Socio-spatial vulnerability assessment of heritage buildings through using space syntax

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ABSTRACT

This research aims to assess vulnerable spaces around heritage buildings concerning their socio-spatial properties. Additionally, the research explores the predictive relationship between these properties and contextual anthropogenic hazards. The research’s methodology relies on multi-methods applied to twenty-eight heritage buildings in historic Cairo, Egypt. Firstly, the research employed the Delphi technique and ICCROM-CCI-RCE method to assess the potential rates of contextual anthropogenic hazards in the study area. Afterwards, the literature review was conducted to explore a new paradigm for assessing vulnerable spaces using the space syntax-based methodology. Space syntax provides a better understanding of space, its structure, and how it affects human behaviour. Moreover, the research employed two main analytical methods of space syntax, axial graph, and visual graph analyses, which were achieved by “Depthmap 4” software to investigate the syntactic context of the study area. Furthermore, the exploratory factor analysis was employed to statistically analyse the syntactic output data to develop fewer factors of socio-spatial vulnerability. These factors served as inputs for multiple linear regression analysis as predictive models of the influence of socio-spatial vulnerability on the assessed contextual anthropogenic hazards. Finally, the resulting models highlighted the importance of investigating the socio-spatial properties around heritage buildings to predict human destructive behaviours based on quantitative analytical methods. Such results would help authorities formulate suitable and sustainable strategies for the adequate performance of heritage buildings. Also, the predictive models can potentially be used in other livable historic cities.

1. Introduction

Recently, several liveable cities’ most valuable structures have been destroyed due to human impacts such as man-made fires, vandalism, looting, and pollution, in addition to effects of high population density, overcrowding, and marginal housing [1]. These contextual anthropogenic impacts persistently affect heritage buildings and cause pressure. Contextual anthropogenic hazards are defined as all human spatial misbehaves towards heritage buildings under the condition of being inside vulnerable contexts [2].

Even though the anthropogenic hazards are limited, if compared with natural hazards such as earthquakes, floods, and climate change [5], anthropogenic impacts cause severe threats to heritage buildings. In 2014, the world heritage centre conducted a study to address the hazards of cultural heritage assets. It concluded that the most widespread and constant hazards are “building and development” [4], in addition to the destructive impact of human encroachments on heritage structures. Moreover, many developing countries suffer from unplanned and rapid urbanisation, in addition to environmental concerns, which deteriorate, dysfunctional, and unsightly environments [5, 6].

Inherently, one of the principal aspects for suppressing the potential risks of anthropogenic hazards that threaten historical contexts is addressing the vulnerability (i.e., the susceptibility or exposure to hazards) [7]. Vulnerability assessment requires a spatial analysis to explore which heritage buildings are directly exposed to a particular risk [8]. In former reports related to assessing spatial vulnerability, those reports focused mainly on investigating the physical characteristics of the space to evaluate parameters like urban form and distance from the hazard source [9, 10, 11]. Further, the previously mentioned reports focused mainly on assessing spatial vulnerability towards catastrophic natural hazards [12, 13].

By closer examination of these prior approaches unveils a gap in spatial vulnerability assessment, i.e., these approaches lack applicability on numerous hazards, primarily contextual anthropogenic hazards, where space users-who reside around the heritage buildings-are the

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source of hazards. Consequently, analysing the surrounding physical elements is not satisfactory in assessing vulnerable areas since the interaction between humans and physical spaces must be considered more in-depth [14, 15]. Human beings have always been affected by their surrounding [16, 17]. The space composites from physical properties and social fabric, interacting with each other's [14, 18, 19]. It is problematic to make appropriate risk management and conservation strategies of heritage buildings within sight into the syntactic characteristics of the heritage buildings’ sites and the consequences of diverse spatial specifications on human behaviours [20].

Accordingly, many theories have been developed to investigate the interaction between space and society and explore the impacts of urban forms on human behaviours. The leading theory in this regard is space syntax, which seeks to clarify the social logic of space by mathematical and graphical analysis rather than intuitive explanations [21]. Space syntax has established a set of theories. The generic city, domestic space, the duality of spatial structure, and space and society are the prominent syntactic theories. These theories address the interaction between the physical spaces and the socio-economic processes mediated by spatial laws. They were established on two main propositions. The first is that space is not a backdrop to human activity but rather a driving force behind it. Therefore, each activity poses a distinct spatial pattern [22]. The second proposition to consider is that space is configurational; buildings and spatial structures are configurations. Configuration is defined as “relations that consider other relations” in a complex network [23]. Thus, space syntax provides quantitative answers on the impact of the built environment and urban morphology on human behaviour in space [24].

Hereafter, Space syntax allows the exploration of the heritage building as an individual element to be a part of the social space components [25, 26, 27]. In reality, space syntax can be implemented in risk management to assess hazards and vulnerabilities by investigating how spatial configurations around heritage buildings affect the patterns of human spatial behaviour. It does not examine the physical space but the way human uses it and the impact of spatial properties on human activities [28]. Therefore, understanding the built environment from a functional standpoint regarding humans' actions is essential in assessing vulnerable spaces and predicting spatial behaviours.

From this perspective, and to fill the gap in the preceding approaches of spatial vulnerability, a novel concept will be interpreted in this research for assessing vulnerable spaces around heritage buildings. That is to be achieved by combining simulation and statistical analysis to assess vulnerable spaces around heritage buildings; this concept will be named Socio-Spatial Vulnerability (SSV). It is defined as “the susceptibility to an existent hazard due to the heritage's surrounding socio-spatial properties”. SSV will be discovered based on space-syntax theories and methods for quantitatively addressing how spaces around heritage buildings support or constrain spatial destructive behaviours.

Moreover, this research intends to develop predictive models of SSV impacts on contextual anthropogenic hazards to prove the significant influence of socio-spatial properties on rates of spatial destructive behaviours towards heritage buildings. The resulted models would be beneficial in predicting the future development of the current contextual anthropogenic hazards rates. Consequently, these models would aid in formulating sustainable mitigation strategies via upgrading and

![Figure 1. Research's structure.](image-url)
modifying vulnerable spaces, which enhance hazardous behaviours in historical contexts. This research is divided into five main parts, as illustrated in Figure 1.

1.1. The study area (Historic Cairo – Egypt)

In this study, a set of heritage buildings located in different areas inside historic Cairo have been selected as case studies. The historical city was inscribed on the UNESCO world heritage list in 1979, citing its "undeniable historical, archaeological, and urban worth". It encompasses numerous streets and historical dwellings, preserving patterns of human settlement dating back to the Middle Ages in the heart of the traditional urban fabric.

Hitherto, historic Cairo is a living entity with high density. Commonly, high population densities produced many problems, such as environmental pollution and unplanned urbanisation [29, 30]. Consequently, the historic city is susceptible to numerous anthropogenic hazards, as mentioned in the report of environmental risks facing historical Cairo, which defined a set of anthropogenic factors such as fires, all kinds of man-made pollution, accidents, and crimes. In addition, all human activities, such as undesirable views of garbage heaps, street vendors, dirty roads, modern structures, and many others, degrade the city's outstanding universal value [31]. Therefore, the report declared an increasing necessity for implementing measures and projects for mitigating the rapid deterioration of historic Cairo and the impact of the community on it.

Figure 2. The location of the case study area and the designated heritage buildings.
On the other hand, historic Cairo is a multi-layer city from a morphological point of view. Urban tissues of historic Cairo possess extraordinary geometries of buildings, blocks, and streets [32]. The hierarchy of streets and asymmetrical shapes contribute to formulating vulnerable contexts, exclusively after the deformation that happened to historic Cairo through ages of human encroachments and urban sprawl on heritage assets amongst the historic city. Hence, it should investigate the interaction between human behaviour and different spatial configuration throughout the study area.

In this study, a total of twenty-eight heritage buildings with different typologies and urban tissues were selected in nine districts within the study area, as displayed in Figure 2. The researchers investigate the influence of socio-spatial configurations around the designated heritage buildings on the contextual anthropogenic hazards.

2. Material and methods

The analysis of the underneath socio-spatial mechanism and interacters between physical spaces and humans can be considered as a novel addition, as it was used to state the characteristics of the vulnerable spatial context of heritage buildings and their influence on hazardous spatial behaviours. The research relied on an innovative multi-method analysis ranging from urban spaces simulation around a set of heritage buildings in historic Cairo by space syntax methods to statistical predictive analysis. This combination is to reach the factors of assessing the vulnerable spatial context of heritage buildings based on socio-spatial consideration using an Exploratory Factor Analysis. Then, using these factors to display the predictive relationship between socio-spatial vulnerability and the rates of contextual anthropogenic hazards in a regression analysis. The resulting predictive models offer some lessons concerning the rates of destructive behaviours towards heritage buildings and the surrounding spatial configurations.

This research received ethics approval from the Engineering Ethics Research Committee faculty of the Zagzaig University, Egypt. The committee confirmed that all experiments in this research were conducted according to established ethical guidelines. The study also complies with all regulations. Figure 3 shows a diagram of the used methodological procedures to reach the research objectives.
2.1. Hazard assessment

UNESCO [33] defined hazard as natural or anthropogenic threats of given intensities that may arise in designated areas and owe negative impacts on at-risk elements. Hazards are also classified according to their origins, into internal or contextual (external). The scope of research is restricted to contextual anthropogenic hazards as the most threatening hazards in liveable historic cities. There is a direct interaction between historical buildings and society. Hazards assessment seeks to identify hazards types, then evaluate each hazard severity, along with the probabilistic estimated based on the occurrence frequency [34].

2.1.1. Hazards' identification

Hazard assessment requires identifying and grouping hazards for analytical purposes. The hazard categorisations may vary from one place to another based on the types of threats affecting cultural assets in each locality [8]. It is critical to address all anthropogenic hazards types to various heritage contexts. In this regard, State of Conservation (SOC) reports are prepared for cultural properties inscribed on the World Heritage List and located in different parts of the World. These reports are significant sources of information to identify hazard categories. SOC Reports have been prepared by the World Heritage Centre and the Advisory Bodies to the World Heritage Committee. The authors have reviewed these reports to extract the initial list of contextual anthropogenic hazards based on the classification of UNESCO’s SOC reports for hazards affecting heritage Property.

However, this study aims to identify all types of contextual anthropogenic hazards that affect heritage properties, in addition to the physical and social context in specific study areas. Therefore, the authors used the Delphi technique to develop an accurate and comprehensive list of hazards. Delphi technique is among the most common methods in hazard categorisation, especially in the risk assessment process of cultural heritage [35, 36, 37]. The Delphi studies’ success is based on the experts for the current study were chosen based on having professional expertise in preserving and managing cultural heritage for more than ten years. Moreover, they should be involved in the Historic Cairo Project. Additionally, they also should have a decent knowledge of the issues and hazards that intimidate the study area currently and previously.

Experts who met the inclusion criteria were invited by email to participate in the study and asked to consent to participation. They were a multidisciplinary group of twenty-eight experts who responded to the invitation. The explanation of the experts’ profiles and their demographic characteristics are presented in Table 1.

In this research, the criteria for selecting experts were adopted from Chan et al. [38] and Manoliadis et al. [40]. They identified specific requirements in the chosen expert represented in the working experience of the expert and his participation in a certain kind of project. Accordingly, the experts for the current study were chosen based on having professional expertise in preserving and managing cultural heritage for more than ten years. Moreover, they should be involved in the Historic Cairo Project. Additionally, they also should have a decent knowledge of the issues and hazards that intimidate the study area currently and previously.

Experts were consulted to evaluate the identified hazards due to the inability of the researchers to acquire the entire quantitative required data from public institutions (due to the confidentiality of that data or non-availability). Therefore, the surveying results were reviewed and enriched with experts throughout the accessible historical data about hazards collected from public institutions.

The authors surveyed the same chosen Delphi panel of experts in the hazards identification step to rate each identified hazard’s frequency and intensity using the ICCROM-CCH-RC method. This method provides scores based on fractions or verbal scales ranging from a maximum score of 5 to a minimum of 0.5, as reflected in Table 2. In addition, a time horizon of the last 20–30 years was selected to evaluate each hazard from that moment in time. The evaluated rates will be used to develop the predictive models in the coming statistical analysis.

2.2. Socio-spatial vulnerability assessment

The literature review states that the critical indicators of spatial vulnerability are accessibility and location or proximity to settlement areas, which influence the occurrence of a hazard [8, 10]. Commonly, location is inspected regarding the proximity of heritage buildings to hazard sources [9, 11, 41]. Regarding anthropogenic hazards, location examines the extent of the heritage building’s integrity with the surrounding environment. As most construction and development activities occur in new development areas and around settlements, the proximity to settlement areas influences the vulnerability of the heritage building. Space syntax techniques reinforce the capability to examine the location’s integrity with the surrounding area regarding how the people exploit the space. It investigates the capacity to relocate to a particular space by looking at human movement patterns [23].

The other indicator of accessibility is an alternative critical indicator that has been extensively analysed [42]. The entirety of studies has
Table 2. The ICCROM-CCI-RCE scales for measuring intensity and frequency of hazards.

| Hazard Range | Frequency (F) | Intensity (I) | Score | Definition | Almost certain | Certain | Impossible | Improbable | Almost impossible | Impossible |
|--------------|--------------|-------------|-------|------------|---------------|---------|-------------|------------|--------------------|-----------|
| (1) year     | (1) year     | 0.00       | 0     | 0          | 0             | 0       | 0           | 0          | 0                  | 0         |
| (1-2) years  | (1-2) years  | 0.01       | 1     | 1          | 1             | 1       | 0           | 0          | 0                  | 0         |
| (2-3) years  | (2-3) years  | 0.02       | 2     | 2          | 2             | 2       | 0           | 0          | 0                  | 0         |
| (3-4) years  | (3-4) years  | 0.03       | 3     | 3          | 3             | 3       | 0           | 0          | 0                  | 0         |
| (4-5) years  | (4-5) years  | 0.04       | 4     | 4          | 4             | 4       | 0           | 0          | 0                  | 0         |
| (5-6) years  | (5-6) years  | 0.05       | 5     | 5          | 5             | 5       | 0           | 0          | 0                  | 0         |
| (6-7) years  | (6-7) years  | 0.06       | 6     | 6          | 6             | 6       | 0           | 0          | 0                  | 0         |
| (7-8) years  | (7-8) years  | 0.07       | 7     | 7          | 7             | 7       | 0           | 0          | 0                  | 0         |
| (8-9) years  | (8-9) years  | 0.08       | 8     | 8          | 8             | 8       | 0           | 0          | 0                  | 0         |
| (9-10) years | (9-10) years | 0.09       | 9     | 9          | 9             | 9       | 0           | 0          | 0                  | 0         |
| (10-11) years| (10-11) years| 0.10       | 10    | 10         | 10            | 10      | 0           | 0          | 0                  | 0         |

100% \rightarrow 60% \rightarrow 20% \rightarrow 6% \rightarrow 2% \rightarrow 0.6% \rightarrow 0.2% \rightarrow 0.06% \rightarrow 0.02% \rightarrow 0.006% \rightarrow 0.002% \rightarrow 0.000%

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2.2.1. The syntactical analysis using space syntax (measuring the SSV indicators)

The identified indicators of SSV were quantified using a set of measurements performed in two main analytical methods of space syntax: Axial Graph Analysis (AGA) and Visibility Graph Analysis (VGA), as tabulated in Table 3. Both space syntax analytical methods were conducted in Depthmap 4 software. It is a prominent software in current space syntax research created by Turner [45] to analyse architectural and urban spaces at different scales based on space syntax principles. It intends to produce a map of open space elements connecting them via relationships. Then, it performs graph analysis of the resulting network [22]. Depthmap processes different types of analytical techniques. Inputs and outputs for the selected analytical methods are highlighted in Figure 5.

2.2.1.1. Axial Graph Analysis (AGA). Since the spaces around heritage buildings are linear in most cases, such as roads, avenues, streets, alleys, this research would focus on the adjacent axial lines around the designated heritage buildings to investigate movement patterns. Therefore, the study would process AGA and related measures. AGA is a process of examining axial lines networks. It is the most relevant analysis regarding movement patterns [20].

In this study, AGA was applied at both global and local levels to inspect movement possibilities and accessibility for vehicles and pedestrians at different radii, promoting integration and selection measures to identify location integrity and potential accessibility [46]. The analysis was conducted on the whole entry area.

AGA emerges with the foundation stage (drawing the axial map using a reliable map of historic Cairo on AutoCAD software). Axial line map is the smallest and longest line in an architectural plan, permitting entry to all spaces and authorising a person to transfer everywhere and see everything in an environment [14]. AGA was administered in Depthmap 4 software to quantify the magnitudes of integration and choice. This research used these measures to investigate the social logic of space by analysing the movement patterns, as shown in detail in the coming results section.

- Integration: is an expression of movement patterns, whether a global to-movement (vehicles) or a local to-movement (pedestrians). The type of integration varies according to radius-n (Rn), if n comprises all levels, the obtained integration is called global integration [14]. Similarly, if n is up to three steps, the integration acquired is radius-3 (R3) integration.
Choice: is an expression about ‘through-movement’ patterns for both global through-movement (vehicles) and the local through-movement (pedestrians). Choice measures are significant in determining which street axials are more frequently exploited by users rather than the entire [20].

In this study, the mean values of integration and choice at Rn and R3 were computed to the adjacent street axials around the designated heritage buildings. These measures describe the global and local movement patterns to and through the study area.
2.2.1.2. Visual Graph Analysis (VGA). It abstracts the plan of a building or environment into the minimum number of visually coherent units of spaces [14]. Underlying this analysis are visible fields of view from a particular point. Thus, the visibility diagram signifies a spatial outline as a set of inter-visible points in a human-scale grid-connected in an undirected graph [45]. In current work, VGA was conducted on a limited buffer of 50–100 m² around each heritage property until the visual range is fully covered since VGA has principally functioned at the building or small urban scale [20].

Before processing the analysis, convex maps were drawn for nine selected districts in the study area using reliable maps on AutoCAD software. Nearby districts, positioned in the identical region, were drawn in one convex map. As a result, six convex maps were developed for six different zones (A, B, C, D, E, and F), as revealed in Figure 6. A convex space is stated as “a space that will not encompass concave parts” [14]. It is an area outlined by a straight-line border; any two points in this convex space can be united by a straight line that does not exceed the space. The convex map consists of the prime convex spaces that cover the area. They are identified as follows [45]:

- Connectivity in VGA calculates the number of locations directly visible (connected) from a specific point in the convex map.
- Isovist Area: an Isovist is defined technically as the whole visible area from a particular location.

2.3. Statistical data analysis

For evolving the statistical predictive model of SSV impact on contextual anthropogenic hazards, the output data from the literature, Delphi method, and space syntax were analysed statistically by the following techniques. All the statistics were performed using the statistical package for social sciences (SPSS) version 23. Two main phases of statistical analysis were conducted as follows:

Phase 1: Developing SSV factors: this phase started with testing the data's reliability by calculating the Cronbach’s Alpha, which ranges from 0 to 1. It is the most recognised measure of reliability. It is based on repeating the identical experiment and receiving the same findings every time [47]. Based on Cronbach’s Alpha examination, validity was also determined, viewing the variables’ suitability for measuring SSV. Afterwards, Exploratory factor analysis (EFA) was employed to explore grouping between variables and develop fewer composite factors of SSV. These factors served as inputs for the subsequent statistical analysis. An oblique method (Promax) was selected, as factors were assumed to be correlated with one another [48]. For determining the number of factors that should be extracted from a set of data, the research adopted the most common approach, which utilises only factors with a latent root or eigenvalue greater than one [49].

Phase 2: The predictive study: at this phase, Multiple linear regression analysis (MLRA) was used to determine the variation of the independent variables in the dependent variable [50]. In this study, seven regression models were processed to investigate whether or not the extracted SSV factors from EFA—the independent variables—were significantly predictive of the contextual anthropogenic hazards’ rates—the dependent variables—based on the ANOVA statistics.

3. Results

Within the research context, the main goal was to determine how to assess vulnerable spaces based on their socio-spatial properties and to what extent these properties affected rates of contextual anthropogenic hazards on heritage buildings. To fulfil this aim, the syntheitical properties around a set of valuable heritage buildings located in various social and spatial urban tissues across historic Cairo, Egypt, were detected to

Figure 6. Allocating six different zones in historic Cairo for conducting the Visual Graph Analysis (VGA).
investigate their socio-spatial vulnerability factors. Then, these factors were used as predictors in a regression analysis to display the relationship between SSV factors and rates of contextual anthropogenic hazards. Results were divided into subsections regarding the order of the data analysed in the research work.

### 3.1. Assessment of contextual anthropogenic hazards

This research started with identifying the contextual anthropogenic risk sources. Literature was conducted to yield the initial list of hazards. Firstly, a set of risk sources were extracted from UNESCO's SOC reports and merged by authors into an initial list of composites from eight categories of contextual anthropogenic hazards: 1) Social/cultural uses of heritage, 2) Biological resource use/modified, 3) Inappropriate human activities, 4) Pollution, 5) Building, 6) Transportation infrastructures, 7) Services infrastructure, and 8) Physical resource extraction. The details of each category are shown in Table 4.

Then, the Delphi technique was performed to refine the initial list on two rounds. In Round 1, a questionnaire was designed to collect responses on the exitance of each identified hazard and its category.

| Table 4. The initial list of contextual anthropogenic hazards on cultural heritage in light of UNESCO's State of Conservation (SOC) reports. |
|---------------------------------------------------------------|
| **The primary group of hazards** | **Subgroup of hazards** |
|---------------------------------|-------------------------|
| Social/cultural uses of heritage | • Impacts of tourism/visitor/recreation |
|                                 | • Ritual/spiritual/religious and associative uses |
|                                 | • Identity, social cohesion, changes in local population and community, changes in livelihoods, migration to or from site |
| Biological resource use/modified | • Land conversion |
|                                 | • Crop production |
|                                 | • Livestock farming/grazing |
| Inappropriate human activities  | • Deliberate destruction of heritage |
|                                 | • Fire |
|                                 | • Lootings |
|                                 | • Civil unrest |
|                                 | • War |
|                                 | • Terrorism |
|                                 | • Military training |
| Pollution                       | • Air pollution with smoke and fuel, |
|                                 | • Garbage and solid waste |
|                                 | • Visual pollution |
| Building                        | • Housing |
|                                 | • Commercial development |
|                                 | • Industrial development |
|                                 | • Tourism development (e.g., interpretive and visitations facilities, major visitor accommodation) |
|                                 | • Greenery and recreation development |
|                                 | • Extensive urban facilities (e.g., education, health facilities) |
| Transportation infrastructures  | • Ground transportation infrastructure |
|                                 | • Effects arising from the use of transportation infrastructure |
|                                 | • Marine transportation infrastructure |
|                                 | • Underground transportation infrastructure |
|                                 | • Air transportation infrastructure |
| Utility infrastructure          | • Major linear utilities (pipelines, power lines) |
|                                 | • Renewable/non-renewable energy facilities |
|                                 | • Localised utilities |
| Physical resource extraction    | • Mining |
|                                 | • Oil and gas |
|                                 | • Quarrying |
|                                 | • Water (extraction) |

Experts were asked to express their opinions on the 5-point Likert scale. A mean score was calculated for each hazard. In light of the exitance investigation, all-hazards showed mean scores higher than 3 points (moderate) except the 'Physical resource use/modified' and 'Biological resource use/modification' categories.

Regarding experts' agreement on categorising, two categories showed mean scores lower than 3 points: 'Social/cultural uses of heritage' and 'Inappropriate human activities. Experts suggested rearranging them into three new categories: 'Looting and violence', 'Vandalism and inappropriate uses', and 'Distortion of the historical scene'. In contrast, experts were content with reformulating the name 'Building' to 'Urban development' and 'Pollution' to 'Man-made pollution. In the end, seven categories of contextual anthropogenic hazards were obtained.

The results of round 1 were reflected in the questionnaire for round 2. The expert panel was asked to re-rate the exitance and the new categorisation of hazards on the 5-point Likert scale. The goal of this round was to reach a reasonable consensus among the experts. The mean scores were calculated for Round 2. All the seven categories of hazards had a mean score of higher than 3 points in light of the exitance and the agreement on the new categorisation. Although, there was general agreement among the experts' opinions on making a higher classification by merging the seven identified categories into two primary groups: 1) Individual hazards H_ind and 2) Institutional hazards H_inst.

The standard deviation was checked to explore the agreement level among the participants. It was higher in Round 1, compared with it in Round 2. This result implies that in Round 2, the experts took others' evaluations into serious consideration. Finally, a hazards list was complete, as demonstrated in Table 5 for further hazard assessment.

Afterwards, the same expert panel was asked to rate each identified hazard's frequency and intensity for each building using the ICCROM-CCI-RCE intensity and frequency scales. After that, the mean score of frequencies and intensities was multiplied to obtain each hazard rate on the building, as obtained in Table 6. The standard deviation results in Table 7 showed a better agreement between experts about the rates of H_ind compared with H_inst. From another hand, the designated heritage buildings were threatened more by H_ind than H_inst. The hazard rates' output data represented the regression models' dependent variables.

### 3.2. The socio-spatial vulnerability analysis

This part was conducted to investigate the indicators of SSV (location and accessibility) based on space syntax methods. Two main analytical methods of space syntax: Axial Graph Analysis (AGA) and Visibility Graph Analysis (VGA), were processed to quantity the identified indicators (the predictors).

In AGA, axial analysis was conducted to investigate the movement patterns by quantifying the magnitudes of integration and choice at Rn and R3. The investigation was performed on the whole entry area of historic Cairo. In Figure 7, the global integration (Rn) was measured to describe how close each street is to all the others in the whole entry area. It was used to investigate vehicular to-movement. Figure 8 shows the local integration (R3) of historic Cairo. It shows how close each street is to other streets up to a radius of 3. It was used to investigate pedestrian to-movement. Red colours indicate well-integrated streets compared to blue colours, which indicate segregated streets. A well-integrated location is well-connected. The integration analysis showed that the designated sample of the heritage building within the study area was divided into two groups. The first was located in well-integrated locations due to having high movements to these locations by both vehicles and pedestrians. Conversely, the second group of buildings was found in segregated locations due to lower rates of to-movements primarily by vehicles.

In Figure 9, choice Rn was measured to express global through-movements. It describes how likely a street is to be passed through to get from space to all other spaces in the system; it reflects through-movement for vehicles. In Figure 10, choice at R3 was used to express local through-movements (pedestrians). This measure describes how to
get from space to other spaces up to radius 3. Red colours indicate higher accessibility than blue colours. The choice analysis showed that almost all the selected buildings have good physical accessibility due to the high movement through their locations, primarily by pedestrians.

In VGA, two parameters were measured: Connectivity and Isovist areas. The analysis was conducted six times on each of the six identified zones (A, B, C, D, E, and F) in Figure 6. Consequently, six maps of connectivity and Isovist areas were developed, as revealed in Figures 11, 12, 13, 14, 15, and 16 sequentially. Red colours indicate high connectivity and more Isovist areas than blue colours, which show low connectivity and fewer Isovist areas.

In the current study, both Isovist areas and connectivity express the visual accessibility indicator. High values of visual accessibility mean that the attached nodes to the heritage building from all directions see too many locations directly and cover a wide visible area which enhances the ability to see through the space. Good visual accessibility was addressed around the heritage buildings of Qadi Yehya Zain El-Dein Mosque, Al-Hussein Mosque, and El-Sayda Rokya dome. On the contrary, Abu Bakr Mazhar School, Rebat Sultan Ainal’s wife, and Amin Effendi Ebn Hazaa sabil-kutab heritage buildings suffer from very low visual accessibility that obstacle the ability to see through their locations. Generally, the selected buildings were approximately divided.

### Table 5. The final list of contextual anthropogenic hazards in the study area.

| Level 0 | Level 1 | Level 2 | Level 3 |
|---------|---------|---------|---------|
| Contextual anthropogenic hazards | (Individual hazards (H\textsubscript{ind})) “The damaging behaviours of individuals or groups” | H1 Looting and violence | All illegal activities that happen intentionally by the local community or visitors (Theft, crime, terrorism, violence, bullying, mistreatment of visitors) |
| | | H2 Man-made pollution | Pollution caused by human waste, “air pollution with smoke and fuel, garbage and solid waste from the remnants of industrial areas and residues of homes.” |
| | | H3 Vandalism and inappropriate uses | All deliberate destruction and inappropriate uses of a heritage building (illegal construction, marking, scratching, or damaging works) |
| | | H4 Distortion of the historical scene | All adverse social activities that contribute to the deterioration of the heritage fabric (religious and spiritual rituals - commercial activities - street vendors) |
| Institutional hazards (H\textsubscript{inst}) “development” | H5 urban development | Uncontrolled urbanisation and rural developments (tourism facilities or housing and building construction) |
| | H6 Transportation infrastructure development | New roads construction, bridges, and subway lines |
| | H7 Services infrastructure development | Water lines, sewage, and electricity networks |

### Table 6. The computed scores of hazards’ rates on the selected heritage building.

| Districts (Shaykha) | Heritage Buildings | Hazards' Rates (F×I) | H\textsubscript{HAI} | H\textsubscript{HA} | H\textsubscript{HAI} |
|---------------------|--------------------|-----------------------|------------------------|------------------------|------------------------|
|                     |                    |                       | H\textsubscript{1} | H\textsubscript{2} | H\textsubscript{3} | H\textsubscript{4} | H\textsubscript{5} | H\textsubscript{6} | H\textsubscript{7} |
| El-Shar'any district | Al-Selhdar Mosque  | 3.680                 | 5.060             | 10.350                | 4.130                | 4.750                | 4.380                | 3.680                |
|                     | Nour El-Dein       | 12.770                | 8.090             | 6.130                 | 5.860                | 6.690                | 4.780                | 4.810                |
|                     | Abu Bakr Mazhar School | 10.220             | 17.080             | 6.720                 | 6.000                | 10.120               | 6.930                | 6.790                |
|                     | Rebat Sultan Ainal’s wife | 12.720       | 12.350             | 6.410                 | 7.410                | 6.810                | 6.020                | 5.470                |
| Qasr El-Shoaa district | Meghlaty El Gamaly School | 9.830            | 4.950             | 5.080                 | 7.900                | 6.750                | 6.260                | 7.340                |
|                     | MarzoKAl El-Ahmady Mosque | 12.240        | 6.240             | 6.330                 | 8.690                | 5.540                | 5.350                | 8.910                |
|                     | Oda Pasha’s home and sabel | 7.190            | 12.900             | 7.010                 | 7.000                | 9.300                | 5.740                | 6.790                |
| Hamzáwy district   | Al-Adrafi Bribay School | 3.240            | 8.920             | 12.850                | 15.600               | 15.030               | 10.000               | 12.000               |
|                     | Sharaf El-Din Mosque | 5.060            | 12.000             | 9.750                 | 16.290               | 14.600               | 14.150               | 15.010               |
|                     | Qadi Yehya Zain El-Dein Mosque | 3.960         | 15.000             | 9.000                 | 10.000               | 16.300               | 14.200               | 12.330               |
| Khan El-Khalil district | Tatar El-Hegazy School | 4.800            | 4.220             | 10.800                | 8.200                | 5.570                | 3.440                | 6.530                |
|                     | Wekalt El-Salhadr   | 3.910            | 6.900             | 8.500                 | 12.000               | 6.250                | 5.100                | 7.140                |
|                     | Al-Ghouri gate      | 5.420            | 7.300             | 10.880                | 11.690               | 10.220               | 4.840                | 6.660                |
| El-Mashhed Hussein district | Al-Hussein Mosque   | 3.100            | 10.030             | 9.520                 | 12.000               | 7.880                | 8.000                | 8.900                |
|                     | Al Molk El-Gokndar Mosque | 6.150           | 10.420             | 6.550                 | 10.200               | 5.960                | 4.310                | 5.870                |
|                     | Amin Effendi Haza sabil-kutab | 5.820        | 7.840             | 6.730                 | 9.230                | 5.820                | 6.790                | 7.620                |
| Al-Arabya district  | Tkiyet Al Kalashni  | 4.380            | 12.920             | 6.910                 | 7.000                | 11.760               | 15.010               | 14.370               |
|                     | Wafk Radwan houses  | 7.770            | 12.300             | 7.960                 | 10.000               | 10.690               | 9.590                | 12.920               |
|                     | Sabil Faraj Ibn Barqeq | 4.300           | 8.200             | 6.570                 | 12.050               | 15.330               | 14.850               | 15.810               |
| El-Mahgr district   | Tkiyet Bastami      | 8.600            | 7.500             | 7.870                 | 8.100                | 4.840                | 3.690                | 5.020                |
|                     | Al-Bimaristan Al-Muayyadiyah | 11.860       | 7.220             | 6.890                 | 5.150                | 6.970                | 3.340                | 4.720                |
|                     | Mangk El-Selhdar Gate | 3.980           | 13.970             | 9.000                 | 10.910               | 15.060               | 15.530               | 15.770               |
| El-Khalefa district | El-Sayda Rorya dome | 4.250            | 6.560             | 4.970                 | 7.580                | 11.250               | 11.660               | 11.940               |
|                     | AA' and El-Ga'yri Dome | 4.110          | 7.000             | 4.170                 | 5.100                | 10.210               | 7.030                | 6.570                |
|                     | Mohamed El-anwer Dome | 4.380          | 5.550             | 5.000                 | 8.840                | 10.030               | 5.010                | 12.300               |
| El-Halmya district  | Prince Taz Palace   | 7.880            | 4.950             | 4.300                 | 6.000                | 6.740                | 5.140                | 5.760                |
|                     | Yashbeck (Kosson) Palace | 5.070          | 12.160             | 7.580                 | 7.290                | 5.620                | 8.760                | 8.280                |
|                     | Sabel Om Abbas      | 5.300            | 7.000             | 7.410                 | 8.980                | 13.880               | 14.760               | 12.830               |
Figure 7. The integration Rn analysis (potential vehicles to-movements; longer trips).
equally between those with a wide Isovist area field and high visual connectivity and others with a narrower Isovist area and lower visual connectivity.

3.3. The statistical data analysis (developing the predictive models)

3.3.1. SSV factors

Firstly, the syntactical output data were subjected to a reliability test to measure the Cronbach's Alpha which appeared to be high, as the data was reliable enough. Validity was also calculated based on Cronbach's Alpha and appeared to be high, too, as seen in Table 8.

Then, EFA was used to explore the grouping between variables. All the measured variables of SSV were subjected to EFA with oblique rotation (Promax). The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis, KMO = 0.595. Bartlett’s test of sphericity $\chi^2 (15) = 109.849$, $p < 0.000$, indicating that correlation structure is adequate for factor analyses. The maximum likelihood factor analysis with cut-off points of 0.60. The analysis was conducted based on the Kaiser’s criterion of eigenvalues greater than 1 yielded two-factor solutions. These factors’ loadings are shown in Table 9. These factors formulate SSV. Of course, the names given to the developed factors are arbitrary, but they considered the variables used. They are defined as follows:

- Factor 1: Movement flow: it is the ability to move to/through the space as it is integrated and permeable. The movement flow factor consists of four variables: (integration (HH) Rn, integration (HH) R3, choice (HH) Rn, and choice (HH) R3).
- Factor 2: Visual accessibility: it is the ability to see through a place. This factor consists of two main variables: (connectivity and Isovist areas).
Furthermore, the component score coefficient matrix \((CS_v)\) as a whole was extracted for each factor. Eq. (2) was used to compute the score of each factor within the SSV:

\[
\begin{align*}
\text{Score}_{F_1} &= \frac{CS_{v1}}{C^2_{v1}} + \frac{CS_{v2}}{C^2_{v2}} + \frac{CS_{v3}}{C^2_{v3}} + \ldots \\
\text{Score}_{F_2} &= \frac{CS_{v4}}{C^2_{v4}} + \frac{CS_{v5}}{C^2_{v5}} + \ldots
\end{align*}
\]

where

\(F_i\) : the extracted factor, \(i = 1, 2, \ldots, 5\)

\(CS_v\) : component score coefficient of each variable within a factor.

\(v_j\) : the \(j^{th}\) variable in the corresponding factor where \(j = 1, 2, \ldots, n\).

The following equations Eqs 3 and 4 were used to compute the score of each factor within the SSV (resulted from EFA):

\[
\begin{align*}
\text{Score}_{F_1} &= 0.317 \times v_1 + 0.310 \times v_2 + 0.250 \times v_3 + 0.391 \times v_4 \\
\text{Score}_{F_2} &= 0.488 \times v_5 + 0.485 \times v_6
\end{align*}
\]

### 3.3.2. The predictive study

The extracted two factors of spatial vulnerability from EFA analysis: movement flow and visual accessibility, were regressed seven times on each of the seven identified contextual anthropogenic hazards categories to promote seven separate regression models according to the ANOVA statistics. The model is noteworthy when the F ratio is significant in at least 0.05 level of significance. Moreover, R-Squared \((R^2)\) shows how well the data fit the regression model (the goodness of fit). \(R^2\) ranges from 0 to 1; as it approaches 1, the model delivers enhanced validity for
explaining the variability in the dependent variable. In Table 10, the results of the seven regression models are illustrated. The goodness of fit result seems good except in model 2, where man-made pollution hazard (H2) is the dependent variable.

In addition, the results affirmed the evidence of a statistically significant effect of SSV factors on the rates of contextual anthropogenic hazards. Hitherto, it was found that six out of the seven models are significant. It can be noticed from Table 10 that the movement flow factor maintains a significant outcome on H1, H3, H5, H6, and H7, in which movement flow increases H3, H5, H6, and H7, while H1 decreases. Contrarily, the visual accessibility factor owes a remarkable influence on H1, H4, H5, H6, and H7, as where the factor increases H4, H5, H6, and H7 increase, while H1 declines.

Based on these findings, the expected values of each hazard could be estimated according to the general formula for MLRA Eqn 5. It is defined as follows:

$$Y = B_0 + B_1 \times X_1 + \ldots + B_n \times X_n$$  \hspace{1cm} (5)

where $Y$ = the expected value of the dependent variable (outcome variable),

$B_0$ = the value of $Y$ when all of the independent variables ($X_1$ through $X_n$) are equal to zero.

$B$ = the estimated regression coefficients.

$X$ = the independent (predictors) variables.

$n$ = number of independent variables.
Figure 11. The connectivity measure in Visual Graph Analysis (VGA) and Isovist area for zone A.
Figure 12. The connectivity measure in Visual Graph Analysis (VGA) and Isovist area for zone B.
Hence, the regression equations for the significant models were obtained as they are shown in Eqn 6, 7, 8, 9, 10 and 11:

**Expected rate** $H_1 = 6.501 - 1.618 \times \text{movement flow} - 1.036 \times \text{visual accessibility} \quad (6)$

**Expected rate** $H_3 = 7.544 + 1.400 \times \text{movement flow} + 0.213 \times \text{visual accessibility} \quad (7)$

**Expected rate** $H_4 = 8.900 + 0.288 \times \text{movement flow} + 1.215 \times \text{visual accessibility} \quad (8)$

**Expected rate** $H_5 = 9.284 + 2.060 \times \text{movement flow} + 1.205 \times \text{visual accessibility} \quad (9)$

**Expected rate** $H_6 = 8.232 + 2.116 \times \text{movement flow} + 2.183 \times \text{visual accessibility} \quad (10)$

**Expected rate** $H_7 = 9.034 + 1.791 \times \text{movement flow} + 1.279 \times \text{visual accessibility} \quad (11)$

Finally, the results presented herein affirmed the research assumptions by proving and demonstrating the significant influence of socio-spatial properties of vulnerable spaces on almost all the identified
Figure 14. The connectivity in Visual Graph Analysis (VGA) and Isovist area for zone D.
Figure 15. The connectivity in Visual Graph Analysis (VGA) and Isovist area for zone E.
Figure 16. The connectivity in Visual Graph Analysis (VGA) and Isovist area for zone F.
contextual anthropogenic hazards that threaten the selected sample of heritage buildings.

4. Discussion

This research stated that heritage buildings in liveable cities are threatened by numerous anthropogenic hazards coming from the surrounding vulnerable context, called contextual anthropogenic hazards. The sources of these types of hazards could be behaviours of individuals and groups or the inconsistent development works of institutions according to the studied sample of heritage buildings in historic Cairo, Egypt.

Predicting the future rates of hazards requires performing spatial analysis to state the characteristics of the vulnerable spaces that enhance the destructive behaviours, whether from individuals or institutions. Vulnerable spaces are assessed by quantifying a set of indicators that examine the interaction between humans and physical spaces and how humans use the space to predict their unfavourable behaviours based on adopting Space syntax propositions. Consequently, the research proposed SSV (Socio-Spatial Vulnerability) as a novel lexicon to describe and assess spatial vulnerability and its embedded social context. SSV is the susceptibility to contextual anthropogenic hazards due to socio-spatial properties related to the surroundings of a heritage building. Location and accessibility (visual and Preamble) are the leading identified indicators of SSV.

Firstly, location evaluates to what extent the heritage building is located in an integrated or segregated space. It describes the ability of pedestrians and vehicles to move to a specific location. Location was

Table 8. Reliability and validity of SSV variables.

| Serial | SSV variables                                      | The Cronbach’s Alpha | Validity |
|-------|---------------------------------------------------|----------------------|----------|
| 1     | Visual connectivity                               | 0.781                | 0.884    |
| 2     | Pedestrians (local) to-movement                   | 0.748                | 0.865    |
| 3     | Vehicles (global) to-movement                     | 0.784                | 0.885    |
| 4     | Pedestrians (local) through-movement              | 0.785                | 0.886    |
| 5     | Vehicles (global) through-movement                | 0.774                | 0.879    |
| 6     | Isovist areas                                     | 0.769                | 0.877    |
| Total |                                                   | 0.804                | 0.879    |

Table 9. The Factor loading of SSV variables.

| Variables                          | Factor 1 Movement flow | Factor 2 Visual accessibility | Communalities |
|------------------------------------|------------------------|-------------------------------|---------------|
| v1                                 | 0.864                  | 0.183                         | 0.768         |
| v2                                 | 0.855                  | 0.206                         | 0.745         |
| v3                                 | 0.802                  | 0.472                         | 0.678         |
| v4                                 | 0.911                  | 0.493                         | 0.859         |
| v5                                 | 0.304                  | 0.990                         | 0.906         |
| v6                                 | 0.367                  | 0.968                         | 0.938         |
| Eigenvalue                         | 3.442                  | 1.452                         |               |
| % Of total Variance                | 57.360                 | 24.196                        |               |
| Total Variance                     | 81.556                 |                               |               |

Notes: Factor loadings higher than 0.60 are in bold.

The destructive behaviours, whether from individuals or institutions. Vulnerable spaces are assessed by quantifying a set of indicators that examine the interaction between humans and physical spaces and how humans use the space to predict their unfavourable behaviours based on adopting Space syntax propositions. Consequently, the research proposed SSV (Socio-Spatial Vulnerability) as a novel lexicon to describe and assess spatial vulnerability and its embedded social context. SSV is the susceptibility to contextual anthropogenic hazards due to socio-spatial properties related to the surroundings of a heritage building. Location and accessibility (visual and Preamble) are the leading identified indicators of SSV.

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Table 10. Results of the seven conducted regression models.

| Model num. | Dependent variable | Predictors | B       | Goodness-of-fit | F       | R²     |
|------------|--------------------|------------|---------|-----------------|---------|--------|
| Model 1    | H1                 | movement flow | -1.618** (-2.569, -0.666) | 13.400** | 0.517  |
|            |                    | visual accessibility | -1.036*(-1.987, -0.084) |         |         |
| Model 2    | H2                 | movement flow | -0.741 (-2.117, 0.636) | 2.619   | 0.173  |
|            |                    | visual accessibility | 1.518 (0.141, 2.895) |         |         |
| Model 3    | H3                 | movement flow | 1.400** (0.652, 2.149) | 9.776** | 0.439  |
|            |                    | visual accessibility | 0.213 (-0.536, 0.361) |         |         |
| Model 4    | H4                 | movement flow | 0.288 (-0.886, 1.461) | 6.648*  | 0.451  |
|            |                    | visual accessibility | 1.215* (0.041, 2.388) |         |         |
| Model 5    | H5                 | movement flow | 2.060** (0.980, 3.134) | 15.905** | 0.560  |
|            |                    | visual accessibility | 1.205* (0.125, 2.284) |         |         |
| Model 6    | H6                 | movement flow | 2.116** (0.865, 3.368) | 19.916** | 0.614  |
|            |                    | visual accessibility | 2.183** (0.932, 3.343) |         |         |
| Model 7    | H7                 | movement flow | 1.791** (0.566, 3.017) | 10.714** | 0.462  |
|            |                    | visual accessibility | 1.276* (0.053, 2.504) |         |         |

Notes: Factors loadings higher than 0.60 are in bold.

*p < 0.05. **p < 0.01.

Reference Category.
evaluated by measuring the integration values at Rn and R3 in AGA for the adjacent street axials to each designated heritage building within the study area. Rn is an expression about the axial global integration, where the integration values of the axial lines are at the infinite radius, which can represent a picture of the integration pattern at the largest scale. Therefore, Rn was used to investigate vehicles' movement patterns. In contrast, R3 was used to explore the axial local integration, which is the integration values of the axial lines at radius 3 (root plus two topological steps from the root). R3 can be used to represent a localised picture of integration to describe the pedestrian movement.

On the other hand, accessibility consisted of two main parameters: physical accessibility and visual accessibility. The physical accessibility or permeability evaluates the ability of pedestrians and vehicles to move through a particular space. The global choice at Rn and local choice at R3 were measured in AGA to evaluate the physical accessibility parameter. At the same time, visual accessibility evaluates the ability to see through the space. Two measures were obtained from VGA to represent visual accessibility. They are connectivity and Isovist areas. Connectivity in VGA was measured depending on calculating the number of nodes directly visible from all the adjacent nodes to the selected heritage buildings, then an average was calculated. In contrast, Isovist Area was measured by calculating the visible areas from all the adjacent nodes to a particular heritage building.

These indicators were reliable enough to be used in an EFA to develop the SSV factors. EFA yielded two main factors of SSV: Movement flow and Visual accessibility. The first factor evaluated the human’s ability to move to and through the space as integrated or permeable. In contrast, the second investigated the human’s ability to see through a place. When these factors were used as predictors in MLRA to advance the statistical predictive models, they predicted all the identified categories of contextual anthropogenic hazards except one hazard’s category in the study area.

In regression model one, it was clarified that when heritage buildings are located in segregated and less accessible spaces where people move less to and through the space, looting and violent activities like crimes and theft increase and vice versa. These results are expected, as most space syntax research has indicated that crime, particularly property and theft increase and vice versa. These results are expected, as most research findings show that crime is higher in areas with limited accessibility, i.e., segregated spaces.

According to Hillier [51], if the spatial system suppresses pedestrians’ natural movement, there will not be sufficient people to generate the perception of well-appropriated and utilised spaces. Empirical research demonstrated that places with increased physical accessibility have lower crime rates, whereas places with limited accessibility, i.e., segregation, have higher crime rates. Most empirical space syntax research results have followed these results [54, 55, 56]. Furthermore, the results of model one were consistent with Newman [57] in terms of the effect of visual accessibility on criminal activities. Newman has assumed that crime and violence possess a higher tendency in narrow spaces between buildings than in wide streets. He was one of the pioneers to suggest that restricting visual accessibility and creating unequal distribution of Isovist Area can represent a picture of the integration pattern at the largest scale.

On the other hand, model two failed to predict the potential hazards of man-made pollution (e.g., garbage and solid waste). Therefore, these kinds of hazards could not be predicted by the proposed analytical method of SSV. Since assessing factors related to cultural aspects may prove benefical results. In regression model three, the movement factor was only the significant predictor of vandalism and inappropriate uses. There was a strong relationship between the predictor and the independent variable. This relationship can be explained as the higher movement and accessibility to the place, the higher clustering of people, and socio-economic activities. Therefore, in areas with high activities, heritage buildings may threaten more by inappropriate uses (e.g., illegal construction, marking, scratching, or damaging works).

Model four revealed that the visual accessibility factor was the only variable that significantly predicted distortion of the historical scene hazard rate. It is an unexpected result, as spaces with wide visual fields are threatened more by the distortion of their historical scene. This result may be explained as wide visual fields expose more unfavourable scenes. Another possible explanation is that distortion of the historical scene is associated with all adverse social activities, contributing to the deterioration of the heritage fabric and disturbing the historical scene (e.g., religious and spiritual rituals - commercial activities - street vendors - events and festivals). Hereafter, the high values of visual accessibility and wide visual fields may attract more socio-economic activities, negatively affecting the historical scene.

The results of the last three models related to all institutional hazards increase dramatically by increasing the movement flow to and through space. It was demonstrated that the construction and development activities influence heritage buildings located on the main streets with high traffic. Inconsistent development works cause severe impacts on the heritage buildings due to the construction debris, ground vibrations, and modifying or destroying some parts of the heritage assets, as happened in several recent construction and development projects in Egypt. Furthermore, institutional hazards increase in places with good visual accessibility because they may encourage more developing works.

Finally, the discussed results of this study proved the research assumption by demonstrating that there is a social aspect incorporated in the physical spaces. This social aspect directly affects how humans interact and behave negatively toward heritage buildings and historical context. The research assumption came in contrast to the previous studies in the field of heritage risk assessment. Those studies have examined only the physical properties to assess vulnerable spaces towards all kinds of hazards, whether anthropogenic or natural. This gap may result in inaccurate hazard assessment and mislead the mitigation strategies. Therefore, the study highlighted the problem and developed a quantitative analytical method for assessing vulnerable spaces towards contextual anthropogenic hazards, in addition to a predictive study.

The significance of the results of this work lies in helping risk managers and authorities predict patterns of spatial behaviours concerning the socio-spatial properties of the historical contexts. By applying the research results in the heritage risk management field, more effective and sustainable interventions could be conducted by modifying vulnerable configurations that enhance negative behaviours. Other interventions such as fixing fences or monitoring cameras generate barriers between the heritage building and humans and make their behaviours more aggressive in some cases according to the assumptions of the human psychology theories [58].

5. Conclusion

Anthropogenic hazards cause severe damage to heritage buildings and structures. One of the significant challenges posed by the field of risk assessment and management of cultural heritage is concentrating on physical features only in assessing vulnerable space, mainly towards natural hazards. These approaches did not match the anthropogenic hazards category in which humans in the surrounding are the source of risk. Therefore, this research assumed that the social aspect has a considerable effect which has to be investigated in assessing vulnerable spaces and predicting contextual anthropogenic hazards to formulate suitable and sustainable strategies for the adequate performance of heritage buildings in a liveable context.

A set of methodological procedures has been conducted to meet the research assumption. They initiate with literature review and the Delphi method to identify the contextual anthropogenic hazards for a set of valuable heritage buildings located in various social and spatial urban tissues across historic Cairo, Egypt. Two main categories of hazards were identified: 1) Individual hazards $H_{ind}$ and 2) Institutional hazards $H_{inst}$. The first consists of four subcategories of hazards: H1-Looting and violence, H2-Man-made pollution, H3-Vandalism, and inappropriate
uses, and HD-Distortion of the historical scene, while the second consists of three other subcategories: H5-Urban development, H6-Transportation infrastructures development, and H7- Services infrastructure development. The frequencies (F) and intensities (I) of the seven subcategories of hazards were evaluated using the ICCROM-CCI-RCE method to obtain the required data on rates of these hazards.

After that, a socio-spatial analysis was conducted in Depthmap 4 to evaluate the key indicators commonly used to address the vulnerable spaces (location and accessibility) using two main analytical space syntax methods: AGA and VGA. In AGA, integration and choice measures at local and global levels were calculated, while Connectivity and Isovist areas were obtained from VGA. The syntactic output data were subjected to another level of statistical analysis using the Statistical Package for the Social Sciences SPSS. Firstly, Cronbach’s Alpha was tested and appeared to be high, as the data was reliable enough. Then, EFA was used to group the variables of SSV. Consequently, movement flow and Visual accessibility were developed as the main factors of SSV.

Afterwards, the extracted two factors of SSV from EFA analysis were regressed seven times on each of the seven identified contextual anthropogenic hazards categories to promote seven separate regression models according to the ANOVA statistics. SSV factors were significant predictors of all contextual anthropogenic hazards except for man-made pollution. It was found that the movement flow factor positively affects the hazards of vandalism and inappropriate uses, urban development, transportation infrastructure development, and services infrastructure development and negatively on looting and violence hazard category. On the other hand, the visual accessibility factor increases the distortion of the historical scene, urban development, transportation infrastructure development, and services infrastructure development. At the same time, it decreases rates of looting and violence.

The research results clearly showed that the social context should be fully considered along with the spatial context. We cannot ignore their interaction while assessing vulnerable spaces and predicting rates of contextual anthropogenic hazards in historical settings. Therefore, risk managers should extensively investigate the social context and how humans use the space. Otherwise, the assessment would not be comprehensive enough. It would mislead the mitigation strategies towards spatial destructive behaviours.

This study breaks new ground in proposing the ‘socio-spatial vulnerability’ not only as a new lexicon but also as an analytical method to be used by those responsible for risk management in cultural heritage. This novel method helps address the characteristics of vulnerable configurations that enhance negative spatial behaviours. Hence, reshaping these configurations may be a sustainable mitigation strategy. In addition, following up mitigation works by applying the proposed analytical method could help explore what happens to the vulnerable space if its objects are shaped differently.

Moreover, the predictive model, which is one of the research outcomes, can be applied not only to historic Cairo (the chosen case of study) but also for similar areas with spatial configurations and urban structures that encourage the destructive practices of humans. For instance, Rome, Florence, and Barcelona lie below the analytical model and have the same criteria which those cities profit from such a model.

In the end, this work had a limitation in terms of the authors’ inability to acquire all necessary quantitative data about hazards frequencies and intensities from the public institutions. This limitation backs to the confidentiality of the data or its unavailability. However, those data would reinforce the research reliability. Instead, the researchers depended on experts’ judgments to handle this limitation. On the other hand, socio-spatial vulnerability factors are analysed by inspecting human interaction with the spatial context like pedestrian/vehicles movement flow and human visual accessibility rather than investigating the social standard of living such as poverty, illiteracy, unemployment. Social living standards are beyond the scope of this research. Although, they can be future indicators presented to the SSV analytical model in further research.

Declarations

Author contribution statement

Yasmine Sabry Hegazi and Doaa Tahab: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Noura Anwar Abdel-Fattah: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Mahmoud Fathi El-Alfi: Contributed reagents, materials, analysis tools or data.

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Data will be made available on request.

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