PRIORITIZATION OF INTERVENTIONS FOR STRENGTHENING ARCHITECTURAL HERITAGE

Fatemeh MEHDIZADEH SARADJ
Associate Professor, PhD, Department of Architecture and Environmental Design, Iran University of Science and Technology, Tehran, Iran, e-mail: mehdizadeh@iust.ac.ir

Kypros PILAKOUTAS
Professor, PhD, Department of Civil and Structural Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD; UK; e-mail: k.pilakoutas@sheffield.ac.uk

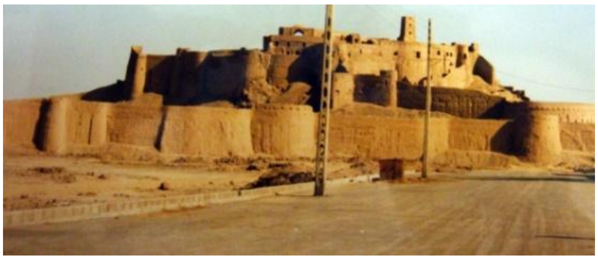
Iman HAJIRASOULIHA
Senior Lecturer, PhD, Department of Civil and Structural Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD; UK; e-mail: i.hajirasouliha@sheffield.ac.uk

Abstract. Architectural heritage is continuously exposed to natural disasters, such as strong earthquakes and this highlights the importance of reducing their vulnerability. While it is not possible to simultaneously strengthen all architectural heritage structures due to the limited skilled labour and budget restrictions, different buildings may need different treatments due to differences in exposure to seismic hazard, relative importance and vulnerability. Therefore, there is a need for a decision making strategy to find optimized solutions to achieve the highest possible stability and benefits. The primary objective of this research is to develop a practical step-by-step decision making process for the planning and prioritization of interventions in architectural heritage structures based on the level of seismic hazard, vulnerability and condition assessment, available preservation and strengthening techniques, compatibility with conservation ethics, available budget and expected benefits in various time schedules. The proposed methodology, is shown by diagram and mathematical formulae, and is demonstrated through a case study example.

Key words: architectural heritage, decision making, intervention priority, planning, seismic strengthening

1. Introduction

Architectural heritage is a key and irreplaceable aspect of cultural heritage which provides a 'sense of national identity', as they are the visible symbols of an invisible past, giving life and soul to cities (PPG 15, 1994). History reveals many examples of the destruction of magnificent heritage constructions due to natural disasters, in particular, earthquakes. Prominent examples can be named as the devastation of ancient largest mud citadel of the Arg-e-Bam (UNESCO, 2007) during 2003 earthquakes (Fig. 1) and the loss of historic temples in Kathmandu following the recent 7.8 magnitude earthquake in April 2015 (Fig. 2).



(a)

(b)

Fig. 1. Bam citadel (a) before earthquakes (in 1986) (b) after 2003 earthquakes (in 2007)

(a)

(b)

Fig. 2. The stupa in Durbar square of Patan in Kathmandu (a) before earthquake (in 2013); (b) after the 25 April 2015 earthquake (BBC, 2015)

Strengthening and seismic upgrading of structures can extend their life and lower their vulnerability to hazards. However, the protection of historic buildings goes beyond the ordinary norms adopted for the interventions in contemporary buildings, because new materials and techniques, however novel, could possibly damage their value and authenticity (D'Ayala and Forsyth, 2007; Hegazy, 2015) and therefore needs to comply with relevant regulations and codes of ethics, such as the Burra Charter (2013).

Furthermore, it is not possible to simultaneously strengthen all architectural heritage of the country, such as Iran with numerous heritage properties, mostly vulnerable unreinforced masonry buildings with all their advantages such as original dynamic characteristics (Paret *et al.*, 2008) and disadvantages (Hamiane *et al.*, 2016), due to limited skilled labour and budget restrictions. Moreover, different buildings need dissimilar treatments because of differences in exposure to seismic hazard, relative importance and vulnerability. Therefore, there is a need for a planning strategy to help decision makers to find optimized solutions based on maintaining maximum value, and achieving the highest possible stability and higher benefits according to their re-use or tourist attraction.

This article describes the following main decision making factors, which will be then used to develop a practical framework to make initial recommendations for the repair and seismic strengthening intervention of historic buildings:

(1) Seismic hazard
(2) Value and significance of architectural heritage

(3) Vulnerability and condition assessment
(4) Preservation and strengthening techniques for seismic protection
(5) The philosophy and ethics of conservation about any intervention on historic buildings

All these criteria need to be considered for the final prioritization of interventions, described in detail in section 2, to strengthen architectural heritage in any country. The policy, with all its fuzzy nature, needs to consider the first-best protection of values of architectural heritage and second-best pricing and functional efficiency (Nuccio and Ponzini, 2016; Zhang and Kockelman, 2016).

1.1. Seismic hazard

For efficient management and protection of historic places, there is a need to assess all potential hazards that can be categorised such as natural hazards, human actions and socioeconomic factors (Kalman, 2014). In high seismicity regions, the seismic risk requires effective management and advanced preparation to mitigate potential damage to historic buildings. There are several deterministic and probabilistic studies to assess earthquake induced hazards in various regions using historical and instrumental earthquake records including maximum magnitudes, the frequency of earthquakes and the depth of the source of earthquakes, fault activities, geological and tectonic information (Amiri *et al.*, 2003; Zafarani and Ghafoori, 2013; Syrmakezis, 2006; Stepanova and Rubel, 2015).

The seismic hazard maps usually indicate the earthquake hazard in the form of iso-acceleration contour lines for the return periods of 75 and 475 years, providing the basis for the preparation of seismic risk maps and seismic hazard zoning (Tavakoli and Ashtiany, 1999). Though, the general perception of risk is mostly related to the expected damage rather than the probability of occurrence (Karanikola et al., 2015).

Based on the results of seismic hazard assessment, a seismic hazard grade (Sz) can be assigned to each seismic risk zone, assigning the highest number to the very high seismic risk zones and the lowest to the low seismic risk zone regions. Table 1 shows an example of the Sz values suggested based on the seismic zones in Iran, updated in the latest edition of Standard No. 2800 of Building and Housing Research Center (BHRC) (2014). The seismic hazard grades will be used in the conservation decision making policy framework in Section 2.

Table 1. Seismic hazard grades (Sz) (BHRC, 2014)

Seismic hazard zone of the building's location	Seismic hazard grade (Sz)
Very high seismic risk zone	4
High seismic risk zone	3
Medium seismic risk zone	2
Low seismic risk zone	1

1.2. Value and significance of architectural heritage

There are various factors attributed to the value and significance of architectural heritage such as: Informational, documentary, aesthetic, architectural quality, authenticity (related to both visual and original fabric), integrity, antiquity, rarity and uniqueness, communal, social, historical, evidential, age, cultural, political, artistic, technological, structural and architectural design, craftsmanship, scenic and contextual, identity, economic, usage, educational/scientific, sense of place, group value, urban context value, commemorative or associational values, communal value, social importance, recreational and amenity values and all other potentials (Feilden, 2003; Saradj, 2011; Tomback, 2007; English Heritage, 2008, Mason, 2002; Gulzar *et al.*, 2015; Al-hagla, 2010; McArthur and Jofeh, 2016; Hamma, 2017; Al-hagla, 2010).

To summarize these many values, (either intangible and immaterial or related to tangible material (Vecco, 2010; Ahmad, 2006; Pujia, 2016) various categorizations have been suggested such as the one suggested by Feilden (2003) as emotional, cultural and use values or the breakdown of Serageldin (1999) to extractive use value, non-extractive use value and non-use values and the suggested typology of heritage values by Mason (2002) as sociocultural and economic values. It should be noted that these attributed values cannot always be segregated rigorously as most of the time they overlap. Moreover, historic buildings have several layers of value, which cannot be all identified easily.

Value assessment of historic buildings is one of the main debates, related to both art and science. International charters and standards dealing generally with listing and grading of historic buildings do not provide specific criteria. For instance, according to Pickard (1996), the ranking system in the United States is mainly based on historical significance, architectural significance and physical condition. Listing criteria in England are mainly based on age and survival condition; the values then applied are architectural interest, historical interest, close historical associations, and group value (Ross, 1996; Mynors, 2006).

Grading of listed buildings is mainly based on their relative importance represented by a correlated degree of care. The range of values of monuments and their perception could differ by different individuals (Gard'ner, 2007). The reality is that historic buildings have multiple layers of 'value' to the community, while non-functional heritage brings non-financial benefits to the society and play a central role in the quality of life (Tomback, 2007).

Strategic decision-making with respect to heritage recognition and protection requires a more rigorous evaluation process to determine the significance of each historic place under consideration. To prioritise historic buildings for intervention planning, a numerical scale can be used to assign a relative total value grade according to the viewpoints of local people, stakeholders and decision-makers. Assigning the relative importance could be either qualitative or quantitative, depending on the context and the number of heritage properties. Mason (2002) believes that qualitative methods elicit cultural values more effectively. While it is possible to elaborate the relative importance more precisely, to simplify the decision making process, the classifications reduced in numbers to three qualitative categories of very high value, high value and medium value in Table 2.

Table 2. Allocation of total grades of Value importance (Vi) to historic buildings

Relative classification importance	The grade of value importance (Vi)
Internationally recognized	Very high value (3)
Nationally important	High value (2)
Known at local level	Moderate value (1)

1.3. Vulnerability and condition assessment

Before taking any decisions on strengthening remedies, there is a need to pursue investigations and diagnosis to understand the architectural proportions, structure, and then evaluate the damage and vulnerabilities of the historic building (Luca *et al.*, 2016; Souami *et al.*, 2016; Vicente *et al.*, 2011). The seismic safety and condition assessment of the historic buildings is possible through qualitative or quantitative methods (Bento *et al.*, 2005) through examining geometry and fabric at different levels based on direct observation, historical research, structural analysis by computation or simulation, and experiments using non-destructive instruments and laboratory tests. The selection of the method depends on the type of monument and information required, budget, use, the accuracy of data and the rate of error in each appraisal technique (Theodossopoulos, 2012). The obtained knowledge is very important to understand the real seismic behavior of heritage structures (Clementi *et al.*, 2016).

There is possibility of applying the computer expert systems for evaluating and analysing the main risks for heritage buildings such as fuzzy buildings service life (FBSL) (Ibánez *et al.*, 2016). D'Ayala and Speranza (2002) suggested a procedure for Seismic vulnerability of masonry historic buildings based on a failure analysis by identifying the collapse mechanisms and their related failure load factors (D'Ayala and Speranza, 2002). Moreover, direct expert observation of structural damage, by using simple measuring instruments, is a type of the qualitative diagnosis approach. Whilst expert opinion is superior to numerical vulnerability assessment in historic buildings (Hume, 2007), this method relies mainly on professional experts who have the ability to correctly interpret the qualitative knowledge obtained from site and historical sources (D'Ayala and Forsyth, 2007).

As the output of the proposed methodology is expected to be a prioritization of interventions for a large number of cultural properties, therefore simplified approaches to determine qualitative vulnerability level is applicable. Based on the results of vulnerability assessments, a relative qualitative vulnerability condition grade (Vc) can be assigned to each historic building. Table 3 shows suggested values based on the condition of historic buildings. These values will be directly used in the decision making framework in the section 2.

Table 3. Allocation of vulnerability condition (Vc) grade to historic buildings

Vulnerability condition	Vulnerability grade factor = VC
Lower vulnerable situation	3
Moderate vulnerable	2
Higher vulnerable condition	1

1.4. Preservation and strengthening techniques for seismic protection

There are various levels of interventions in historic buildings, which can be classified depending on the purpose and the individual specificities of building, its value and context. The efficiency and the applicability of each strengthening method should be also evaluated for each case of historic buildings based on the ethics of conservation.

Different strengthening techniques have been proposed for the historic buildings at different intensity levels using the Modified Mercalli Intensity (MMI) scales (Saradj, 2007). For example, Table 4 presents the possible seismic strengthening and rehabilitation methods for vulnerable Un-Reinforced Masonry (URM) buildings.

Table 4. Expected damage and possible seismic strengthening and rehabilitation methods in various intensities for unreinforced masonry buildings

The level and scale of earthquakes	**Damage**	**General Possible Strengthening Solutions**
Mild - I (Up to 2.5 Richter)	Imperceptible and instrumental • No damage; registered only by seismographs	Prevention of deterioration • Removal of the existing vegetation and micro-organisms such as algae
Mild - II (2.5-3.5 Richter)	Very slight and feeble • No damage; Delicately suspended objects may swing	Prevention of deterioration • Hand cleaning of the façade
Mild - III (3.5-4 Richter)	Slight • No damage • Hanging objects swing back and forth	Prevention of deterioration • Hand cleaning of bricks and mortar joints
Moderate - IV (4.0-4.5 Richter)	Moderate • Slight non-structural damage; • Hanging objects swing; • Windows, doors and crockery rattle	• Preservation of the existing state • Desalination by diffusion, convective transport and electro-migration (Friese and Protz, 1998) • Correction of dampness or humidity; Refilling the masonry joints (Binda *et al.*, 1999)
Moderate - V (4.5-4.9 Richter)	Fairly strong Moderate non-structural damage: • Hanging objects swing considerably • In a few cases windowpanes break • Most failures due to slide off loose and non-anchored objects Slight structural material damage: • Hairline cracks in very few walls; Fall of few stones from upper parts	Preservation of the existing state • Emergency strutting or shoring; Replacement of fallen bricks or stones (Lester *et al.*, 2013) • Removal of excess moisture • Grouting: • Refilling masonry joints with compatible mortar with existing one • Low pressure grouting of the cracks Non-structural elements: Anchor and fix heavy furniture or appliances
Intermediate - VI (4.9-5.5 Richter)	Strong • Heavy non-structural damage: windows, crockery and glass break Moderate structural material damage: • Cracks in masonry walls, diagonal cracks between windows or openings (Levy and Salvadori, 1997) • Fall of fairly large pieces of plaster Slight structural damage: Creating cracks and empty spaces in walls	Consolidation or direct conservation: Addition of supportive materials Grouting: grouting the fractures and cracks Adding ties: adding pre-stressed ties for integrity (Huerta and Lopez, 1997)
Intermediate - VII (5.5 -6.2 Richter)	Very strong Very heavy damage to non-structural elements: • Hanging objects quiver, furniture breaks Heavy structural material damage: Collapse of fairly large pieces of plaster, loose bricks, tiles and architectural ornaments	Consolidation of the fabric: Thicken, enlarge, or strengthen elements Grouting: grouting of small cracks by injection, and larger cracks by inserting bonders Wrapping the building: Encircle the walls at risk at each floor level (Bowyer, 1980)

Table 4. Expected damage and possible seismic strengthening and rehabilitation methods in various intensities for unreinforced masonry buildings

The level and scale of earthquakes	**Damage**	**General Possible Strengthening Solutions**
	Moderate structural damage: • Severe cracking of walls mostly X-shape • Collapsed parapets and non-anchored cornices • Foundation movement and settlement	Reinforcement of joints and corners Foundation: Enlargement of the overloaded parts
Severe - VIII (6.2-6.9 Richter)	Destructive Destroy of non-structural elements: • Falling of objects like TV sets, • Overturning of furniture Very heavy structural material damage: Twist of tall structures, thrown out of loose panels Heavy structural damage: • Chimney, monuments, towers collapse; The wall begins to deform • Anchorage failure: Failure at the structural connections; Splitting at the joint of intersecting walls (Abdelmegeed et al., 2015); Shift off the buildings	Restoration: Adding new shear walls, vertical bracings and columns Foundation: Enlargement of the foundation Joints and connections: Providing a continuous path from roof to foundation, Reducing the distance between wall supports (Cestari and Roccati, 1999), connecting façade walls to floors and cross-walls by tie-rods and bracing (D'Ayala *et al.*, 1997; Abdelmegeed et al., 2015) Dampers: inserting dampers all around the building
Severe - IX (6.9-7.3 Richter)	Highly Destructive Destroy of structural material: • Material of horizontally weak constructions destroyed • Very heavy structural damage: • Wall or ceiling collapse; Frame structures lifted, or collapse • Joint and connection: • Movement, loosening and separation of joints, • Foundation: • Settlement, overturning or toppling of foundation	Rehabilitation: Emergency interventions; To revert the columns to their vertical position Foundation: sufficiently tying of the whole foundation system together Inserting concrete beams and columns and tying them together Inserting dampers, in particular viscous dampers, all around the building and connecting by springs and shock absorbers (Ambrose and Vergun, 1999), Inserting base isolation system in suitable locations (Gavrilovic *et al.*, 2003; Branco and Guerreiro, 2011)
Severe - X (7.3-7.9 Richter)	Extremely destructive and Disastrous Destroy of majority of masonry structures and serious damage to steel structures Foundation: different settlement of the foundation Joints: failure of connector; Concentration of stresses in the zones of no uniformity,	Reproduction: removing the artifacts to preserve them Emergency intervention: Temporary strutting or shoring (Cestari and Roccati, 1999) Returning the original structural stability: reverting the leaning columns Adding structure: Symmetric distribution of resisting elements; bonding reinforcing mesh Inserting the seismic separation joints: In suitable places

Table 4. Expected damage and possible seismic strengthening and rehabilitation methods in various intensities for unreinforced masonry buildings

The level and scale of earthquakes	Damage	General Possible Strengthening Solutions
Catastrophe - XI (7.9-8.5 Richter)	Very Disastrous Destroy and collapse of most structures even the reinforced ones: • Only a few buildings remain standing	Reconstruction: Reinforced concrete cladding of the building Installation of gravity framing systems separated from the un-reinforced masonry walls
Catastrophe - XII (8.5-8.9 Richter)	Major disaster and Catastrophic • Large-scale changes in the ground structure • Waves seen on ground • Waterfalls are created; lakes are dammed up or burst their banks • Damage nearly total. Almost everything is destroyed • Practically all structures above and below ground are destroyed	Reconstruction: Nothing can be useful

The first column (from the left) in this Table indicates the general ordering of earthquake intensities and shows the Mercalli Intensity scale and in brackets the approximate equivalent Richter magnitude scale (The Geography Site, 2013; Feilden, 2003; USGS, 2016). The second column indicates the descriptive term and effects in each modified Mercalli intensity scales explaining the expected seismic vulnerability based on the classification proposed by macroseismic scale (Feilden, 2003; Tomazevic, 1999). The third column suggests the strengthening measures based on ascending degrees of intervention. The second and third columns have exploited the experiences of various past case studies which are mentioned individually in the Table 4 (Feilden, 2003; Croci, 1998; Bader and Mahran, 2015).

It should be noted that some of the mentioned solutions for the 'intermediate', 'severe' and 'catastrophe' levels of earthquake intensity are very heavy and intrusive, and need to be analysed case by case to ensure the integrity and authenticity aspects of cultural heritage construction which will be discussed further in section 1.5.

1.5. Philosophy and ethics of conservation

The permissible level of intervention for seismic upgrading of historic buildings requires a philosophical debate, to avoid damage and controversy (Hejazi and Saradj, 2014; Mansfield, 2008; Viñas, 2002). A balance needs to be achieved between:

1. Avoiding destroying past evidence and authenticity of material and structure contained in every relic
2. Enabling the building to regain its integrity and unity to provide public legibility and continue to be understood and express its story
3. Complying with standards
4. Facilitating current re-use and securing its future

Authenticity is of prime importance to avoid deceiving the audience and destroying architectural heritage, and can act as a leading strategy for conservation based on genuine information, traditional methods of repair and achieving an honest result. The unnecessary replacement of historic fabric could have an adverse effect and could reduce their value, disturbing the authenticity (Earl, 2003).

The dichotomy in solutions needed to comply with current safety standards and the desire for authenticity stems from the fact that standards are attached to modern materials, technologies and processes. Nonetheless, age and uniqueness are always a part of the value of historic buildings, which means that the deviation from the norms may be vital for conservation purposes (D'Ayala and Forsyth, 2007). Specifically a significant challenge arises when dealing with seismic retrofit of traditional masonry structures, which almost always require the introduction of new techniques and materials to increase their strength and ductility. These approaches are not practically reversible but are indispensable for seismic strengthening of historic masonry buildings (Gavrilovic *et al.*, 2003).

The following are some fundamental conservation principles that need to be considered:

- Cultural heritage significance is their most important characteristic and should be kept by safeguarding their values.
- Minimum effective essential preservation and sensible repairs to maintain the remains in their existing state and also secure the safety of structures.
- Respecting all contribution of past interventions, as testament to the process of creativity as stated in article 11 of the Venice Charter (1964).
- Treating the visible and invisible parts alike to not remove the messages of the past and to tell a true story.
- Continued use (if it is the only way to preserve) through the adaptation of the building to present-day standards and ways of living.
- Making repairs or introduction of elements in a manner compatible with the character of existing structural forms and scheme, specifically in view of distinguishability, and materials in terms of stiffness, durability, movement, etc.
- Reversibility of repairs so as not to preclude future intervention and the ability to undo a treatment without damaging the original fabric (McCaig, 2013).
- Every tiny piece of the traditional material should be respected for the aesthetic, historic worth, physical integrity and original concept of the object. Repairs must, however, be strong enough for extensive use and future reparation.

The nature of intervening actions depends on the value and type of building. The more irreplaceable, the less changing actions need to be taken; for example only minimal structural preservation is allowed on scheduled monuments to allow public access. Ruskin proposes restricting structural interventions to merely introducing ties and anchors to stop cracks and the effects of movements, and even prefers the permanent shoring over rebuilding the part of historic building in danger of collapse (D'Ayala and Forsyth, 2007).

Finally it is important to mention that there are no right-every-time and all-purpose-fits-all-situations solutions on offer and all buildings need to be preserved on an ad-hoc basis. Moreover, the buildings of various styles from different periods need to be treated with their own restoration style (Earl, 2003).

2. Intervention strategies for seismic strengthening of historic buildings

While there is no universal strategy for maintaining cultural heritage (Bamert *et al.*, 2016), to develop appropriate context-specific intervention solutions at the regional or country level, all the factors discussed in previous sections need to be considered in a plan of action (or conservation plan) that manages the unavoidable change (Feilden, 2003; Ferretti *et al.*, 2014). To arrive at a conservation plan, the following questions need to be answered:

1. Which one out of numerous listed buildings has priority for action?
2. What is the mechanism of decision making for determining the necessary actions?
3. What is the time scale for the implementation of the actions?

In this study, a practical step-by-step decision making methodology is proposed as a mechanism for the seismic retrofitting of historic buildings based on a simple method using different intervening input factors and the above interdependent criteria (Wang and Zeng, 2010; Dutta and Husain, 2009). Fig. 3 shows the diagram of the proposed step-by-step conservation planning procedure.

The various stages of the diagram in Fig. 3 are determined as follows:

- 1-1- Earthquake hazard assessment, rating the seismicity of the region very high, high, moderate, and low according to the design building codes. For simplicity, the seismic hazard value (Sz) can be assigned from Table 1.
- 1-2- As described in section 1.2, evaluating the value of the historic buildings is a complex issue, as there is a need to identify the various values of each property (e.g. architectural, historical or structural) and then assign an appropriate importance rate for each value for that specific built heritage. After discerning the values, and according to their relative hierarchical importance order (Saradj, 2011) , buildings could be ranked in comparison to each other based on their value importance (Vi) as simplified in Table 2.
- 1-3- The vulnerability of historic buildings is assessed as discussed in section 1.3. In the absence of a more refined method for determining the Vulnerability condition (Vc), Table 3 can be used.
- 2- The overall Level of Intervention (INT_L) can be obtained by multiplying the value of seismic hazard (Sz) for the region by the sum of the rates related to the buildings' importance value (Vi) and the buildings vulnerability condition (Vc) (Eqn. 1). The reasoning behind Eqn. 1 arises from the fact that the sum of building's characteristics has a magnifier role in each seismic location to determine the need for intervention. However, this one-dimensional formula can be developed further in future researches.

$$INT_L = Sz \times (Vi + Vc) \qquad \text{(Eqn. 1)}$$

This factor determines the level of intervention required for the specific building needs as shown in Table 5. Structures with higher INT_L are expected to be qualified for higher earthquake magnitudes and require shorter time schedule for strengthening interventions. The various possibilities for interventions to strengthen buildings against different severity of earthquakes can be selected from Table 5. However, this numerical suggestion is mainly based on rational thinking and logical judgment and is utilised here as a medium to be able to introduce the mechanism in the size limit of journal papers instead of an oversize flowchart.

- 3- Table 5, determines the required severity of the earthquake for which buildings need to be strengthened against. After deciding on the necessary level for earthquake retrofitting, Table 4 can act as a guiding tool in determining the required interventions.
- 4- As mentioned in section 1.5, not all actions are permissible for heritage properties and all technical interventions need to be checked, evaluated and filtered to abide by the appropriate philosophy and ethics of historical conservation and to respect the historical character and fabric of monuments. Attempts at preservation must have certain characteristics including simplicity, the least expense, the minimum intervention, reversibility, architectural coherence, compatibility, authenticity, integration with the whole, structural stability, and documentation. Work must be carried out with techniques that match the original construction of the building.
- 5- Estimating the cost of actions, can lead to the eventual ranking based on the available budget. It should be mentioned that money is not an appropriate metric (Throsby, 2016) and is just considered to evaluate the feasibility of the project according to the budget available for heritage preservation (Bertacchini and Segre, 2016). However, this stage can go further by assessing not only the monetary cost, but also the value cost for buildings and how much will be added or reduced from the value of buildings as a result of strengthening actions.

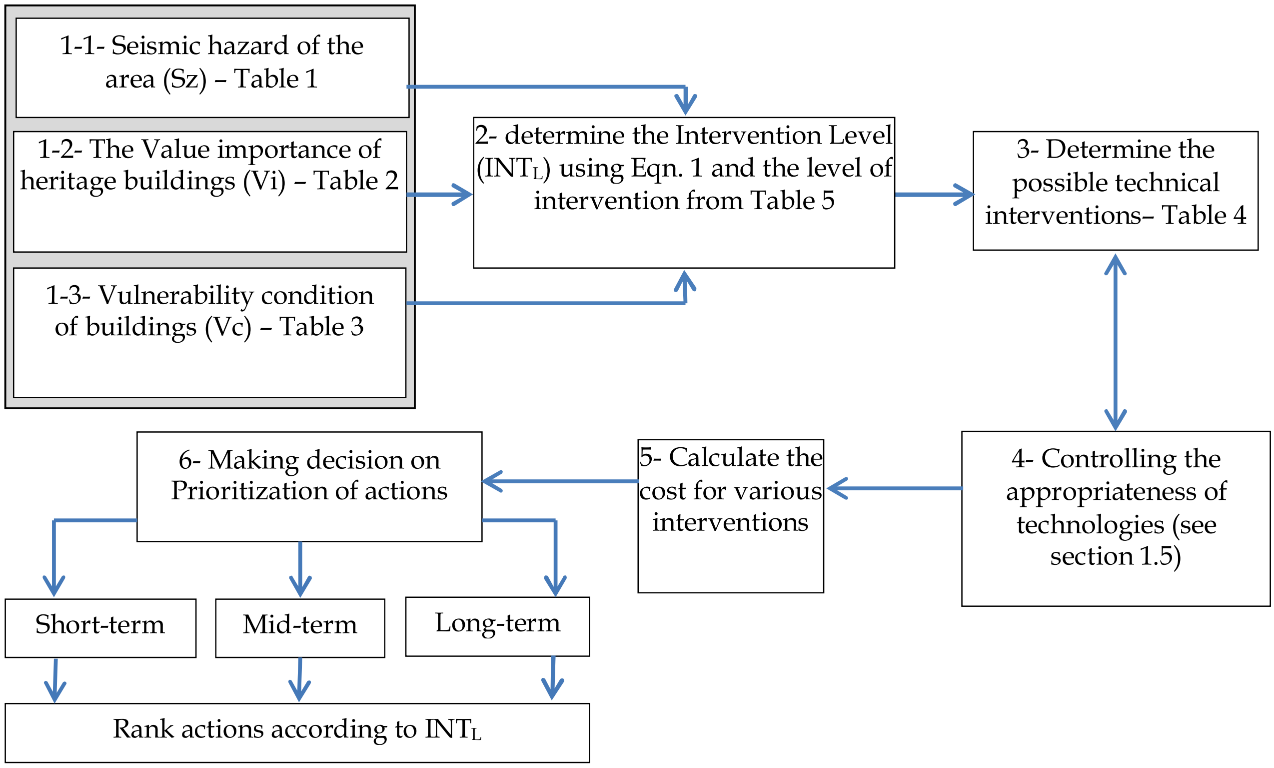


Fig. 3. Proposed diagram for the step-by-step procedure of conservation planning to strengthen historic buildings against earthquakes

Table 5. Required level of interventions

INT_L	**The required level of intervention in various time schedule**
$20 \leq INT_L \leq 24$	-protection against severe earthquakes in short-term planning
$15 \leq INT_L \leq 19$	-protection against intermediate earthquakes in short-term planning -protection against severe earthquakes in mid.-term planning
$11 \leq INT_L \leq 14$	-protection against moderate earthquakes in short-term planning -protection against intermediate earthquakes in mid.-term planning -protection against severe earthquakes in long-term planning
$8 \leq INT_L \leq 10$	-protection against mild earthquakes in short-term planning -protection against moderate earthquakes in mid.-term planning -protection against intermediate earthquakes in long-term planning
$5 \leq INT_L \leq 7$	-protection against mild earthquakes in mid.-term planning -protection against moderate earthquakes in long-term planning
$INT_L \leq 4$	-protection against mild earthquakes in long-term planning

- 6- The last stage of the procedure deals with the final decisions on prioritization of required actions at various time scales. For each time scale, prioritization can take place based on INT_L.

The proposed procedure is examined through a case study in the following section.

2.1. Case study - Sheikh Lotfollah mosque

To highlight the feasibility and to examine the efficiency of the new proposed management procedure (Nieto *et al.*, 2016), a prominent sample from Persian architectural heritage, has been chosen. This building is located in the world heritage site of Naqsh-e-Jahan square in Isfahan. The Sheikh Lotfollah mosque (1619 AD) (Fig. 4) is in a medium seismic risk zone (Sz = 2, Table 1), very important and prominent historic building of very high value (Vi=3, Table 2) with very good condition (Vc=3, Table 3).

Following the equation 1, the INT_L is calculated for this mosque as 2 × (3 + 3) = 12; according to Table 5, the building should be protected against moderate earthquakes in short-term planning (0-5 years), against intermediate earthquakes in mid-term planning (up to 10 years) and against severe earthquakes in long-term planning (next 20 years or so).

Fig. 4. Sheikh Lotfollah mosque located in the Naqsh-e-Jahan square in Isfahan city, Iran,

According to Table 4, preservation of the existing state by regular maintenance has the highest priority for this building in the short-term and this is not in contradiction with current conservation philosophy and ethics. The mid-term actions could include consolidation of the fabric of the building. In this case, it would be suitable to re-grout the structure as well as the tiles of the dome. For longer term resistance against severe earthquakes, possible actions could include reinforcing and tying the foundation system and providing localized strengthening to create an integrated seismic resistance mechanism, which requires suitable planning in advance with enough budgets.

Obviously, the survival of this building in the event of any possible future severe earthquake, not only benefits in saving this prominent architectural heritage, but will also help in retaining the spatial boundaries of the Naqsh-e-Jahan square, which is the best focal point in attracting tourists in the city and consequently assures the economic growth of Isfahan.

3. Conclusions

Architectural heritage are one of the most valuable assets for all societies and, therefore, should be protected from the utmost devastating threats including sudden natural hazards such as earthquakes. The developed forces during extreme events can go beyond the tolerance limits of vulnerable historic buildings if not enough remedies are planned in advance.

The appropriate level of strengthening actions for historic structures depends on three main factors: (a) The seismic hazard (e.g. anticipated severity of earthquakes in the area), which is usually classified as very high, high, medium and low (section 1.1); (b) The level of significance of buildings which is determined through their importance value (section 1.2); (c) The existing safety condition of the building that is related to its vulnerability condition (section 1.3). These three sets of information can lead to the required level of interventions at various time scales. On the basis of the required level of intervention (Table 5), possible technical interventions can be selected based on past experience (Table 4). After filtering these to comply with conservation ethics, the cost of each intervention can be determined. Prioritization can then take place at different time scales using the intervention level and appropriate budget.

The above concept is used in this study to develop a practical decision making strategy framework to make initial recommendations for intervention solutions to achieve the highest possible stability and benefits. The proposed procedure is examined through a case study example, Sheikh Lotfollah mosque, from the Safavid era in Iran.

Future proposal: The suggested mechanism can be developed further as a basis for a decision making computer program. It is possible to assign more detailed numerical values for seismic risk, building importance and vulnerability with an objective metric with some uncertainty levels.

REFERENCES

Abdelmegeed M. M., Badogiannis E., Kotsovos G., Vougioukas E. (2015), *Structural Damage Assessment of Historic Traditional Masonry Buildings: A Case Study*, International Journal of Conservation Sciences **6(2)**: 165-176.

Ahmad Y. (2006), *The Scope and Definitions of Heritage: From Tangible to Intangible*, International Journal of Heritage Studies **12(3)**: 292-300.

Al-hagla K. S. (2010), *Sustainable urban development in historical areas using the tourist trail approach: A case study of the Cultural Heritage and Urban Development [CHUD] project in Saida, Lebanon*, Cities **27**: 234-248.

Ambrose J., Vergun D. (1999), *Design for Earthquakes*, Wiley, New York.

Amiri G. G., Motamed R., Eshaghi H. R. (2003), *Seismic Hazard Assessment of Metropolitan Tehran, Iran*, Journal of Earthquake Engineering **7(3)**: 347-372.

Bader N. A. E., Mahran A. F. (2015), *Restoration and preservation of artistic elements applied on Islamic architectural façade of Shahin Agha Sebil, Cairo, Egypt*, International Journal of Conservation Science **6(1)**: 63-78.

Bamert M., Ströbele M., Buchecker M. (2016), *Ramshackle farmhouses, useless old stables, or* *irreplaceable cultural heritage? Local inhabitants' perspectives on future uses of the Walser built heritage*, Land Use Policy **55**:121-129.

BBC World News (2015), *Photos Taken in Kathmandu an Hour Apart*, https://twitter.com/bbcworld/status/591940986386939904.

Bento R., Lopes M., Cardoso R. (2005), *Seismic evaluation of old masonry buildings. Part II: Analysis of strengthening solutions for a case study*, Engineering Structures **27**: 2014–2023.

Bertacchini E., Segre G. (2016), *Introduction: Culture, sustainable development and social quality: A paradigm shift in the economic analysis of cultural production and heritage conservation*, City, Culture and Society **7(2)** 69-70.

Binda L., Tedeschi C., Baronio G. (1999), *Influence of thick mortar joints on the early and late mechanical behaviour of Byzantine constructions,* in: Brebbia C.A., Jäger W. (Eds.), *the 6th International Conference on Structural Studies, Repairs and Maintenance of Historical Buildings VI, STREMAH 99*, Dresden, Germany, pp. 211-220.

Bowyer J. (1980), *Vernacular Building Conservation*, Architectural Press, London.

Branco M., Guerreiro L. M. (2011), *Seismic rehabilitation of historical masonry buildings*, Engineering Structures **33(5)**: 1626-1634.

Building and Housing Research Center (2015), *Standard No. 2800*: *Iranian Code of Practice for Seismic Resistant Design of Buildings, 4th Edition* [in Farsi], BHRC Publication, Tehran.

Burra Charter (2013), *the Australia ICOMOS for Places of Cultural Significance*, Australia ICOMOS.

Cestari B. C., Roccati R. (1999), *Computer modelling of an active space steel structure reinforcement: A case study*, in: Brebbia C. A., Jäger W. (Eds.), *Proceedings of the 6th International Conference on Structural Studies, Repairs and Maintenance of Historical Buildings VI, STREMAH 99*, Dresden, Germany, pp. 263-275.

Clementi F., Gazzani V., Poiani M., Lenci S. (2016), *Assessment of seismic behaviour of heritage masonry buildings using numerical modeling*, Journal of Building Engineering **8**: 29-47.

Croci G. (1998), *The Conservation and Structural Restoration of Architectural Heritage*, Computational Mechanics Publications, Southampton.

D'Ayala D., Forsyth M. (2007), *What Is Conservation Engineering*?, in: Forsyth, M. (Ed.), *Structures & Construction in Historic Building Conservation*, Blackwell Publishing Ltd, Oxford, pp. 1-11.

D'Ayala D., Spence R., Oliveira C., Pomonis A. (1997), *Earthquake Loss Estimation for Europe's Historic Town Centres*, Earthquake Spectra **13(4)**: 773-793.

D'Ayala D., Speranza E. (2002), *An integrated procedure for the assessment of seismic vulnerability of historic buildings*, in: *Proceedings of The 12th European Conference on Earthquake Engineering [ECEE]*, Barbican Centre, London, UK.

Dutta M., Husain Z. (2009), *An application of Multi criteria Decision Making to built heritage-The case of Calcutta*, Journal of Cultural Heritage **10**: 237-243.

English Heritage (2008), *Conservation Principles - Policies and Guidance for the Sustainable Management of the Historic Environment*, English Heritage, London.

Feilden B. M. (2003), *Conservation of Historic Buildings*, Architectural Press, London.

Ferretti V., Bottero M., Mondini G. (2014), *Decision making and cultural heritage: An application of the Multi-Attribute Value Theory for the reuse of historical buildings*, Journal of Cultural Heritage **15**: 644-655.

Friese P., Protz A. (1998), *Desalination of Brickwork and Other Porous Media*, In: Baer N., Fitz S.S., Livingston R. A. (Eds.), *Conservation of Historic Brick Structures*, Donhead Publishing Ltd, Dorset.

Gard'ner J. M. (2007), *Preparing the Conservation Plan*, In: Forsyth, M. (Ed.), *Understanding Historic Building Conservation*, Blackwell Publishing Ltd, Oxford, pp. 156-174.

Gavrilovic P., Kelley S. J., Sendova V. (2003), *A study of seismic protection techniques for the Byzantine churches in Macedonia*, APT Bulletin **34(2/3)**: 63-69.

Gulzar S., Chaudhry M. N., Burg J. P., Saeed S. A. (2015), *Mughal Sandstone Heritage of Lahore: Formulating the Future Restoration Strategy*, International Journal of Conservation Science **6(2)**: 177-188.

Hamiane M., Djefour I., Merabet H., Bouallala D., Zekagh A., Turki Y., Saidi M. (2016), *Design of Adobe Bricks of Local Raw Materials for Use in the Monuments of Earthen Architecture - Case of Adrar Hospital - Algeria*, Civil Engineering and Architecture **4(4)**: 147-152.

Hamma W. (2017), *Classification and Recognition of the Heritage Values of the Monuments of Tlemcen*, Urbanism Architecture Constructions **8(2):** 129-142.

Hegazy S. M. (2015), *Conservation of historical buildings – The Omani–French museum as a case study*, Housing and Building National Research Center **11**: 264-274.

Huerta S., Lopez G. (1997), *Stability and consolidation of an ashlar barrel vault with great deformations: The church of Guimarei*, in: Brebbia C. A., Sanchez-Beitia S. (Eds.), *Proceedings of the Fifth International Conference on Structural Studies, Repairs and Maintenance of Historical Buildings, STREMAH V*, WIT Press, Spain, pp. 587-596.

Hume I. (2007), *Repairs to Historic Structures*, In: Forsyth, M. (Ed.) *Structures & Construction in Historic Building Conservation*, Blackwell Publishing Ltd, Oxford, pp. 140-150.

Ibánez A. J. P., Bernal J. M. M., Diego M. J. C., Sánchez F. J. A. (2016), *Expert system for predicting buildings service life under ISO 31000 standard. Application in architectural heritage*, Journal of Cultural Heritage **18**: 209-218.

Kalman H. (2014), *Heritage Planning, Principles and Practice*, Routledge, London.

Karanikola P., Panagopoulos T., Tampakis S., Karantoni M.-I. (2015), *Perception and knowledge about natural disasters in the sporades islands of Greece*, Journal of Environmental Protection and Ecology **16(2)**: 498-509.

Lester J. R., Brown A. G., Ingham J. M. (2013), *Stabilisation of the Cathedral of the Blessed Sacrament following the Canterbury earthquakes*, Engineering Failure Analysis **34**: 648–669.

Levy M., Salvadori M. (1997), *Why the earth quakes: the story of earthquakes and volcanoes,* W. W. Norton & Company, New York.

Luca O., Stanescu A. A., Gaman F. (2016), *Considerations Related to Housing and Seismic Risk*, Urbanism Architecture Constructions **7(2)**: 125-136.

Mansfield J. R. (2008), *The ethics of conservation: some dilemmas in cultural built heritage projects in England*, Engineering, Construction and Architectural Management **15(3)**: 270-281.

Mason R. (2002), *Assessing Values in Conservation Planning: Methodological Issues and Choices,* In: de la Torre, M. (Ed.), *Assessing the Values of Cultural Heritage*, Getty Conservation Institute, Los Angeles, pp. 5-30.

McArthur J. J., Jofeh C.G.H. (2016), *Portfolio retrofit evaluation: A methodology for optimizing a large number of building retrofits to achieve triple-bottom-line objectives*, Sustainable Cities and Society **27**: 263-274.

Mynors C. (2006), *Listed Buildings, Conservation Areas and Monuments*, Sweet & Maxwell, London.

Nieto J. R., Silva L. S., Murtinho V., Rigueiro C., Gonçalves A. (2016), *Conceptual Model for the Sustainable Rehabilitation of Medium-size Inner cities in Europe: Coimbra, Portugal*, Journal of Urban Planning and Development **142(3)**: 1-18.

Nuccio M., Ponzini D. (2016), *What does a cultural district actually do? Critically reappraising 15 years of cultural district policy in Italy*, European Urban and Regional Studies [in press].

Paret T. F., Freeman S. A., Searer G. R., Hachem M., Gilmartin U. M. (2008), *Using traditional and innovative approaches in the seismic evaluation and strengthening of a historic unreinforced masonry synagogue*, Engineering Structures **30**: 2114-2126.

Pickard R. (1996), *Conservation in the Built Environment*, Longman, Essex.

PPG 15 (1994), *Planning and Policy Guidance 15: Planning and the Historic Environment*, Department of National Heritage, Department of the Environment.

Pujia L. (2016), *Cultural Heritage and Territory. Architectural Tools for a Sustainable Conservation of Cultural Landscape*, International Journal of Conservation Sciences **7(1):** 213-218.

Ross M. (1996), *Planning and the Heritage, Policy and Procedures,* E & FN SPON, London.

Saradj F. M. (2007), *Earthquake Intensity, Damage and Conservation of Unreinforced Masonry Buildings*, Architectural Science Review **50(2):** 130-140.

Saradj F. M. (2011), *Prioritization of Historic Buildings Based on Their Values*, International Journal of Architectural Engineering and Urban Planning **21(1)**: 17-26.

Serageldin I. (1999), *Very special places: The architecture and economics of intervening in historic cities*, World Bank, Washington DC.

Souami M. A., Zerouala M. S., Ait-Meziane Y. (2016), *The impact of building proportions in the preservation of Algiers architectural* *heritage against the seismic hazards*, Journal of Cultural Heritage **20**: 686-693.

Stepanova K., Rubel O. (2015), *Approaches to natural hazard risk assessment and management in Ukraine*, Journal of Environmental Protection and Ecology **16(3)**: 908-918.

Syrmakezis, C. A. (2006), *Seismic protection of historical structures and monuments*, Structural Control Health Monitoring **13(6)**: 958-979.

Tavakoli B., Ashtiany M. G. (1999), *Seismic Hazard Assessment of Iran*, Annali di Geofisica **42(6)**: 1013-1021.

The Geography Site (2013), *The Richter and Mercalli Scales*, http://www.geography-site.co.uk/pages/physical/earth/richt.html

Theodossopoulos D. (2012), *Structural Design in Building Conservation*, Routledge, London.

Throsby D. (2016), *Investment in urban heritage conservation in developing countries: Concepts, methods and data*, City, Culture and Society **7(2)**: 81-86.

Tomazevic M. (1999), *Earthquake-Resistant Design of Masonry Buildings*, Imperial College Press, London.

Tomback D. H. (2007), *Valuing Our Heritage*, In: Forsyth, M. (Ed.), *Structures & Construction in Historic Building Conservation*, Blackwell Publishing Ltd., Oxford, pp. 204-210.

UNESCO WHC [World Heritage Centre]; *Bam and Its Cultural Landscapes*, http://whc.unesco.org/en/list/1208.

USGS (2016), *Magnitude / Intensity Comparison*, http://earthquake.usgs.gov/learn/topics/mag_vs_int.php

Vecco M. (2010), *A definition of cultural heritage: From the tangible to the intangible*, Journal of Cultural Heritage **11(3)**: 321-324.

Vicente R., Parodi S., Lagomarsino S., Varum, H., Silva J. A. R. M. (2011), *Seismic vulnerability and risk assessment: case study of the historic city centre of Coimbra, Portugal*, Bulletin of Earthquake Engineering **9**: 1067–1096.

Viñas S. M. (2002), *Contemporary theory of conservation*, Studies in Conservation **47(3)**: 25-34.

Wang H., Zeng Z. (2010), *A multi-objective decision-making process for reuse selection of historic buildings*, Expert Systems with Applications **37**: 1241-1249.

Zafarani H., Ghafoori S. M. M. (2013), *Probabilistic Assessment of Strong Earthquake Recurrence in the Iranian Plateau*, Journal of Earthquake Engineering **17(3)**: 449-467.

Zhang W., Kockelman K. M. (2016), *Optimal policies in cities with congestion and agglomeration externalities: Congestion tolls, labor subsidies, and place-based strategies*, Journal of Urban Economics **95**: 64-86.

Received: 9 October 2016 • **Revised**: 7 November 2016 • **Accepted**: 14 November 2016