Modern Civil Engineering (ISSN 2470-4180)
March 2025, Volume 5, No. 1-3, pp. 1-10
Doi:10.15341/mce(2470-4180)/01-03.05.2025/001
Academic Star Publishing Company, 2025
www.academicstar.us

Evaluation of Retrofit Interventions in Terms of Seismic Resistance

Gülru Koca

Işık University, Istanbul, Türkiye

Abstract: Historical buildings are being abandoned in many parts of the world in order to meet modern requirements, and these neglected structures negatively affect the urban texture, economy, and social structure of urban area. There is a growing trend towards repurposing historical buildings, which play a crucial role in transferring cultural heritage to future generations. These interventions sometimes involve minor enhancements such as strengthening the structure. However, they sometimes include extensive measures such as adding modern equipment or changing the function of the building. These different scaled interventions influence the building's resistance and can sometimes reduce the earthquake resistance of the building in earthquake prone regions. However, the standards which are used to determine the earthquake resistance of buildings are often based on modern construction techniques. Therefore, it is usually difficult to evaluate the earthquake resistance of historical buildings constructed by using traditional methods. These interventions sometimes negatively affect the historical character of the building as well. In order to preserve the historical and urban texture of cities it is crucial to prevent excessive interventions and to carry out these interventions in a controlled manner. This study evaluates the preservation and improvement interventions which are carried out in earthquake-prone regions.

Key words: historical buildings, traditional construction techniques, heritage protection, intervention, seismic resistance

1. Introduction

Historical buildings hold significant cultural, social, and economic importance for all cities. However, as cities develop and expand, these structures are often abandoned because they can no longer meet modern needs. The abandonment of historical buildings harms cities in different ways. The abandonment of historical buildings in urban centres results with an economic loss due to the inefficient use of valuable land. Moreover, as these buildings often have historic and touristic value, it negatively affects the cultural heritage and touristic value of the region. These outcomes collectively contribute to the deterioration and desolation of valuable and tourist-attractive urban areas. The economic and tourism-related policies are also adversely affected.

Corresponding author: Gülru Koca, Associate Professor; research areas: interior finishing materials, properties of building materials, timber building materials, evaluation of building materials. E-mail: gulru.koca@isikun.edu.tr.

There has been a growing emphasis on the preservation, improvement, and repurposing of historical buildings in recent years. Various projects, ranging in scope, have been undertaken for this purpose. While some historical buildings are reintroduced into the building stock with minor interventions, others undergo excessive interventions, including change of function.

In the improvement of historical buildings, the primary focus is on addressing the lack of modern technology and evaluating the specific construction needs of the region. The priority of these interventions is to provide modern requirements by adding systems such as plumbing and HVAC. Another common intervention in this type of projects is the addition of vertical circulation elements like elevators.

Another crucial consideration during these interventions, particularly in cities with touristic value, is the region’s needs. The residential buildings in tourist-heavy city centres usually loose comfort due to the surrounding tourist activities, creating a demand for

accommodation structures. Consequently, the improvement processes of historical buildings in city centres frequently involve functional changes, converting residential buildings into accommodation facilities.

Adding modern systems and changing function of historical buildings increase the scale of interventions and result with uncertainties about the resistance of structural system. Therefore, it is crucial to determine the structural resistance of historical buildings before retrofitting interventions. The evaluation of structural resistance is particularly important in earthquake-prone regions. The effect of retrofitting interventions needs careful consideration on previously earthquake-damaged buildings. The impact of these interventions on the historical character of buildings is another critical aspect that requires attention. This study evaluates the effect of interventions on historical buildings in earthquake-prone cities.

2. Historical Buildings and Interventions

The preservation of historical buildings is crucial for the protection and transmission of cultural heritage. Ensuring the sustainability of these buildings is necessary for the preservation of cultural identity and transmission of historical and cultural knowledge to future generations [1].

However, historical buildings, equipped with the technology of their construction period, cannot meet the requirements of the modern world. This leads to either their abandonment (Fig. 1) or their improvement through the addition of modern systems to repurpose them.

Fig. 1 Abandoned buildings in Tarlabaşı, İstanbul [2].

When preservation and improvement practices of historical buildings are carried out with respect to the urban fabric, original function, material and technique, the built environment offers a greater opportunity to

understand the past. Carefully carried out improvements result with harmonious results with both the urban and historical fabric. On the other hand, improvements made solely to meet current requirements often result in practices that do not align with the concept of preservation [1].

Throughout history, the preservation of historical artifacts has involved interventions at various levels. Nonetheless, all preservation guidelines emphasize that the most valuable practices are those that preserve the structure with minimum intervention [1].

Excessive interventions can negatively affect both the authenticity and resilience of the buildings. In earthquake prone regions, the effects of these interventions on the structural resistance must be thoroughly examined.

2.1 Types of Interventions

There are several international charters that define the scope and limits of preservation for historical buildings. These charters, which are produced for use in the conservation and restoration processes of monuments, historical sites, and buildings, provide definitions for the levels of interventions carried out on structures [3].

According to the Burra Charter, which is the latest updated agreement that sets forth the conservation principles, there are different levels of interventions used in the preservation of historical buildings which can be described as follows:

- Maintenance: Maintenance is the fundamental principle of preservation. Periodically maintaining the building and its surroundings (i.e., regular inspection and cleaning) is essential for sustaining the cultural value of the structure and delaying potential deterioration [3].
- Repair: Buildings age with the effect of various factors and inevitable deterioration occurs in time. Repair involves replacing the worn and deteriorated parts of the building with new ones [3].
- Renewal: Renewal includes the revitalization of the building and the implementation of measures aimed at bringing it back to life [3].
- Reuse: The scope of architectural preservation is continuously evolving to ensure ongoing urban development and sustainability in the built environment. This includes preventing the abandonment of buildings and reintegrating them into active use. Repurposing the historical buildings with compatible functions (Figs. 2 and 3) is within the concept of reuse [3].

Fig. 2 Adaptive reuse of an industrial building, New York [4].

Fig. 3 Adaptive reuse of a railway as an urban area "High line", New York [5].

- New Design: New design refers to the redesign of historical buildings. New design emphasises on minimal intervention to the structure. It also highlights that the impact of these interventions should have minimum impact on the surrounding urban environment. Several other charters, in addition to the Burra Charter, provide guidelines related to this topic.
  - Athens Charter, Article 3 (ICOMOS 1931): The construction must respect the character of its environment. Particular attention should be paid in areas which include monumental buildings [6].
  - Venice Charter Article 13 (ICOMOS 1964): The distinctive features of the building should not lose their authenticity, the traditional character should not be altered, and the existing balance and harmony with the environment should be maintained [7].
  - Washington Charter (ICOMOS 1987): Emphasizes the importance of the spatial organization of the building, especially concerning scale and spatial dimensions [8].
  - Burra Charter (ICOMOS 2013): New additions should resemble the original parts of the historical structure [3].

As shown in Fig. 4, the level of interventions used in the preservation of historical buildings increases from maintenance to new design.

All charters indicate that interventions should be minimized to preserve the authenticity of historical buildings and maintain the harmony of the existing urban fabric. Keeping interventions at minimum is also important for preserving the multi-layered nature of buildings and the urban fabric formed in time [1].

Minimal intervention is also an important necessity in the preservation of the intangible values of the region. Protecting the urban scale, preventing irregular development, and enhancing the life quality of local

community are prioritized in the preservation of the intangible values. This approach aims to improve social and environmental features of the region [9].

However, there are some features that affect the determination of the level of interventions.

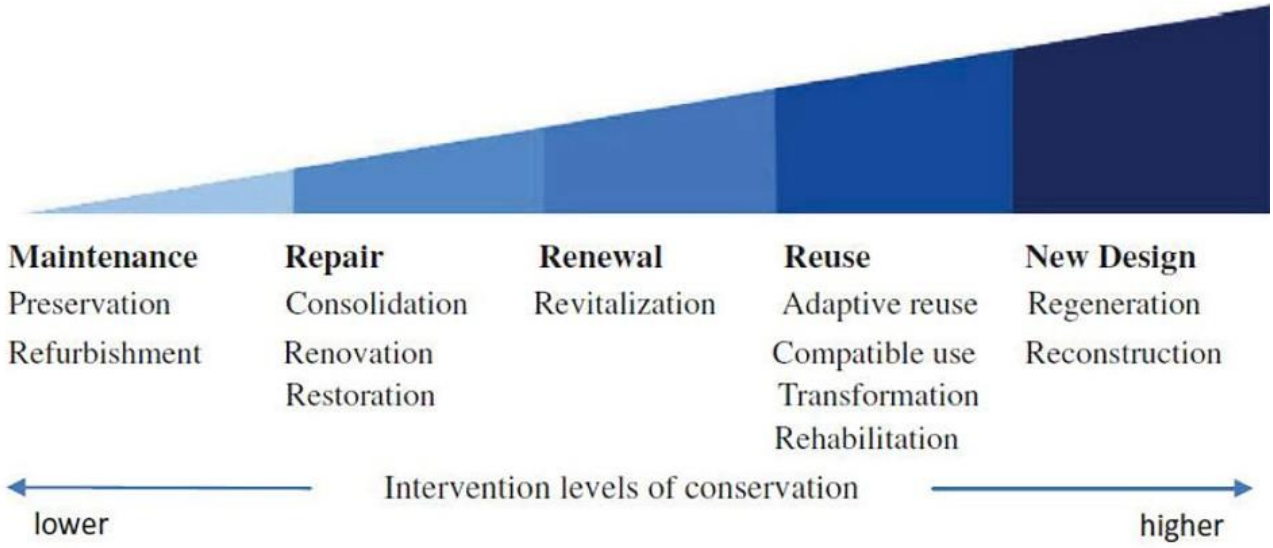

Fig. 4 Levels of conservation interventions [3].

3. Factors Affecting the Level of Interventions

The level of interventions in historical buildings is affected by some features which can be stated as follows:

- The identity of stakeholders,
- The type of building,
- The need for functional changes,
- Protection against risks (natural disasters, etc.)
- The cost of preserving and improving [1].

One of the most significant factors in the improvement of historical structures is the identity of the stakeholders. As stakeholders have a participation in preservation decisions, they are the most influential group in determining the outcomes of improvement efforts. Therefore, the identity of these groups must be clearly identified. Various stakeholder groups participate in improvement projects. Politicians and investors are the most powerful groups as stakeholders. Professional groups and communities working in the preservation field are the ones expected to provide the most input. Balancing the participation and suggestions of stakeholder groups is crucial for ensuring a high-quality preservation outcome. It is crucial to focus on stakeholders, establish balanced management, and consider the opinions of local community to enhance participation in preservation and improvement efforts [10].

The characteristics and components related to the function of the building are also important. Improvement policies differ for different types of buildings such as industrial, commercial, residential, cultural, and governmental buildings. Additionally, the surrounding fabric of each structure differs in its characteristics. The urban fabric surrounding the historical building should be protected by urban policies. The historical and cultural heritage value of the building should be comprehensively examined, ensuring that the preservation outcome meets the social needs and physical characteristics of the region. Components such as the structural system and materials also important in the determination level of proposed interventions [1].

Changes in the building's function are among the most effective factors on the level of interventions.

Repurposing a building designed for residential use into an accommodation facility or an office may lead to many interior space arrangements, which can affect the building's structural system. In the improvement of buildings which require functional change, it is essential to adopt designs compatible with the existing structural system and plan layout in order to achieve minimal intervention [1, 11].

Predicting the behaviour of historical buildings against the effects of disasters and correctly planning risk management is another important factor that affects the level of intervention. A key consideration about seismic resistance of historical buildings is the lack of compatibility between modern and traditional construction techniques. This can cause some structural problems during the improvement process in buildings constructed with traditional methods [1, 12].

Economic factors are another significant feature in the preservation and improvement of historical buildings. The method used for accurate valuation, budget determination, and resource procurement is important. However, although any economic value not synonymous with commercial value can be numerically expressed, especially in the context of cultural heritage artifacts, the direct use value of the property and the resulting non-market value are also included. Therefore, valuing cultural heritage is quite challenging. Cultural value is a multidimensional, uncertain, and potentially contentious issue, making it difficult to express the value of a historical artifact in qualitative and quantitative terms [13].

Each of these factors is important from different perspectives when determining the intervention level in preservation and improvement projects. However, in earthquake prone regions, the seismic response of the building should be accurately predicted. Besides the intervention studies which are proposed for functional change should be carried out more carefully. Extensive interventions in historical buildings not only create uncertainties regarding earthquake resistance but can also negatively impact the surrounding urban fabric and the economic sustainability of the region if not accurately foreseen.

4. Effect of Interventions on Seismic Resistance and Ways to Mitigate These Effects

Extensive interventions primarily affect the load-bearing capacity of the building, which is exposed to various environmental factors over many years, and subsequently affect the urban fabric and economic sustainability of the region. When these three features come together, buildings with uncertain seismic resistances, an urban fabric that has lost its authenticity and an economically undervalued region emerge.

The long service life of historical buildings proves the high resistance values of these buildings. However, all structures are inevitably affected by the aging process over time. During this process, buildings are affected by the deterioration in materials, human factors, climatic and environmental changes. Therefore, all buildings should be periodically inspected with qualified visual inspections and appropriate experimental methods throughout their service lives. This approach can delay the effects of aging and protect the buildings from significant damages [14].

However, earthquakes cause the most substantial damages to masonry buildings (Fig. 5) and the long recurrence periods of destructive earthquakes make it difficult to evaluate the seismic resistance of buildings. Obtaining structural information such as the material properties and construction details which are used in these buildings without causing damage is also difficult. Consequently, determining the seismic resistance of historical buildings is challenging [14, 15].

Preservation and improvement work in historical buildings sometimes increase uncertainties regarding seismic resistance. Interventions which include

Fig. 5 Ulu Mosque after earthquake, Kahramanmaraş [16].

functional changes often require significant architectural and structural modifications, Additional loads such as additional storeys or structural changes for expanding ground floor areas mat affect the structural properties of buildings [17, 18].

Recent earthquakes have proven that strengthening interventions are often ineffective and some interventions particularly negatively affect the buildings' seismic behaviour. Besides, post-disaster restoration interventions frequently include strengthening and partial reconstruction of buildings, which negatively affect the building's authenticity as well. Strengthening interventions which are carried out according to existing building codes are unsuitable for historical buildings as these codes are produced with an overly protective approach and simplify complex system of historical buildings [14, 17].

Solving this type of important problems and reducing the risk in heritage buildings requires adopting an appropriate method. The intervention method should be chosen according to the structural features of the building. likely to be affected during an earthquake, and interpreted specifically for the structure, avoiding an overly protective approach based on standardized methods designed for modern construction techniques.

Before starting the improvement work, the history of the building should be researched, as it contains essential information for the proposed interventions. Then, a detailed examination of the building should be carried out. This stage should identify the building's structural features, surrounding factors, and existing deterioration and damages. This examination often involves non-destructive and semi-destructive tests, which help to locate the hazard. After obtaining this information, the material characteristics and deterioration morphologies should be analyzed [18].

Following these general evaluations, a method for improvement should be determined based on the set objectives, which include user safety, maximum preservation of cultural and artistic contents, and maintaining the building's integrity as a cultural heritage object [18].

The chosen method should prioritize minimal intervention while ensuring maximum preservation. The interventions should be compatible with the building's existing features, removable and should not hinder future interventions [18].

In order to increase the seismic resistance of existing buildings some improvement methods can be carried out. the US Federal Emergency Management Agency simplified and presented these methods in the "Guidelines for the Seismic Rehabilitation of Buildings". According to this guideline, the possible interventions for seismic improvement can be summarized as follows [19]:

1) Local Modification of Components: Buildings with high resistance and stiffness may have elements lacking sufficient strength, toughness, and deformation capacity. Regional improvements can address these deficiencies to prevent important problems during an earthquake. Local improvements can increase the material or component's resistance against the earthquake loads. In this way, the deformation capability and ductility of the component can be increased locally and it can be ensured that it can resist large deformation levels during an earthquake [19].
2) Removal or reduction of existing irregularities and discontinuities: Irregularities in the

building's stiffness, weight, and resistance significantly affect seismic performance, leading to structural instability. Structural reinforcement with frames and shear walls can improve soft or weak stories. Partial demolitions, such as removing additional floors and side wings, can also be an efficient improvement method, although they will alter the building's appearance [19].

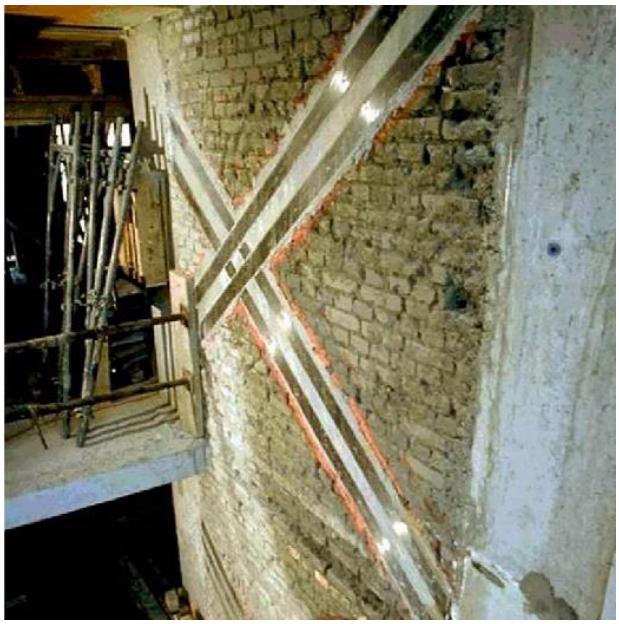

Fig. 6 Seismic retrofitting with fiber reinforced polymers (FRP) [20].

Fig. 7 Seismic retrofitting of a soft story, San Francisco [21].

3) Structural Stiffening: Flexible structures may not show adequate resistance to lateral deformations due to insufficient ductility and stiffness of structural components. Increasing the building's stiffness is a common method to prevent this kind of problems. Usually, braced frames and strengthening connections between building elements are used for this purpose [19].
4) Structural Strengthening: Buildings with weak lateral force resistance can come across with adverse effects even during very low levels of ground movements. Adding shear walls and braced frames can provide additional resistance. However, care must be taken during these interventions in historical buildings, as increasing stiffness in one part can negatively affect the building's overall seismic behaviour. Having a certain flexibility and deformation capacity in the structure helps to dissipate the seismic energy [19].
5) Mass Reduction: The loads and deformations experienced by buildings during an earthquake are proportional to their weight. Reducing the building's weight lowers the risks. This can be achieved by removing added floors, heavy exterior cladding, interior partitions, stored loads, and technical equipment. Care must be

taken to ensure that removed elements are not historically significant [19].

6) Seismic Isolation: It involves flexible supports placed between the building's foundation and superstructure, which absorb ground energy and prevent deformation in the upper part of the building. While seismic isolation is effective for buildings with heavy and stiff buildings, it is not suitable for light and flexible structures [19].
7) Supplemental Energy Dissipation: Special devices mounted to the building can distribute and control seismic energy. Supplemental energy dissipation devices undergo significant deformation during an earthquake, and the building is expected to experience considerable lateral displacements. Therefore, they are not suitable for light and flexible structures [19].

These solutions should be evaluated according to the structural and material characteristics of the historical building, aiming for minimal intervention and maximum preservation.

5. Conclusion

The revitalization of historical buildings, which significantly impact the city's skyline, fabric, tourism potential, and economic sustainability, has become a widely preferred urban planning practice in recent years. However, it is crucial that these buildings are not subjected to extensive interventions, especially in earthquake prone regions.

Extensive interventions during improvement works can negatively affect their seismic resistance in earthquake prone regions. Buildings that undergo functional changes and the addition of modern equipment such as elevators often experience uncertainties in resistance due to the inclusion of modern materials like concrete and comprehensive renovations. Therefore, it is important to develop an efficient and safe method to enhance the seismic resistance of these structures.

Interventions which are carried out to improve the seismic resistance of historical buildings usually use methods developed for modern construction systems. However, modern codes frequently proved to be ineffective for the complex structures of historical buildings and can sometimes even have adverse effects.

In the process of strengthening interventions, firstly the history of the building should be examined and evaluated. The current condition of the building, including decay and damage, should be identified using various methods. Following this evaluation, a suitable improvement method should be selected and carried out.

US Federal Emergency Management Agency simplifies and suggests different improvement methods in order to increase the seismic resistance of historical buildings. Among these methods, one or more, suitable for the building's construction technique, can be chosen and applied. US Federal Emergency Management Agency briefly recommends:

- minimal intervention to the building,
- local modification of load-bearing elements,
- strengthening methods to enhance resistance to lateral forces,
- removal of additions that increase weight,
- use of additional systems for more effective strengthening.

When these applications are evaluated and implemented together with the existing characteristics of the historical building, compatible solutions with the existing architectural and historical fabric can be achieved. More importantly, the seismic resistance of the region can be increased.

References

[1] Zhang Y., & Dong. W (2021). Determining minimum intervention in the preservation of heritage buildings, *International Journal of Architectural Heritage* 15 (5) 698-712.

[2] 52 Suburbs around the World, 2012, accessed on 07.06.2024, available online at: https://52suburbs.com/wp-content/uploads/2012/03/death-row1.jpg.

[3] ICOMOS, Burra Charter, the Australia ICOMOS, Charter for places of cultural significance, 2013, available online at: http://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf.

[4] Perkins Eastman, Empire Stores Brooklyn, 2020, accessed on 07.06.2024, available online at: https://www.perkinseastman.com/wp-content/uploads/2020/10/Empire-Stores_58000.00.9_Ext-Courtyard-Staircase-2-1065x710.jpg.

[5] The High Line, 2024, accessed on 07.06.2024, available online at: https://www.thehighline.org/visit/.

[6] ICOMOS, The Athens charter: The restoration of historic monuments, 1931, available online at: https://www.icomos.org/en/167-the-athens-charter-for-the-restoration-of-historic-monuments.

[7] ICOMOS, Venice Charter: International charter for the conservation and restoration of monuments and sites, in: *Second International Congress of Architects and Technicians of Historic Monuments*, 1964, available online at: https://www.icomos.org/images/DOCUMENTS/Charters/venice_e.pdf.

[8] ICOMOS, Washington Charter: Charter for the Conservation of historic towns and urban areas, 1987, available online at: https://www.icomos.org/images/DOCUMENTS/Charters/towns_e.pdf.

[9] Bullen, P. A., & Love, P. E. (2011). Adaptive reuse of heritage buildings, *Structural Survey* 29 (5) 411-421.

[10] Mason R., & Avrami E. (2002). Heritage values and challenges of conservation planning, *Management Planning for Archaeological Sites* 13-26.

[11] Loulanski, T. (2006). Cultural heritage in socio-economic development: local and global perspectives, *Environments: A Journal of Interdisciplinary Studies* 34 (2).

[12] Taboroff, J. (2000). Cultural heritage and natural disasters: incentives for risk management and mitigation, *Managing Disaster Risk in Emerging Economies* 2 71-79.

[13] Throsby, D. (2003). Determining the value of cultural goods: How much (or how little) does contingent valuation tell us? *Journal of Cultural Economics* 27 275-285.

[14] Mavroulis S., Alexoudi V., Grambas A., Taflampas I., Lekkas E., & Carydis P. (2019). Protection of historical structures and interventions for repair and strengthening with emphasis on anti-seismic conservation, in: *Structural Analysis of Historical Constructions: An Interdisciplinary Approach*, Springer International Publishing, pp. 2133-2141.

[15] Tarım, A., & Hattap Onat, E. S. (2018). *Approach on Preservation of Cultural Heritage against Disasters, Kerpiç'18 Back to Earthen Architecture: Industrialized, Injected, Rammed, Stabilized*, p. 169.

[16] CNN Türk Official, Kahramanmaraş'ta tarihi cami depremde yıkıldı, accessed on 07.06.2024, available online at: https://www.cnnturk.com/turkiye/kahramanmarasta-tarihi- cami-depremde-yikildi.

[17] Ferah F. E. (2009). 1755 Lisbon earthquake and protection of cultural heritage from future earthquakes: With a comparative study about earthquake and risk preparedness in Istanbul, master's thesis, Universitat Politècnica de Catalunya.

[18] Roca Fabregat, P. (2021). The ISCARSAH guidelines on the analysis, conservation and structural restoration of architectural heritage, in: *SAHC 2021: 12th International Conference on Structural Analysis of Historical Construction*, International Centre for Numerical Methods in Engineering (CIMNE), pp. 1629-1640.

[19] US Federal Emergency Management Agency (FEMA) (1997). *Guidelines for the Seismic Rehabilitation of Buildings*, FEMA, NEHRP, Washington, DC.,.

[20] Gkournelos, P. D., Triantafillou, T. C., & Bournas, D. A. (2022). Seismic upgrading of existing masonry structures: A state-of-the-art review, *Soil Dynamics and Earthquake Engineering* 161 107428.

[21] Build LLC, Shearwalls 101: Why you can't have a window there, accessed on 07.06.2024, available online at: https://blog.buildllc.com/2014/05/shearwalls-101-why-you-cant-have-a-window-there/.