



## Article

# Urban Form Resilience: A Comparative Analysis of Traditional, Semi-Planned, and Planned Neighborhoods in Shiraz, Iran

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**Abstract:** As cities are exposed to a portfolio of risks, the concept of resilience has risen to prominence over the past two decades. Consequently, a large volume of research has been published on different aspects of urban resilience. However, urban form resilience is still relatively understudied. As a step toward filling this gap, this study examines resilience of nine selected neighborhoods from Shiraz, an old Iranian city. The selected cases represent three different urban form patterns, namely, traditional, semi-planned, and planned. Different indicators related to the physical configuration of lots, blocks, open and green spaces, and street networks are used to examine resilience of each neighborhood to three major stressors, namely, earthquakes, extreme heat events, and floods. Additionally, a combination of Shannon entropy and the VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje in Serbian) method is used to rank the resilience of each neighborhood to each of the three stressors. Results show that, overall, the physical form of the planned neighborhoods is more conducive to urban resilience. In contrast, the urban form of traditional neighborhoods was found to be less resilient. There were, however, some variations depending on the type of stressor considered. The paper concludes by emphasizing the need to consider social and economic factors in future studies of urban form resilience.

**Keywords:** urban form; resilience; earthquake; heat stress; flooding; traditional neighborhood; semi-planned neighborhood; planned neighborhood



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## 1. Introduction

Over the past two decades, the concept of urban resilience has increasingly received the attention of academics and policymakers alike [1]. It is generally defined as the capacity to “plan and prepare for, absorb, recover from, and more successfully adapt to adverse events” [2]. Multiple socioeconomic, institutional, physical, and environmental dimensions contribute to achieving these capacities. The growing attention to urban resilience can be explained by the fact that cities, as engines of economic growth and major hubs of global population, need to deal with a wide range of natural and humanmade hazards [3]. According to some estimates, on average, the global annual economic loss attributable to disasters in cities is about 300 billion United States dollars (USD) [4], and this amount is projected to further grow since climate change is expected to increase the frequency and intensity of adverse events [3].

The literature on urban resilience is vast and still expanding. It covers various issues and concepts related to urban planning and design, such as governance [5], disaster risk reduction [6], climate change adaptation and mitigation [7,8], justice [9], urban economy [10], critical infrastructure [11], and nature-based solutions [12].

Despite the significance of urban form for development and functionality of cities, its importance for enhancing urban resilience was not recognized until recently. This is probably because urban form is often associated with physical elements and structure of

cities that are characterized by slower rates of transformation compared to other social or economic processes [13]. In turn, these are perceived not to be compatible with some underlying resilience characteristics such as flexibility, agility, and adaptive capacity [14]. However, over the past few years, there has been a growing recognition of the potential direct and indirect linkages between urban form and resilience characteristics such as robustness, redundant capacity, efficiency, diversity, and self-organization [14]. Following this, several studies have been published that explicitly examine linkages between urban form and resilience [15,16]. These studies are mainly focused on linkages between urban form and resilience to climatic stressors [17] and seismic events [15]. Despite this, “urban form resilience” is still a relatively underexplored area of research. For instance, there is still a lack of research comparing resilience of traditional and planned neighborhoods from the urban form perspective.

Against this background, the main aim of this study was to build on the “urban form resilience” literature through comparative analysis of nine selected neighborhoods from Shiraz, Iran, which represent three different urban form patterns (typologies), namely, traditional, semi-planned, and planned. Using a selected group of urban form indicators and a combination of Shannon entropy and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian) methods, we discuss the resilience of each neighborhood to three major stressors with a high chance of occurrence in Shiraz, namely, earthquake, extreme heat, and flooding. This study is important because these three urban form patterns can be observed in many cities around the world, especially in historic ones. Better understanding regarding the performance of these different patterns can inform planners and policymakers of their strengths and weaknesses. This, in turn, is likely to facilitate taking actions toward improving urban resilience.

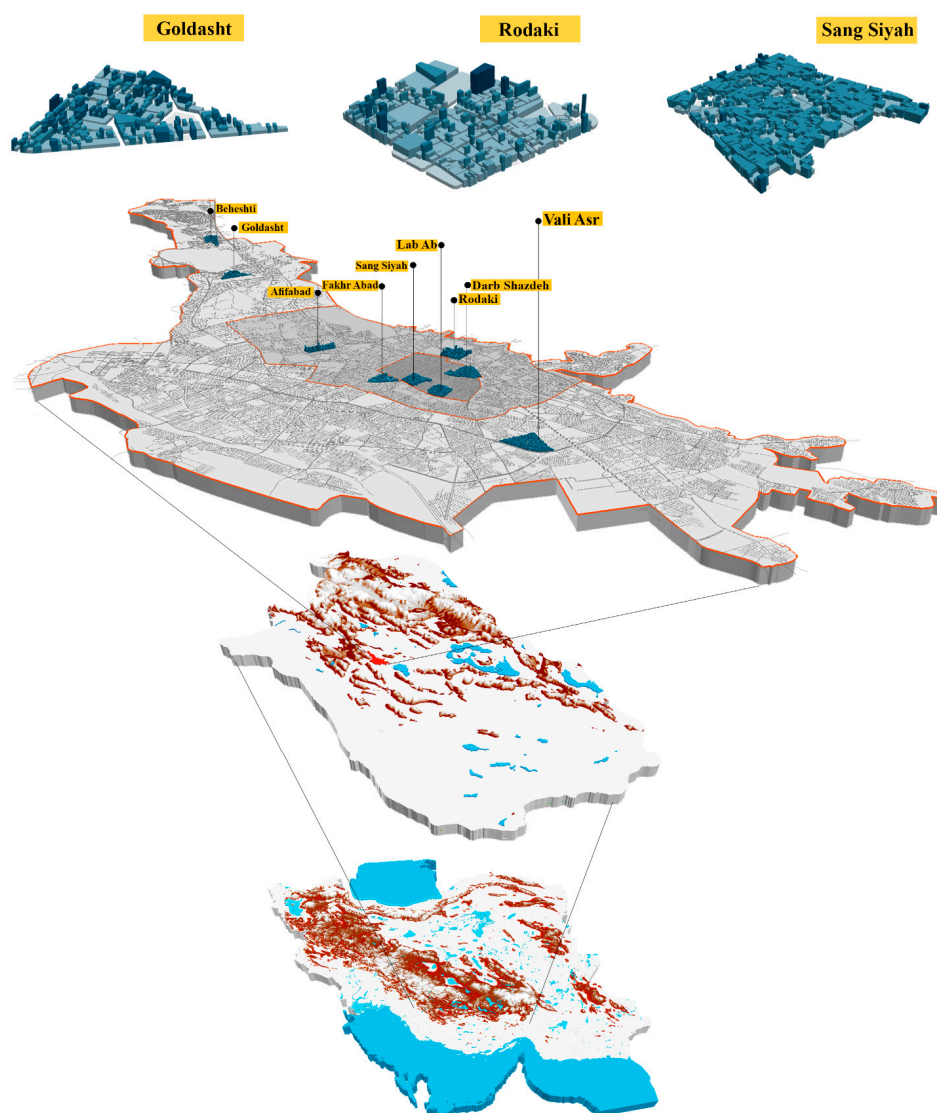
The paper is structured as follows: the case study area is introduced in the next section. Research methods and materials and a brief literature review on associations between selected indicators and resilience are presented in Section 3. Results of the comparative analysis are reported in Section 4. Section 5 discusses the major findings related to urban form resilience of the selected neighborhoods. Lastly, Section 6 concludes the study by summarizing the main findings and highlights areas that need further research.

## 2. The Case Study Area and Selected Neighborhoods

Shiraz, the capital city of Fars Province, is a major Iranian city located in the southern part of the country (29°36′37.1″ north (N), 52°31′52.1″ east (E)). The city has a total area of about 240 km<sup>2</sup> and is the fifth most populous city of Iran, with a population of about 1.55 million according to the latest census data (Fars Statistical Annals). Shiraz is bounded by mountains on three sides and, according to the Köppen Climate Classification, features hot and semiarid (BSh) and cold and semiarid (BSk) climates (Fars Metropolitan Planning Organization). It is an old city and was the capital of the country during the Zand Dynasty. Like other old Iranian cities, Shiraz features different urban patterns, making it a suitable case for comparative analysis. Due to its exposure to several climatic and non-climatic risks, increasing resilience in the city is essential. Shiraz is prone to seismic hazards due to its proximity to the Kareh Bas fault [18]. Heat stress is also a major hazard as, during some summer days, the maximum daily temperature reaches about 43 °C. Heat stress is expected to further increase in the future due to climate change impacts. Furthermore, during the past few years, several major flash floods have occurred in the city, causing substantial human and economic losses. As a case in point, during the catastrophic (March) 2019 flood event, 21 people died, and many properties were damaged (the governor of Shiraz announced that the damage caused by the flood was about 8 million USD according to the reports prepared by the metropolitan organization). Accordingly, in this study we examine resilience to earthquakes, extreme heat, and flood events.

In terms of urban pattern, the city can be divided into three major rings, as shown in Figure 1. The inner ring is the historical core of the city that has, historically, experienced organic development and growth patterns. It has an organic urban pattern, characterized

by narrow and irregular street networks flanked by one- to two-story buildings that are built on small lots. Buildings in this part of the city often feature inner courtyards and share walls with adjacent buildings. The neighborhoods selected from this ring are referred to as “traditional” in this study. The city’s urban growth was limited to the boundaries of the inner ring until the 1930s. The physical growth of Shiraz has significantly expanded beyond the boundaries of the historical core since the beginning of the Pahlavi Era (1925–1979). The areas developed over the past century are divided into two rings as shown in Figure 1. In this study, the intermediate ring is called “semi-planned”, as its development followed a combination of both organic (unplanned) and planned patterns. While some narrow and winding streets exist, streets are generally wider and more regular. Moreover, street connectivity is higher and comparatively fewer cul-de-sacs can be observed. Additionally, compared with the inner ring, more multistory buildings exist, and lot and block sizes are larger. The neighborhoods selected from this ring are, therefore, referred to as “semi-planned” in this study. The structure of the outer ring, which has mainly been developed over the past four decades [19], is similar to that of the intermediate ring. The major differences are that street networks are completely regular (gridded), the size of lots and blocks is larger, and more multistory buildings exist. The neighborhoods selected from this ring are referred to as “planned” in this study.



**Figure 1.** Location of the selected cases.

For comparative analysis in this study, we selected nine neighborhoods representing these three urban patterns. To improve generalizability of the results, three neighborhoods were selected from each ring. The selected neighborhoods were, namely, Sang Siyah (I1), Lab Ab (I2), and Darb Shazdeh (I3) (from the inner ring), Fakhr Abad (In4), Afifabad (In5), and Rodaki (In6) (from the intermediate ring), and Vali Asr (O7), Goldasht (O8), and Beheshti (O9) (from the outer ring). Some descriptive statistics related to the selected neighborhoods are presented in Table 1. Furthermore, the layout pattern of each neighborhood is shown in Figure 2.

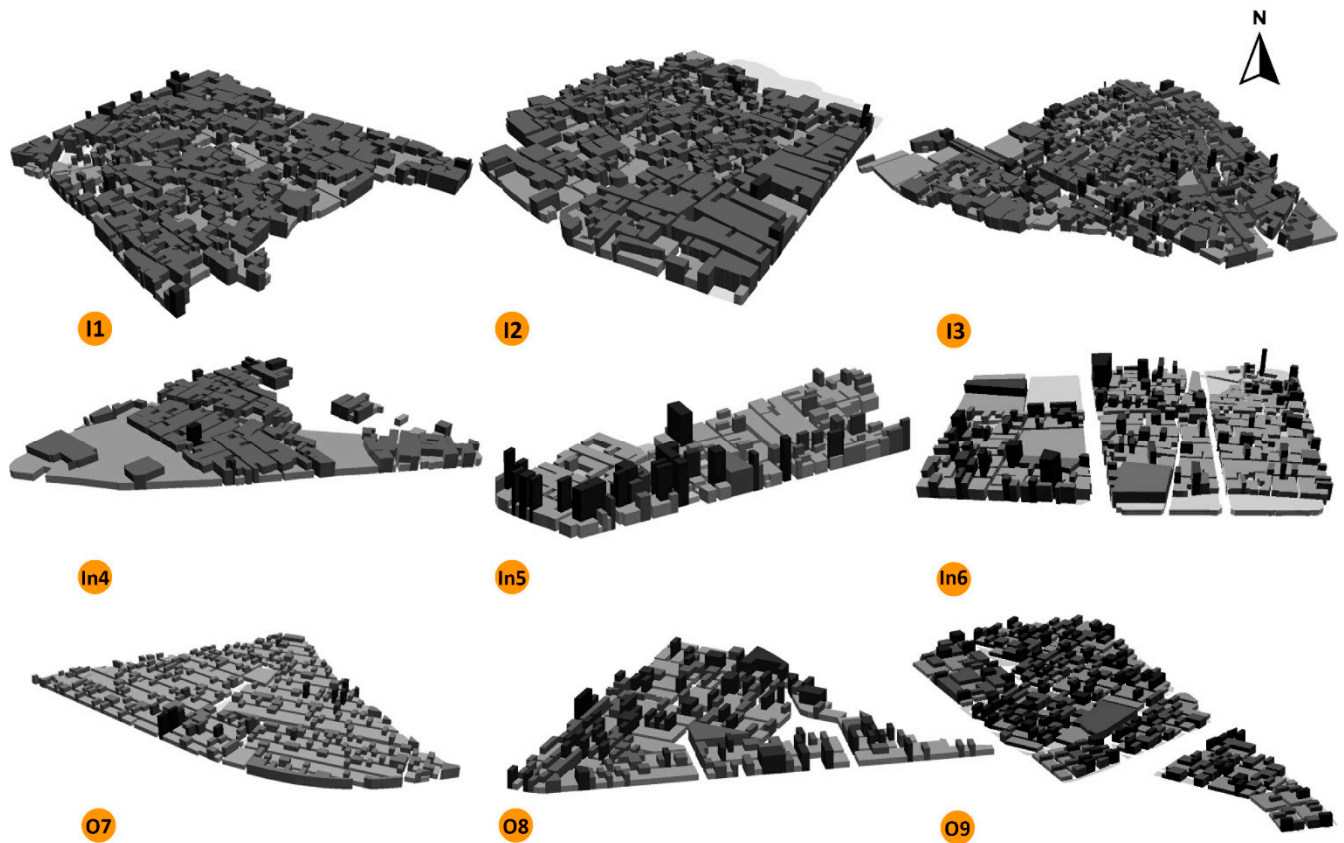


Figure 2. Layout patterns of the selected neighborhoods.

Table 1. Some descriptive statistics related to the selected neighborhoods (source: master plan of Shiraz).

Type	Neighborhood Name	Neighborhood Size (ha)	Population	Population Density (Person/ha)	Population Male	Population Female	Household
I1	Sang Siyah	33	3763	114	1969	1788	1233
I2	Lab Ab	37.7	5466	145	2856	2609	1740
I3	Darb Shazdeh	50.83	6541	129	3375	3150	1638
In4	Fakhr Abad	29.6	1951	66	933	1017	680
In5	Afifabad	30.46	3326	109	1584	1741	1169
In6	Rodaki	48.68	5704	117	2712	2990	1882
O7	Vali Asr	69.21	7872	114	3909	3958	2518
O8	Goldasht	44.08	4069	92	1974	2091	1333
O9	Beheshti	51.16	4781	93	2328	2452	1538



### 3. Materials and Methods

The study was conducted using a mixed-methods approach involving a brief literature review to determine potential linkages between selected urban form indicators and resilience, extracting data related to the selected indicators using spatial analysis techniques, assigning weights to the selected indicators using Shannon entropy analysis, and ranking resilience of the selected neighborhoods using the VIKOR method, which is a multicriteria decision analysis method. In the remainder of this section, we first discuss the selected indicators and their potential linkages to resilience. Following that, we discuss the procedures taken for extracting data related to the selected indicators, the Shannon entropy analysis used for assigning weights to indicators, and the VIKOR method used for obtaining final rankings.

#### 3.1. Urban Form Indicators and Their Association with Resilience

In order to carry out a comparative analysis across the selected neighborhoods, we selected a group of urban form indicators that, according to the literature, are appropriate for assessing resilience at the neighborhood scale [20–22]. These indicators and their descriptions are presented in Table 2. This table also indicates the potential associations between each indicator and the three stressors (i.e., earthquake, extreme heat, and flooding). Here, the positive sign (+) indicates the desirability of higher values. For example, it is assumed that higher values of connectivity contribute to resilience to all stressors. In contrast, the negative sign (−) indicates that lower values are more desirable. For instance, lower values of betweenness centrality are assumed to contribute to resilience. These assumptions are made on the basis of evidence reported in the literature and considering the context-specific conditions of Shiraz. Therefore, they should not be considered as universally applicable. In other words, depending on local conditions, the nature of associations between urban form indicators and resilience may vary. These are briefly explained here.

As a frequently studied urban form measure, density is an indicator of development intensity. Among various indicators of density, gross population density is probably the most commonly used [20]. Diverging evidence has been reported in the literature on the relationship between density and resilience. Regarding resilience to seismic events, there are arguments that major destructions in high-density areas are likely to have negative impacts on absorption and recovery processes through, among other things, delaying evacuation and emergency response programs [23]. In terms of resilience to extreme heat, evidence suggests that desirable levels of density vary depending on the context. Overall, moderate levels are argued to be more appropriate for semiarid climates such as Shiraz [21,22,24]. In contrast, very high levels of density may not be appropriate as they may intensify the heat island effect by disrupting natural ventilation patterns and leading to excessive exhaust of heat from air conditioners [25]. It should, however, be noted that high levels of density do not necessarily intensify the heat island effect. In fact, high density can be achieved using multiple configurations, and those that are carefully designed can minimize negative impacts on indoor and outdoor thermal comfort. In this regard, optimal design, appropriate land use and street configurations, adequate provision of open and green spaces, and careful choice of construction and pavement materials (e.g., high-albedo materials) can contribute to mitigating the heat island effect [26,27]. Despite this, in this study, we assumed that high density is not desirable for resilience to heat stress, because high-density areas in the city often lack carefully designed and adequate levels of open and green spaces. As for resilience to floods, high-density development in flood-prone areas such as Shiraz is not desirable as it will expose more people and properties to risk [28]. Here, it should also be noted that high density alone is not necessarily a risk factor. Again, careful land-use planning and urban design can minimize flood vulnerability of high-density areas. For instance, avoiding risk-prone areas and increasing surface permeability to manage stormwater runoff can mitigate urban flooding in high-density areas. These are, however, not appropriately considered in Shiraz [29]. Accordingly, as density levels in all selected

neighborhoods are already relatively high (see Table 2), in this study, we assume that those that are relatively denser have lower absorption and response capacities.

**Table 2.** Some descriptive statistics related to the selected neighborhoods (source: master plan of Shiraz). NA, not applicable.

Indicator	Earthquake	Extreme Heat	Flooding	Description
Density	—	—	—	Gross population density (population/area (H))
Lot size	+	—	—	Area
Lot shape	—	—	—	Perimeter/area ratio (regular or simple is better than complex)
Block size	+	—	—	Area
Block shape	—	—	—	Perimeter/area ratio
Size of open space	+	+	+	Area
Shape of open space	NA	—	NA	Perimeter/area ratio
Access to open space	+	+	+	Average network distance of households to open space
Fraction of green space	+	+	+	Total area of green space/total area
Fraction of paved space	NA	—	—	Total area of paved space/total area
Land-use mix	+	+	+	$LUM = \frac{-1(\sum_{i=1}^n pi \times \ln(pi))}{Ln(n)}$ , where LUM is the land-use mix score, $pi$ is the proportion of land use $i$ , and $n$ is the number of land-use categories [30]
Building structure	+	NA	NA	The total area of reinforced buildings divided by the total area of buildings
Street connectivity	+	+	+	Connectivity refers to the number of the lines directly connected with a given line. $C_i = K$ , where $K$ is the number of the lines without intermediaries [31]
Street integration (R3[i])	+	+	+	integration = $\frac{1}{\sum_k d_{ik}}$ , where $d_{ik}$ refers to the shortest path between line $i$ and line $k$ [31]
Betweenness centrality	—	—	—	Betweenness value for a segment $x$ in a graph of $n$ segments can be defined as follows: betweenness centrality = $B_\theta(x) = \frac{\sum_{i=1}^n \sum_{j=1}^n \sigma(i,x,j)}{(n-1)(n-2)/2}$ , such that $i \neq x \neq j$ , where $\sigma(i,x,j) = 1$ if the shortest path from $i$ to $j$ passes through $x$ , and 0 otherwise [32]
Street depth (R3)	—	NA	—	Mean depth (MD) is calculated by dividing the total depth (TD) by the number of turns from one axial line to another line minus one (that is, without itself) $MD = \frac{TD}{(K-1)}$ , where TD is the sum of the number of connections between a particular node and every other node in the set [33]
Street width	+	+	+	Average street width
Sky view factor	+	—	NA	The sky view factor (SVF) is calculated using the aspect ratio considering all the streets of the urban block as street canyons

As the smallest units of urban land subdivision, “lots” are basic elements of urban form on which individual buildings sit. Lots have implications for the ability to adapt to incremental changes. The overall argument made in the literature is that fine-grained lots are more desirable for urban resilience as they improve flexibility and adaptive capacity [20]. Generally, fine-grained lots facilitate better connectivity and accessibility and allow accommodating a diverse range of uses and activities that contribute to enhancing

absorption and response capacities. In contrast, large lots that are mainly allocated to specific uses (e.g., residential) may result in high building density and leave limited space for open and green spaces that, as discussed earlier, are critical for resilience to heat stress and flooding. Accordingly, larger lot size may put constraints on the ability to achieve optimal urban design and urban form configurations [20,34]. For instance, for Shiraz, evidence shows that there is a strong positive correlation between lot size and land surface temperature, which is an indicator of heat stress [21]. Regarding earthquake resilience, however, in this study, we assume that small lots (dominant in the historic core) are not desirable as they are often associated with low building resistance in Iran [35]. It should be noted that this may not be always the case as small lot size does not necessarily mean lower building resistance. Therefore, context-specific conditions should be considered in other studies that intend to explore links between lot size and seismic resilience. The shape of lots is also argued to be important. Simpler lot geometries are more desirable as they improve flexibility of urban form, enable better connectivity and accessibility, and allow easier aggregation/disaggregation [36].

Similar arguments can be made about “blocks” that are defined as subdivisions of cities surrounded by streets and/or other urban features such as green spaces. In much a similar way to that of lots, larger built-up blocks reduce flexibility to incremental change by making it more difficult to aggregate/disaggregate lots if needed. Such blocks are also often associated with long street edges that reduce connectivity and accessibility, thereby having negative impacts on disaster response and recovery processes [37]. Large and paved blocks that do not include appropriate levels of green and open spaces are also likely to intensify heat stress and flooding hazard, through reducing surface reflectance and water percolation, respectively [20]. Again, this might not be always the case, and optimal configurations may facilitate minimizing the negative impacts of large blocks on heat stress and flooding. For instance, optimal configurations such as those in perimeter urban blocks can mitigate negative impacts [20]. Regarding the shape, what was discussed about lots also applies to block. Here, the argument about the desirability of larger blocks should again be taken with caution and considering context-specific conditions.

Open spaces in this study refer to “any unroofed ground space in the city (either natural or humanmade), excluding various types of right-of-way, which can be either publicly or privately owned” [20]. Size, shape, and accessibility of open spaces are important indicators that influence absorption, recovery, and adaptation capacities. There is strong consensus in the literature that open spaces contribute to earthquake resilience through enhancing evacuation and recovery processes [38,39]. By increasing urban porosity and, thus, improving air flow, urban spaces also contribute to reducing heat stress [40]. Heat stress can also be mitigated by increasing the fraction of unpaved open spaces covered with high-albedo materials such as greenery [17,21]. Additionally, open spaces can play important roles in accommodating and controlling floods and contributing to stormwater runoff management [41]. The flood control benefits can be maximized through reducing the fraction of paved surfaces. Regarding size and accessibility, larger and more accessible open spaces are argued to, overall, better contribute to all three stressors examined in this study [20,42]. The shape, however, is mainly relevant to heat stress, and less complexity is argued to be more desirable [42]. For instance, a study of 33 urban parks in Changchun, China showed that higher shape complexity (i.e., higher values of the perimeter to area ratio) is associated with a decreased cooling effect [43].

Mixed-use development is likely to influence resilience through both direct and indirect pathways. Directly, unlike single-use developments, it allows inclusion of various facilities and utilities in the neighborhood that can facilitate a nimbler response in the face of adverse events. Indirectly, land-use mix is believed to strengthen social interactions and social capital in the neighborhood that can be effective in improving absorption and recovery capacities [44]. Therefore, higher values of mixed used are deemed desirable in this study.

We also considered indicators related to streets and street canyons. As streets are major constituent elements of cities, their role in improving accessibility is particularly important. Higher levels of street connectivity improve redundancy and are, therefore, more desirable for maintaining accessibility during adverse events such as earthquakes [45]. High street connectivity, in combination with pervious surfaces and green infrastructure, can also increase resilience to heat and flooding events [46,47]. Street integration is also another measure of accessibility and, therefore, higher values are more desirable [48]. Centrality indicates the relative importance of nodes/links in a street network. In case a node/link with high centrality values is obstructed, it may cause significant disruptions in terms of accessibility to damaged areas. Such a situation may occur when centrality values are not homogeneously distributed. As a result, a highly central node/link may be surrounded by nodes/links with lower centrality values. This erodes response capacities during adverse events such as earthquakes and floods due to the strong reliability on the highly central node/link. Additionally, there is evidence showing that higher levels of centrality are associated with a more intense urban heat island effect [47]. Street depth is a measure of complexity of the network and indicates the ease of reaching from one point to another [48]. Higher values of street depth indicate less accessibility and are not desirable. Street width has also implications for resilience. Wider streets are generally deemed more desirable as they can facilitate better accessibility and also allow integrating elements such as green infrastructure that can contribute to stormwater management and heat island mitigation. Addressing the latter, however, is also dependent on the height of buildings that flank street edges. In other words, the height/width ratio has implications for thermal comfort in the street canyon, as it can affect patterns of solar irradiation and wind circulation. Therefore, depth of the street canyon should also be considered as it may affect accessibility, as well as the microclimatic conditions related to heat stress (in other words, the height/width ratio). Destructions of high-rise buildings adjacent to deep street canyons make response and recovery efforts more challenging. Therefore, such canyons are not desirable in terms of earthquake resilience [45]. However, for climatic conditions of Shiraz, deeper canyons can provide shading benefits and, thus, mitigate heat stress.

### 3.2. Data Collection and Modeling

After determining the likely associations between selected urban form indicators and resilience, required data for analysis were obtained from two major sources, namely, the master plan of Shiraz and Open Street Map. Details on the definitions of the indicators and formulae used for quantification are available in Table 2. Mapping and analysis of indicators related to density, land-use mix, blocks and lots, open spaces, green spaces, and paved spaces were done using ArcMap 10.7. After extracting data using the UCL depthmapX, ArcMap was also used for analyzing indicators related to the street network.

After extracting all the necessary information related to the selected indicators, we used a combination of Shannon entropy and the VIKOR model for multicriteria decision analysis to rank the selected neighborhoods according to their resilience to earthquake, heat events, and flooding.

The VIKOR method can be used to rank performance/desirability of different alternatives (various neighborhoods with different urban forms in this case) on the basis of a set of incommensurable criteria (urban form indicators in this case) [49]. This method allows multicriteria ranking according to the extent of proximity to the ideal solution [49]. It is useful for situations where one needs to determine relative importance/rank of different alternatives by reaching a compromise solution that maximizes advantages and minimizes disadvantages [50].

The steps taken for ranking using the VIKOR model are as follows [49,50]:

- Establish the decision matrix on the basis of resilience indicators;
- Identify the relative weights of the indicators and developing a normalized weight matrix using the Shannon entropy method;



- Determine the best  $f_i^*$  and worst  $f_i^-$  values for all the criteria as follows:  $f_i^* = \max_j f_{ij}$ ,  $f_i^- = \min_j f_{ij}$ , where  $f_{ij}$  is the value of the  $i$ -th criterion for the alternative  $j$ ;
- Compute the values of maximum utility ( $S_j$ ) and minimum regret ( $R_j$ ) using the following formulae:

$$S_j = \sum_{i=1}^n w_i \cdot \frac{f_i^* - f_{ij}}{f_i^* - f_i^-}, \quad (1)$$

$$R_j = \max \left[ w_i \cdot \frac{f_i^* - f_{ij}}{f_i^* - f_i^-} \right], \quad (2)$$

where  $w_i$  represents the indicator weights calculated using the Shannon entropy method;

- Lastly, compute the values of VIKOR index ( $Q_j, j = 1, 2, \dots, j$ ) using the following formula:

$$Q_j = v \cdot \frac{S_j - S^-}{S^* - S^-} + (1 - v) \cdot \frac{R_j - R^-}{R^* - R^-}, \quad (3)$$

where  $S^* = \max S_j$ ,  $S^- = \min S_j$ ,  $R^* = \max R_j$ ,  $R^- = \min R_j$ , and  $v$  is introduced as the weight of the strategy of “the majority of criteria” (or “the maximum group utility”); here,  $v = 0.5$ .

The overall flow of the methods used in this study is shown in Figure 3.

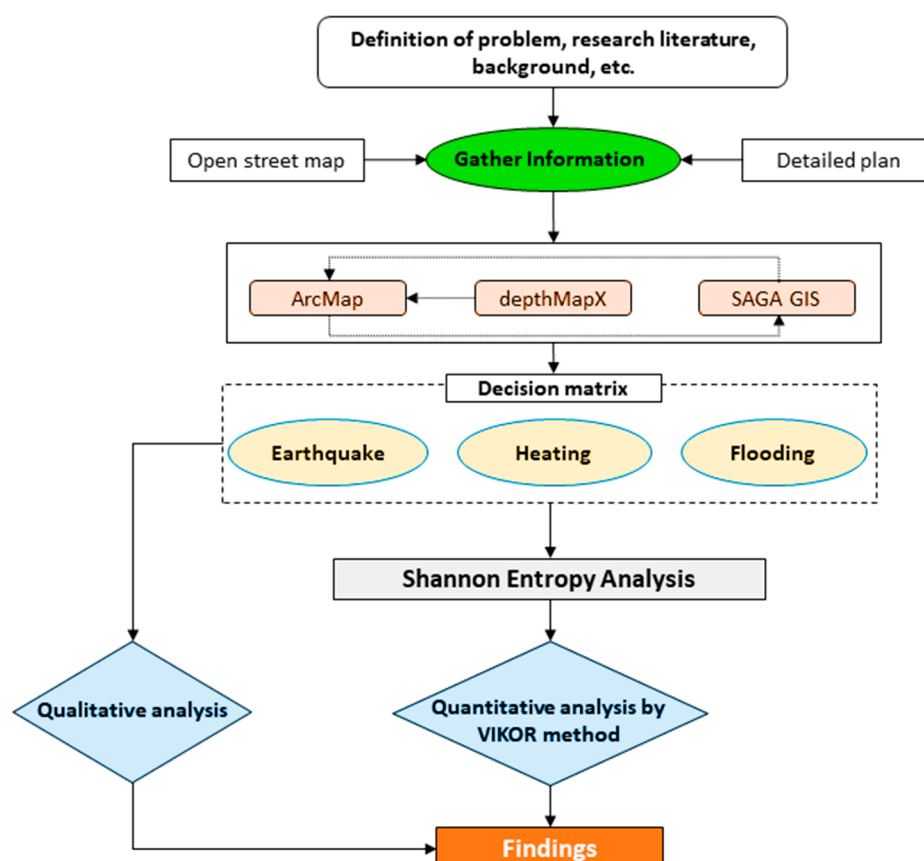


Figure 3. Flowchart of the study.

#### 4. Results

In this section, we report on the overall performance of the different types of neighborhoods in terms of the selected urban form indicators, and we present the results of overall ranking of each neighborhood according to the VIKOR analysis. Numerical results associated with each of the urban form indicators across the nine selected neighborhoods

are presented in Table 3. Moreover, Figures 4 and 5 provide more information on selected indicators. These figures are also useful for comparative analysis of the selected cases. Table 3 shows that, on average, the traditional neighborhoods had the highest levels of density, followed by the semi-planned neighborhoods.

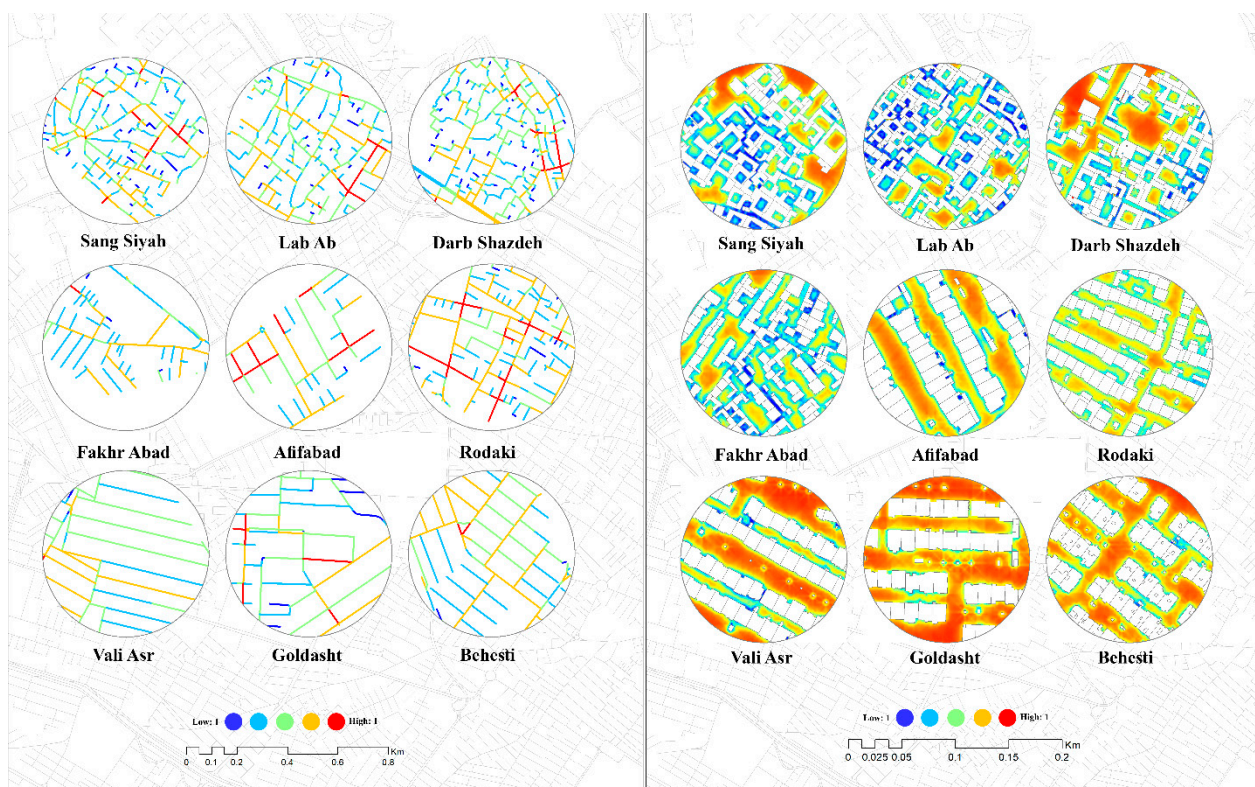
As expected, overall, lots and blocks were smaller in the traditional neighborhoods. It is, however, clear from Figure 2 that the geometric shape of lots and blocks was more complex in traditional neighborhoods compared to their semi-planned and planned counterparts. The same applied to the size and shape of open spaces. As for the fractions of green and open spaces, they were larger in planned and semi-planned neighborhoods. However, traditional neighborhoods examined in this study provided better access to the available green and open spaces. This can be explained by their compactness that can contribute to improved accessibility. Regarding paved spaces, the fraction was smaller in traditional neighborhoods. This is mainly because streets in these neighborhoods were narrower. Other indicators related to the street network indicated that the traditional neighborhoods were less accessible, and the best accessibility was provided by more planned neighborhoods (that showed higher values for connectivity and integration and lower values of street depth). Accessibility in traditional neighborhoods was hampered by the organic pattern of the street networks that featured lower levels of connectivity. Moreover, unlike the grid pattern of the more planned neighborhoods, the organic fabric of the traditional ones resulted in nodes/links with high centrality values that, in case of being disrupted, can significantly reduce accessibility of the network. The last indicator related to the street canyon, i.e., the sky view factor, was higher in more planned neighborhoods. This is mainly because the ratio of building height to street width was lower in them.

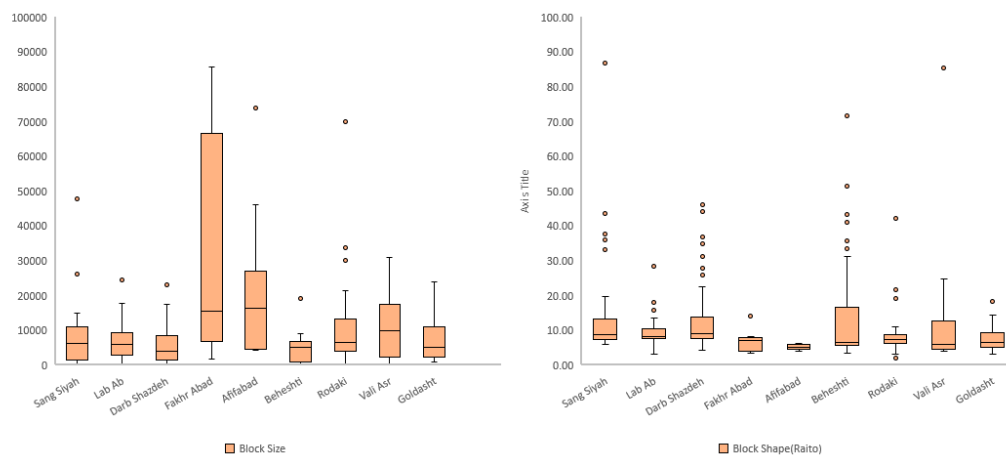
Building structure and land-use mix were two other factors considered in this study. Examining the neighborhoods on the basis of the former shows that more planned neighborhoods performed better. This is explained by the fact that planned neighborhoods were built more recently and in compliance with the new regulations that require compliance with building codes. They are, therefore, expected to have better seismic resistance. Lastly, land-use mix values show that semi-planned neighborhoods (located in the intermediate ring) provided a better mix of uses, followed by traditional neighborhoods. The planned neighborhoods located in the outer circle were mainly single-use (residential).

After calculating the numerical values of the indicators across the selected cases, we used the Shannon entropy method to assign normalized weights related to the three major stressors (earthquake, heat, and flooding) to each indicator. The output of this process is shown in Table 4. Following this, we used the VIKOR method to rank the selected neighborhoods on the basis of their overall urban form resilience. Results, presented in Table 5, show that, overall, traditional neighborhoods with old urban fabric performed more poorly against the three major stressors. This was particularly the case for resilience to earthquake risks. In contrast, planned neighborhoods that were built recently provided the best overall performance. There were, however, some exceptions. For instance, the urban form of Beheshti (O9), a planned neighborhood, is not desirable for resilience to heat risk. These results are further discussed in the next section.

**Table 3.** Urban form resilience indicators for each neighborhood.

	Sang Siyah	Lab Ab	Darb Shazdeh	Fakhr Abad	Afifabad	Rodaki	Vali Asr	Goldasht	Beheshti
Density (people per hectare)	104	145	108	66	109	117	114	92	93
Lot size (sq. m)	198.0	207.1	225.2	344.3	408.9	326.3	356.1	489.2	381.6
Lot shape (ratio)	0.375	0.383	0.420	0.344	0.251	0.319	0.237	0.220	0.284
Block size (sq. m)	7587	7102	5949	30,102	21,747	10,729	10,782	7361	4367
Block shape (ratio)	7.636	7.470	8.012	4.404	4.892	5.895	5.256	5.316	6.573
Size of open space (sq. m)	312	270	309	330	449	296	555	1651	484
Shape of open space (ratio)	0.336	0.343	0.337	0.284	0.204	0.268	0.258	0.191	0.538
Access to open space (m)	64	76	51	103	223	118	103	161	46
Fraction of green space (%)	1.644	0.350	0.555	19.433	8.165	0.174	0.165	6.120	6.386
Fraction of paved space (%)	12.3	13.4	18.6	11.7	13.9	20.7	22.8	22.9	22.3
Land-use mix (ratio)	0.361	0.458	0.525	0.645	0.297	0.628	0.209	0.318	0.239
Resilient building structure (%)	9.797	18.639	11.863	26.462	96.308	66.737	93.818	92.883	98.700
Street connectivity (No.)	2.751	2.801	2.794	2.993	3.181	3.203	3.775	3.568	3.146
Street integration (ratio)	1.198	1.223	1.213	1.299	1.368	1.382	1.614	1.523	1.370
Betweenness centrality	52,637	65,100	70,700	18,636	16,573	40,630	76,685	19,862	29,631
Street depth (ratio)	2.171	2.180	2.186	2.206	2.201	2.244	2.312	2.280	2.246
Street width (m)	8.60	8.15	8.94	15.00	10.82	10.61	15.05	12.40	11.30
Sky view factor (ratio)	0.674	0.716	0.706	0.811	0.755	0.733	0.848	0.856	0.822

**Figure 4.** The state of connectivity (left) and sky view factor (right) in the selected neighborhoods.



**Figure 5.** Distribution pattern of the size and shape of blocks.

**Table 4.** The indicator weights calculated using Shannon entropy.

Indicator	Earthquake	Heat	Flooding
Density	0.005	0.004	0.006
Lot size	0.065	0.055	0.070
Lot shape	0.255	0.217	0.273
Block size	0.070	0.059	0.074
Block shape	0.006	0.005	0.006
Size of open space	0.201	0.171	0.215
Shape of open space	-	0.203	-
Access to open space	0.034	0.029	0.037
Fraction of green space	0.197	0.168	0.210
Fraction of paved space	-	0.008	0.010
Land-use mix	0.020	0.017	0.021
Resilient building structure	0.070	-	-
Street connectivity	0.002	0.002	0.002
Street integration	0.002	0.002	0.002
Betweenness centrality	0.048	0.041	0.051
Street width	0.018	0.015	0.019
Street depth	0.004	-	0.004
Sky view factor	0.004	0.004	-

**Table 5.** Neighborhood ranking in against different risks (note that darker green and darker red indicate higher and lower rankings, respectively).

Stressor		Earthquake				Heat				Flooding			
Neighborhoods		Si	Ri	Qi	R	Si	Ri	Qi	R	Si	Ri	Qi	R
I1	Sang Siyah	0.627	0.182	0.493	7	0.44	0.16	0.45	4	0.58	0.19	0.51	4
I2	Lab Ab	0.618	0.195	0.539	8	0.48	0.17	0.54	7	0.69	0.21	0.69	7
I3	Darb Shazdeh	0.882	0.255	1	9	0.67	0.22	1	9	0.62	0.21	0.61	6
In4	Fakhr Abad	0.368	0.198	0.355	2	0.33	0.17	0.4	2	0.6	0.27	0.84	9
In5	Afifabad	0.456	0.201	0.436	4	0.36	0.17	0.45	3	0.5	0.21	0.5	3
In6	Rodaki	0.540	0.197	0.485	6	0.46	0.17	0.53	6	0.74	0.21	0.76	8
O7	Vali Asr	0.532	0.197	0.479	5	0.42	0.17	0.49	5	0.55	0.21	0.54	5
O8	Goldasht	0.248	0.136	0	1	0.19	0.12	0	1	0.53	0.21	0.5	2
O9	Beheshti	0.539	0.180	0.415	3	0.63	0.2	0.88	8	0.32	0.14	0	1

Ranking Color Ramp

1 ● ● ● ● ● ● 9

## 5. Discussions

Here, we first discuss rankings with respect to resilience to seismic risks, followed by heat stress and flooding.

### 5.1. Performance against Seismic Risks

The three traditional neighborhoods located in the historical core of the city were at the bottom of the ranking against earthquake risks. This is expectable given that most buildings in this part of the city are old and not reinforced. Considering the high levels of density, in the face of earthquakes, a large population will be at risk [20]. These vulnerabilities can be further compounded due to the narrow and irregular street networks that are not well connected [45]. Such street networks are not conducive to rapid evacuation and emergency response as the access of rescue teams will be challenging. Additionally, some street intersections in this area are highly central and, if obstructed, cause major disruptions across the neighborhoods. Despite all these drawbacks, these neighborhoods feature moderately sized open spaces that are well distributed across the neighborhoods. These can be accessed on foot and can be used by residents as locations for temporary shelter [38,39]. Moreover, the relatively high land-use mix can enable better access to facilities during the immediate aftermath of the earthquake.

In terms of resilience to seismic risks, neighborhoods with semi-planned urban texture (located in the intermediate ring) performed better than traditional neighborhoods. However, overall, their rankings were lower than planned, recently built neighborhoods. The only exception was Fakhr Abad (In4), ranked among the top three resilient neighborhoods. A close look at the values reported in Table 3 shows that density in the intermediate ring is relatively high, building resistance is not reasonable, open spaces are limited and not well-distributed, and connectivity and accessibility of the street network are also relatively low since the street network is semi-organic. As mentioned earlier, these attributes undermine resilience to seismic risks. Fakhr Abad is an exception because it has the lowest level of density among all neighborhoods studied here. At the same time, on average, streets are wider in this neighborhood. Other factors that contribute to better resiliency of Fakhr Abad are reasonable access to open spaces, and a relatively well-connected street network that does not suffer from nodes with very high centrality values.

Lastly, the rankings show that, overall, planned neighborhoods that were recently built and that are located in the outer ring had the best performance against seismic risks. The only exception was Vali Asir, ranked fifth. This was probably because its density is relatively high, and it does not feature a well-connected street network. The, overall, high ranking of these neighborhoods is not surprising. Having been recently developed, their buildings are more seismic-resistant. Furthermore, population density is relatively lower, meaning that a lower population is exposed to risks. Moreover, ample open space is provided that is relatively well distributed. Additionally, streets are wide and well connected, and there are no street segments/intersection with glaringly high levels of centrality. This is conducive to an effective evacuation and emergency response. Despite these advantages, the low levels of land-use mix may also cause difficulties in terms of access to amenities in the immediate aftermath of earthquakes.

### 5.2. Performance against Heat Risks

In terms of resilience to heat risks, results show that, overall, the semi-planned urban form of neighborhoods located in the intermediate ring is more desirable. These neighborhoods showed better ranking, followed by those located in the outer ring. Again, traditional neighborhoods located in the historical urban core were at the bottom of the ranking table. As discussed earlier, among different urban form indicators studied here, size and shape of open spaces, fraction of green and paved spaces, and sky view factor have more influence on resilience to heat risks [14,40,45]. Therefore, here, we mainly discuss the heat resilience of the selected neighborhoods on the basis of these indicators.



The best rankings, in descending order, could be observed in Goldasht (O8), Fakhr Abad (In4), and Afifabad (In5). Table 3 shows that the major difference between these neighborhoods and others is that they feature large-size open spaces and their fraction of green spaces is also significantly higher. While the fraction of paved spaces is comparable to the other neighborhoods, the significantly larger fraction of green spaces is expected to contribute to mitigating heat risks. In addition, greenery along the streets provides shading benefits and can mitigate potential heat risks that may occur due to the high levels of sky view factor in these neighborhoods.

Sang Siah (I1), Vali Asr (O7), and Rodaki (In6) show moderate levels of performance. The fact that Sang Siah, a traditional neighborhood, performed reasonably shows that provision appropriate levels of open and green spaces can make significant contributions to improving resilience in traditional neighborhoods. The other two neighborhoods with moderate levels of performance also feature relatively appropriate levels of open and green spaces. In contrast, Lab Ab (I2), Beheshti (O2), and Darb Shazdeh (I3) were the three neighborhoods with the least potential to mitigate heat stress. Lab Ab (I2) and Darb Shazdeh (I3) are traditional neighborhoods that lack appropriate levels of open and green spaces. These were likely the main factors contributing to their poor resilience to heat risks. Beheshti, however, is a planned neighborhood that features moderate levels of open and green spaces. Despite this, the fraction of paved spaces is high, which is likely to intensify heat stress by reducing surface reflectance. Additionally, streets are wide and lack enough greenery that can provide shading benefits. These are likely explanations for the poor performance of this neighborhood.

### 5.3. Performance against Flood Risks

Regarding resilience to flooding events, as discussed earlier, the following indicators are more influential: size of open space, fraction of green space, block size, lot size, fraction of paved spaces, and betweenness centrality [20,41,46]. Here, overall, planned neighborhoods located in the outer ring showed better resilience potential, followed by traditional neighborhoods. Beheshti (O9), Goldasht (O8), and Afifabad (In5) were the highly ranked neighborhoods. As Table 3 shows, overall, the fraction of open and green spaces is high in these neighborhoods. This is expected to contribute to better surface runoff management through improved rainwater percolation. Furthermore, the relatively smaller size of blocks provides further opportunities for flooding control through integrating green infrastructure and promoting water-sensitive design. Similar to what was discussed considering seismic resilience, open and green spaces can also be used for temporary sheltering during adverse events. However, in cases of flooding, they can only provide such benefits if located in non-flood-prone areas. This is the case for these neighborhoods. Another important indicator of resilience to rapid-onset disasters, such as earthquake and flooding, is betweenness centrality. As discussed earlier, any disruptions in highly central nodes/links is likely to have cascading effects across the neighborhood/city. As betweenness centrality values of the top-three neighborhoods were not high, they are less likely to experience such cascading effects.

Sang Siyah (I1), Vali Asr (O7), and Darb Shazdeh (I3) were the neighborhoods ranked four to six, respectively. This is an interesting result, showing that traditional neighborhoods did not have the lowest level of performance when resilience to flooding was considered. Examining the indicators shows that they feature moderate levels of block and lot size and their fractions of open and green spaces are also comparatively high. As discussed above, these all contribute to mitigating flood risks. However, these neighborhoods had the highest values of betweenness centrality, which may cause significant damages in case of major disruptions.

Lastly, Fakhr Abad (In4), Rodaki (In6), and Lab Ab (I2) were the neighborhoods more likely to be vulnerable to floods. For the latter two, results show that very limited green space, comparatively smaller open spaces, and high centrality values were influential in reducing resilience capacities. Fakhr Abad, however, had a better performance in terms

of these indicators. On the other hand, its blocks are large, and this undermines its flood resilience as large, paved blocks with limited greenery increase stormwater runoff.

## 6. Conclusions

Over the past two decades, a vast body of literature has been published on urban resilience. However, urban form resilience has received limited attention. This is despite the significance of urban form for functionality of cities in the face of increasing natural- and humanmade disasters. As an effort toward filling this gap, this study sought to examine the resilience of three different urban form patterns commonly found in many old cities to three major stressors, namely, earthquake, extreme heat, and flooding. Shiraz, a major Iranian city, was selected as the case study area, and nine neighborhoods representing three different urban form patterns (i.e., traditional, semi-planned, and planned) were examined. In the context of Shiraz, traditional neighborhoods are located in the historical core of the city and are characterized by narrow and irregular street networks that are flanked by one- to two-story buildings. Semi-planned neighborhoods are from the intermediate ring and feature a combination of organic and planned urban patterns. Streets in the semi-planned neighborhoods are generally wider and more regular, and there are also relatively more multistory buildings compared with traditional neighborhoods. Lastly, planned neighborhoods are in the outer ring of the city and were developed more recently. Their street networks are regular, and they also feature more high-rise buildings compared to the other urban form patterns.

Performance of the selected neighborhoods was evaluated on the basis of a group of urban form indicators related to the physical configuration of lots, blocks, open and green spaces, and street networks. After assigning stressor-related weights to the indicators, the VIKOR method was used to rank the selected neighborhoods on the basis of their performance against earthquake, heat stress, and flooding. While the overall results showed that planned and semi-planned neighborhoods are more resilient, there were some variations depending on the type of stressor considered. This was mainly because physical factors influencing resilience may be different for different stressors. For instance, sky view factor is important when considering resilience to heat stress, but its impact on resilience to floods is not significant. Due to these differences, some neighborhoods may perform well in the face of some stressors, but they may fail to absorb the shocks caused by others. This finding confirms earlier arguments in the literature regarding the importance of considering the “resilience to what?” question when studying resilience [51]. It also shows that, during the resilience-building process, tradeoffs between measures may occur. Therefore, in cities such as Shiraz that are exposed to different types of stressors, it is necessary to adopt integrated planning and design approaches that simultaneously consider multiple interactions between different urban form indicators and their associations with different types of stressors. This will facilitate developing optimal design measures that minimize tradeoffs and conflicts between different measures. Given the inertia inherent in the physical form of cities, developing such measures would be essential for avoiding lock-in into undesirable urban patterns that could not be easily repaired and retrofitted later. Developing such integrated approaches should be further explored in future research.

An important limitation of this study is that the quantitative analysis relied on some assumptions regarding associations between urban form indicators and resilience to the stressors that were not always objective and evidence-based, and were context-sensitive. For instance, it was assumed that smaller lots are not desirable for seismic resilience. While this may be the case, further evidence-based and context-specific research is needed before definitive conclusions can be drawn. Another limitation that needs to be considered is that resilience should also be assessed via multiple temporal scales. In other words, ideally, it should be examined how different urban forms perform over time. The method adopted in this study only provided a static evaluation. Further longitudinal research, involving regular baseline measurements, is needed to examine temporal changes. The adopted method is also limited in the sense that it failed to account for multiple interactions that

may occur between different factors and indicators [52]. This is also an area that should be further studied in the future research.

Lastly, a major limitation of this study is that socioeconomic factors were not integrated into the analysis. Future research should also consider such factors when examining the resilience of traditional, semi-planned, and planned neighborhoods. This is important because, for example, while traditional neighborhoods may not perform well in terms of urban form resilience, they feature other important characteristics that are equally or even more important for achieving urban resilience. For instance, social networks/ties are often stronger in traditional neighborhoods of Iranian cities [44]. Such strong social connections enhance social capital and are essential for absorbing and recovering from shocks and adverse events. Therefore, future research should explore ways of improving the urban form resilience of traditional neighborhoods while maintaining their positive social features. This should involve efforts such as retrofitting street networks and providing more open and green spaces.

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