as well as the chemicals that are kept inside the units and warehouses was estimated and system performance in the sub-indicator of secondary hazards (fire and leakage of toxic substances, FL) was calculated according to the Eq. 3.

Structures

Historical structures in Tabriz Bazaar are mainly masonry, constructed with bricks with sand and lime mortars. The ceiling of commercial units is mostly built by timbers and bricks. The ceiling of corridors and other halls is constructed by different materials, some of them at high risk of falling, as shown in Fig. 4.

In some section (such as Timche and Chaharsouq), dome dimensions are significantly larger than other parts. There is no foundation under the walls in many parts of the bazaar. Visible cracks and evidence of moisture in the ceilings and walls as well as intentional and unintentional damage in walls and ancillary components are other major structural problems of the bazaar (Fig. 5). Changing the use of commercial units to warehouses, depots of heavy material in the upper floors or using heavy and vibrating machines in some workshops could increase the structural damage.

There are many soft and hard interventions for improving the system performance in the building vulnerability index, including changing land use, implementing appropriate methods for reinforcing structural components of roofs, foundations, walls and joints against earthquakes, improving non-structural components (such as openings, false ceilings, glasses, window frames, corrugated roofing sheets, showcases and shelves, etc.), and implementing drainage and dehumidification channels in the basements. However, implementing these methods should not cause damage to the historical fabric of the bazaar.

Passage network and open spaces

Different sections of the bazaar are connected by lanes and corridors. These passages are mainly roofed and have the narrow width (3–4 m), as shown in Fig. 6-a. Due to the vulnerability of the roof and walls, debris from structural and non-structural elements are expected to block the passages after the earthquakes. In addition, placing goods in front of the shops could also cause difficulties for escape and evacuation, even in case of small earthquakes. In addition to the routes, the available spaces that can be used for evacuation have been also evaluated in each segment of Bazaar (Fig. 6-b).

Lifelines (water, electricity, gas, telephone)

There is no gas pipelines inside the bazaar. The power distribution network in the study area is mainly consisted of underground cables, which have higher seismic resistance than air lines. In addition, some cables, connectors and junction boxes have been renovated in different sections of the Bazaar, during the ongoing power grid rehabilitation program. However, in some parts, the vulnerability of the network is significant due to multiple and unsafe branches, overloads (especially in industrial sections), weak connections, manipulation by irresponsible people and worn-out cables and junctions (Fig. 7). The power network vulnerability was among the presumed factors causing big fires in the bazaar in 2009 and 2019. In the field surveys, the other networks (water and telecommunication) were also evaluated and finally the system performance in the infrastructure vulnerability index (Vu_{inf}) was calculated by combining all the sub-indices.

Renovating power network, increasing feeder capacity based on consumption (especially in the workshops and industrial zones), modernizing fuses and cables, installing suitable ducts and reducing access to cables and fuses are among the measures that could enhance the power grid quality. Similar recommendations can be also proposed for improving the water and telecommunication networks.

By integrating all the physical indicators, based on their weights the system performance in the physical (PHS) dimension can be evaluated, as shown in Fig. 8.

3-2- Economic dimension

Buying and selling precious goods such as exquisite handmade carpets, gold & jewelries, cloth and textiles are among the main activities in the historical sections of Tabriz Bazaar (Fig. 9). Therefore, destruction of historical fabrics as well as valuable goods may cause major economic losses after the occurrence of earthquake.

According to the field surveys, the economic loss due to destruction of structures and goods in Tabriz Historical Bazaar is about USD 600 million (based on prices in 2021). However, considering the distribution of expensive and exquisite goods, Timcheh Mozaaffariyeh (section no. 65), Al-Mahdi Mall (section no. 48) and Saray-e Miresmail (section no. 63) are on the top, where all of them are dedicated to buying and selling exquisite and high-quality handmade carpets. The next rank is for Amir Bazaar (section no. 114) that is in gold and jewelries business.

On the other hand, Tabriz Bazaar has a main function in tourism industry of Tabriz (about 44% of the total annual revenue of tourism, equal to USD 150 million). Furthermore, around 10 thousand people are directly work inside the Bazaar and the business of much more are indirectly dependent to this center. Thus, a destructive earthquake may endanger their livelihoods. In addition, the total annual income of shop owners (business holders) in the whole Tabriz Bazaar is about USD 104 million. Comparing this figure, with the total turnover in the city (about USD 420 million), reveals the high economic contribution and active role of bazaar in the capital turnover.

In Fig. 10 the system performance in economic dimension (ECM) is presented, considering all relevant sub-indicators and indicators. Some interventions that can be considered to improve the system performance in this dimension are: increasing the redundancy by distributing the valuable merchandises in different sites, enhancing the resistance of traditional units and storehouses against earthquakes, creating additional skills for a second source of income for labors, promoting disaster insurance, etc.

3-3- Social dimension

Estimating population density at different times of the day, considering spatial distribution is of great importance in needs assessment for rescue and relief and post-earthquake emergency services. Overcrowding in some parts of the bazaar, especially in the main routes (such as Taza-RastaBazaar, Shahidi, Safi and Qizbasti lanes) is among the characteristics of Tabriz Bazaar that could be problematic at the time of earthquake, as shown in Fig. 6-a.

In this study, the number of casualties, severely injured people, outpatients and uninjured people was estimated using the methodology proposed by Coburn et al. (1992) and Mansouri et al. (2010). For this purpose, two specific times were considered: 10:30 (daily opening time) with the total number of 3,601 people inside the bazaar, and 12:30 (the most crowded daily time) with the total number of 10,358 people in the bazaar. In order to assess the number of casualty and injured people, it is necessary to estimate the damages to the buildings by potential earthquake. As discussed earlier, most of the buildings in Tabriz Bazaar (in 104 out of 125 zones) are masonry (bricks or mixture of bricks and wood). In 7 out of 125 zones, the structure type is bricks and steel, and in 14 out of 125 zones the majority of buildings are type-II steel, according to JICA classification (JICA and TDMMO, 2004). By using the fragility curves presented in JICA studies for Iran' buildings, damage rates of structures were assessed (equal to 100%, 94% and 80%, respectively). Therefore, almost all the buildings in the bazaar would experience severely damage or destruction (Table 3). Accordingly, the number of casualties and injured can be estimates, as shown in Table 4.

Regarding the security and delinquency rate, Tabriz bazaar has good condition and gains high scores in relevant indices. In addition, social cohesion is favorable in most of the zones. Performing religious practices over the centuries, existence of old and active charities, using supportive social media by those working in the bazaar and high sense of satisfaction are other positive social aspects of this historical fabric. Figure 11 indicates the system performance in the social dimension (SCL) in Tabriz Historical Bazaar that was assessed based on the integration of relevant indices, considering their weights.

Regarding the preparedness level of people in Tabriz Bazaar, field surveys based on questionnaires depicted that the situation is not favorable; almost in whole the segments. In addition, there is no organized plan for promoting public awareness and participation in earthquake risk management. Moreover, there is no evidence about conducting training on emergency response (such as self-protection, evacuation, first aid, etc.) or organizing public drills by DM officials in the bazaar.

In order to improve the social dimension of resilience, different measures can be formulated and implemented, including: promoting public awareness by using various platforms (organizing face-to-face or virtual meetings, using social media, distribution of pamphlet, using the existing billboards for messages on safety measure, etc.), conducting earthquake drills, training volunteer groups, establishment of community-based disaster management groups, etc.

3-4- Organizational dimension

Developing and implementing comprehensive programs for disaster risk mitigation and management could promote resilience as well. Conducted interviews with the experts of disaster management and cultural heritage officials revealed that there is no comprehensive framework for reducing earthquake risk and promoting resilience in Tabriz Bazaar. For instance, the disaster management officials are mainly focused on providing emergency response after an accident. Thus, providing a comprehensive framework for enhancing resilience in the bazaar is a priority for improving the system performance. This framework should pay sufficient attention to disaster prevention and preparedness before earthquake, emergency response (immediately after earthquake) and recovery and reconstruction aftermath of the event.

Currently, different organizations are involved in crisis management in Tabriz bazaar, including cultural heritage office, disaster management organization, and Tabriz municipality as well as firefighting organization. The coordination between these entities is not suitable, thus in case of an accident, there is no unified and comprehensive command system to be able to integrate all the capacities and resources. Therefore, one of the crucial activities that can improve the resilience of the bazaar is developing a mechanism for improving collaboration and coordination of these institutions under the Incident Command System (ICS). In such a system, the roles and responsibility of different agencies are clear and they may provide the necessary services in time and minimize the parallel actions and interferences.

Improving communication between those who work in the bazaar with DM officials and providing necessary supports by relevant authorities to prepare initial action plans for different groups in bazaar are among the other measures for improving the system performance in this dimension. Installing early warning systems for timely evacuation at the time of fire or earthquake, and determining the crisis level in the first couple of minutes after an incident for mobilizing necessary resources in a timely manner are among the other measures that could be addressed in this field.

The average distances to the nearest fire station, hospital and police station from Tabriz Bazaar are 850, 1500 and 400 m, respectively. The main access roads to these centers are shown in Fig. 1. However, it is expected that after a destructive earthquake, the access roads could be blocked and these centers cannot provide necessary services. Therefore, the bazaar should have a contingency plan for self-sufficiency at the first couple of hours after an earthquake. For this purpose, the necessary relief equipment (such as water hydrants, fire extinguishers, water tanks, rescue tools, etc.) should be provided and located in different parts of the bazaar to be used by the people and volunteer groups aftermath of an earthquake. However, the questionnaire survey depicted that the willingness of merchants to be involved in such programs is very low, due to their risk perception and lack of sufficient awareness about the impacts of a potential earthquake. Figure 12 depicts the system performance in the organizational dimension (*STU*) by combining the relevant indices and sub-indices according to Eq. (1) and Table 1.

3-5- Cultural-Historical dimension

The unique and traditional architecture of Tabriz bazaar and presence of valuable tangible and intangible assets in this place, made the bazaar as an attractive place for domestic and international visitors. Besides of valuable carpets that are famous in the world, holding religious ceremonies on Tasua and Ashura, which date back to 500 years ago, are among the intangible heritage of Tabriz Historical Bazaar, indicating its high historical-cultural value (Fig. 13-a). Moreover, existence of historical mosques and religious schools (Hozeh-e Elmiyeh) is another cultural characteristics of Tabriz bazaar. Mosques such as Jameh Mosque (Fig. 13-b) dating back to the Seljuk era; Imam Juma Mosque, Maqbareh Mosque and Saheb al-Amr Mosque dating back to the Safavid dynasty and Haj Safar Ali Mosque, Mojtahed Mosque (63 Sotoun) and Akbari School that were constructed in the Qajar era are among the cultural heritage in this bazaar. These characteristics are some reasons for registering the Tabriz Historic Bazaar Complex as World Heritage by UNESCO in 2010.

In order to evaluate the values of sub-indicators related to historical-cultural dimension, some site surveys were done in this study. In addition, several interviews were conducted with relevant cultural heritage officials in the bazaar to collect required information, such as the originality of the buildings or fabrics (cvb). Despite the general preservation of the historical fabric, some renovations were made during the 1970s and 1980s, without sufficient attention to compatibility with the historical fabric in terms of visual appearance and materials used in structural and non-structural components, facades and equipment. In Fig. 14, the system performance in the cultural-historical (CH) dimension is shown. The numbers are calculated by integrating the values of relevant indicators and sub-indicators and their weights, using Eq. 1.

It is worth mentioning that at this time, the historical buildings in Tabriz bazaar can be restored only in accordance with UNESCO World Heritage guidelines and under the supervision of the World Heritage Base. Therefore, physical interventions in the bazaar are sensitive and expensive. Accordingly, to improve the quality of system in the historical-cultural dimension, the following measures could be recommended that are more feasible: developing comprehensive programs for protecting the bazaar against potential hazards with participation of local residents and relevant authorities, implementing research projects on soft measures for improving the resilience, promoting public and professional knowledge in the field of historical heritage preservation, establishment of expert teams for monitoring and supervision of activities, strengthening collaboration with regional and international institutions for sharing experiences and resources, etc.

3-6- Overall system performance of Tabriz Bazaar against earthquakes

The overall system performance of Tabriz Bazaar against earthquakes could be calculated by integrating the values of different dimensions based on their weights, using Eq. 2 (Figure. 15). The results shows that currently the bazaar does not have good condition and in case of an earthquake, different physical damage, socio-economic loss and cultural consequences are expected. Thus, necessary interventions should be implemented in the weak dimensions, based on the existing values of indicators and sub-indicators to improve resilience.

Among the different segments evaluated in this study, few number of zones, which include mosques and religious schools (11 out of 125 bazaar sections with the score of 6.6-7) have relatively the best conditions. However, they are still significantly far from the maximum scores that can be gained in this model (the total range of scores varies from 4.14 to 7.23 on the 0–10 scale). The worst situation also belongs to red and dark orange colors parts (Fig. 15), representing the parts of the bazaar that the system performance score is 4.14–5.07. Buyuk Shazda Sara, Al-Mahdi Mall (Khan Sara), Razavi Timcheh, Taza rasta bazaar, Butchular Rasta, Haj-Sheikh Complex, Mirza Mehdi Sara, Amir Rasta Bazar, Sheikh-Kazem Timcheh, Mirza-Mohammad Dalan, Ghandchilar Dalan, Jafarieh Mall and Saheb-Abad square are among the most vulnerable sections, which some of the are located in the center of the bazaar.

Although at the first glance, it seems that there are not too much differences between the scores in different zones of bazaar, but using the proposed approach may depict the main causes of weakness in system performance. This would help decision makers to implement most appropriate and effective interventions, based on different dimensions, indicators and sub-indicators. For instance, although the scores for Amir Rasta Bazaar and the Poshte-Amir Rasta Bazaar (blocks 114 and 113) are nearly the same, but the necessary interventions to improve the system performance are different. Accordingly, in Amir Bazaar the indices related to economic dimension should be improved, while in Poshte-Amir Rasta Bazaar, intervention on land-use and social dimensions have better impacts on resilience.

4- Conclusion

In this study a new index-based approach to estimate the system performance as a key parameter in resilience assessment in urban fabrics with historic-commercial value was introduced and calibrated for traditional bazaars in Iran. In this approach, besides of physical, economic, social and organizational dimensions of resilience that were presented by different scholars in the literature, a new dimension named “Cultural-Historical” was introduced to assess the contribution of relevant aspects in resilience score. In addition, different indicators and sub-indicators related to these 5 dimensions in traditional bazaars were listed and weighted using AHP and expert judgments. However, the existence of various parameters affecting the resilience of historical bazaars to earthquakes could make it difficult for managers to decide on appropriate intervention for resilience improvement. Therefore, in order to assess the contribution of different dimensions, indicators and sub-indicators in resilience at traditional bazaar, a conceptual model was introduced in this paper to be used for measuring system performance.

Then the proposed model was applied in Tabriz Historical Bazaar, which is known as a world cultural heritage, and exposed to high risk of earthquake. The results demonstrated that the system performance in all the evaluated dimensions is not sufficient, therefore in case of a strong earthquake significant damage and casualties could be expected in the bazaar that will have long-term consequences. Thus, necessary measures should be implemented in this area to improve its resilience before the occurrence of devastating earthquakes.

It should be noted that currently, most of the programs developed for promoting safety and security of traditional bazaars in Iran against earthquakes, only focus on few measures (mostly related to improving emergency response capacities to provide necessary assistances after occurrence of an earthquake). However, in this study, it was shown that a variety of interventions for risk mitigation, improving preparedness, strengthening response capacity and preparing for recovery and reconstruction should be formulated and implemented in advance to improve resilience of traditional bazaars against earthquakes. Therefore, the proposed model can be utilized by decision makers to select the most effective improvement measures for different parts of traditional bazaars. This could be physical remediation in some areas or socio-economic and cultural interventions at other parts.

Finally, the proposed model can be utilized in similar old urban fabrics in other countries, after calibrating the parameters and their weights based on local conditions.

Declarations

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Tables

Table 1: Dimensions, indicators and sun-indicators of resilience and corresponding weights

Dimensions (weight)	Indicator (weight)	Sub-indicator (weight)	Data collection method
Physical, 0.3	Buildings, 0.63	Quality of historical buildings at each zone (0.12), percentage of retrofitted buildings in each zone (0.38), building use (0.5)	Site survey, checklists, interviews with managers
	Infrastructures, 0.24	Risk of road blockage (0.52), vulnerability of lifelines (water, electricity, gas and telecommunications) (0.35), interdependence of infrastructures (0.13)	Site survey, checklists, interviews with managers
	hazards, 0.13	Earthquake intensity (0.62), ground motion amplification and geohazards (0.12), fire and leakage of hazardous materials (0.26)	Microzonation maps, site survey, checklists
Economic, 0.227	Business, 0.71	Ownership (0.13), economic value of properties and goods (0.53), income due to tourism (0.09), per capita income (0.25)	Site survey, checklists, databases, interviews
	Compensation mechanisms, 0.15	Insurance (0.21), government mechanisms for compensation after the earthquake (loans, grants, protection fund, etc.) (0.19), personal capitals (0.6)	Interviews, questionnaire-based survey
	Interruption of activities, 0.14	Number of people working in the bazaar (0.28), the impact of bazaar on economic activities outside the bazaar (percentage of wholesale to retail) (0.72)	
Organizational, 0.08	Planning, 0.31	Risk reduction or disaster management programs (0.66), variety of contingency programs (0.1), sustainability of programs (0.24)	Site survey, interviews
	Capacities, 0.11	Emergency Response (ER) infrastructures (fire station, medical center,) (0.53), available ER resources (emergency water and electricity supply, fire extinguishing system, etc.) (0.28), emergency routes and evacuation places (0.19)	
	Robustness and diversity of DM structures, 0.37	Early warning and rapid response system (0.24), Incident Command Systems, ICS (0.53), Communication between residents and local managers (preferably IT-based) (0.23)	
	Managerial approach and capabilities, 0.21	Coordination among managers (0.21), availability of community-based actions and programs (0.21), Autonomy (0.58)	
Social, 0.326	Preparedness, 0.38	Education (0.07), public awareness (0.34), earthquake risk perception (0.28), previous experiences (0.31)	Questionnaire-based survey
	Population, 0.31	Population density (0.29), weak population distribution (0.11), adaptability and motivation for post-earthquake recovery (0.6)	Databases, field survey, questionnaire
	Anomalies, 0.17	Security index (0.32), delinquency rate (addiction, conflict, ...) (0.68)	Interviews, questionnaire-based survey
	Diversity of social relations, 0.14	Social cohesion and participation in group activities (NGOs, charities, religious, cultural and social networks) (0.58), sense of belonging and satisfaction (0.22), diversity and relationship between ethnicities (0.2)	Questionnaire-based survey
Cultural-Historical, 0.061	Cultural values, 0.47	Importance level (national heritage, world heritage, ...) (0.55), tourism attractions and number of visitors (0.16), the relationship and interaction of people with the bazaar (0.29)	Interviews, field observation
	Recoverability, 0.23	Restoration of cultural-economic prosperity (0.64), capacity to revive damaged cultural-historical urban fabrics (0.36)	Interviews
	National commitment to protection, 0.3	Executive programs to preserve the historical fabrics (0.51), professional knowledge for heritage preservation and development of related programs (0.37), regional and international cooperation for protection of bazaars (0.12)	Interviews

Table 2: Membership function, upper and lower bounds for the sub-indicator of “sense of belonging and satisfaction”

Membership function: type	triangular			
Fuzzy degrees	l	m	u	$\bar{x}$
Very low	-0.2	0.1	0.1	0.044
low	0	0.3	0.3	0.2
medium	0.3	0.6	0.6	0.5
high	0.5	0.8	0.8	0.7
Very high	0.7	1	1	0.9

Table 3 Separation of structures based on the level of damage after the potential earthquake (Mansouri et al., 2010)

Total zones	125
Number of the zone without damage	0
Number of the zone with severely damaged buildings	33
Number of the zone with destroyed buildings	92

Table. 4 Number of injured people and casualties after the potential earthquake (Coburn et al., 1992)

	10:30 A.M.	12:30 P.M.
Dead (person)	812	3335
Injured (person)	429	1234
Uninjured (person)	2360	6789
Total (person)	3601	10358

Figures

Figure 1

The sections of Tabriz Historical Bazaar evaluated in this research

Figure 2

Iso-acceleration Map for Tabriz city (PGA, return period 2475 years) (Tehran Padir, 2009)

Figure 3

Accumulation of flammable materials and petroleum

Figure 4

Improper roof covering

Figure 5

a- Visible cracks in the ceiling; b- Extensive humidity in many parts of the bazaar; c- an example of damage to walls

Figure 6

a- A sample of narrow passage in Tabriz bazaar; b- an open space inside bazaar

Figure 7

Loose and insecure connections in the electricity and telephone network

Figure 8

System performance of physical dimension (PHS)

Figure 9

Exquisite and precious handmade carpets

Figure 10

System performance in the Economic dimension (ECM)

Figure 11

System performance in the social dimension (SCL)

Figure 12

System performance in the organizational dimension (STU)

Figure 13

a- Tasua and Ashura Religious Ceremony (Mozaffariyeh Timcheh), b- Jameh Mosque of Tabriz

Figure 14

System quality in cultural-historical dimension (CH)

Figure 15

Total system performance of Tabriz Bazaar against earthquake (PT)