DOI: 10.38027/ICCAUA2022EN0003

The role of Structure and Structural Analysis in Adaptive Reuse of Zahir-ol-Islam Historical House in Tehran, Iran

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Abstract
Adaptive reuse of historic buildings is a way of conservation provided for the rehabilitation of historic cities. It helps to revive the heritage value and the integrity of buildings' compatibility with the contemporary needs of the community. Through this process, historic buildings will renew their physical characteristics to adopt new functionality. Therefore, the necessity of analysis and evaluation of building" statements shows the essential practices that need to be taken to confirm new uses for the buildings. This study aims to investigate the structure of the Zahir-of-Islam historic house to initiate the adaptive reuse project through an analytical study of structure and fabric. Using qualitative research methodology, this study concludes that the structure of the historic house of Zahir-ol-Islam can be reused with multifunctional, cultural new services to be rehabilitated.
Keywords: Zahir-ol-Islam Historic House; Adaptive reuse; Structure of heritage buildings; Structural analysis.

1 Introduction

Iranian cities' historical and cultural fabrics and centres are fraught with valued buildings that confront erosion and decline because of ignorance. Rehabilitation of historical buildings that have lost their original functions and remain as a solid fabric with new uses will help create a bond between past inheritances and reduce ancient experiences (Fakhaari Tehrani et al., 1993). Considering the immense changes in communities, the construction and design methods should be upgraded alternately to meet the modern requirements of society. Therefore, heritage buildings are necessary to be rehabilitated in the new era since they are a symptom of the past. Hence, they must be conserved instead of demolished to be the manifestation of a nation's ancestors and cultural lives. Also, conserving historic buildings and granting new uses according to their location, dimension, and possibilities cause a better understanding for future generations (Misirlisoy & Gunce, 2016, Al-Dujaili & Amen, 2018, Aziz Amen & Kuzovic, 2018). Nowadays, the conservation of historic buildings and structures has been altered from mere preservation to conservation and has been retained as a comprehensive urban regeneration and sustainability strategy. In this case, most cultural heritage professionals believe that adaptive reuse made a solid strategy to control the change in urban environments. In these circumstances, adaptive reuse of a heritage building is a challenging process since the heritage values, physical characteristics, and potentials of the heritage building should be well analyzed holistically (Günce & Mısırlısoy, 2014). Having an entirely free hand in the election and deciding on a new function of the historic structure is one of the main challenges in adaptive reuse projects without a deep and holistic review of and building's structural condition. Thereby, the determination of the new function would be based on scientific and analysis methods, which consider the best strategy for adaptive reuse projects. Nonetheless, after a while, the historic building would become impracticable in case of social and economic issues, or the new use will destroy the authenticity of the heritage.

2 Material and Methods

Structural analysis of architectural buildings, specifically the historic buildings with a heritage significance, needs to be carried out in qualitative and quantitative methods during research. While an expert in structural engineering might be a more suitable option to measure the quantity of pressure and forces a structure load, conservator professionals can better understand the loads transferred to the earth. This paper studies the adaptive reuse process of the Zahir-ol-Islam historical house in two phases. In the first part, the study is devoted to investigating the role of structure through analytical studies of heritage buildings to reuse them with contemporary functionality. For this purpose, studies emphasize structural challenges faced in adaptive reuse projects and consider complained theoretical framework adapted from Clark's (2008) research. During this phase, necessary challenges in assessing structural analysis have been acknowledged. Later, the result of the investigation in the former part was used in the case study, Zahir-ol-Islam historic house. Here, after a holistic recognition of the building through a field survey,

other assessments such as reconsideration of the structure and fabric of the building, analysis of the static loads, and tangible damages to the building have been considered to proceed with the adaptive reuse project.

3 Adaptive Reuse of Historic Buildings

Sensitive people about heritage buildings prefer to restore historic structures and retrieve their original glory and condition in the past. However, the costs of renovation practices mostly lead to vain, and Buildings' planning and design processes may seem redundant for various reasons, such as changing economic and industrial practices, demographic shifts, and increasing cost of upkeep or maintenance (Orbaslı, 2008; Aziz Amen, 2022). Despite this reason, there is a need for new preservation, renovation, and adaptation strategies for the cultural heritage with its broad physical, diverse, and intangible components. In order to preserve cultural heritage, the Council of Europe has proposed that new uses be provided for protected buildings so that they can be adapted to meet modern-day needs in terms of living. Hence, an adaptation of old buildings for new uses and an integration of protection requirements with the requirement of economic, social, and cultural activities of modern times are essential. The replaced concept for this plan is an adaptive reuse of heritage buildings (Girginkaya Akdağ & Sayar, 2020:38). Adaptive reuse is a process in which appropriate historic buildings condition for new considered function. It also helps heritage buildings to retain and conserve their historical integrity while responding to modern necessities for contemporary inhabitants. In this situation, if the building stock's life is more prolonged than sustains its function, adaptive reuse with a new function is inevitable. However, the proposed new use must be appropriate in preserving the historic fabric's cultural significance. Thereby, when heritage buildings are adapted for different functions, the new use and the interventions should maintain the originality and architectural character of the building to not give wrong or missing information for the further generations (Misirlisoy &Gunce. 2016).

Orbasli (2009) defines adaptive reuse as an activity which, with change in structure and physical fabric of heritage building and adapting new contemporary use for it, cause to retain building's heritage values. The adoption can consist of; originating new services or functions or a set of changes that occurred in a building or a structure or historic ensembles to safeguard and preserve it. To be more precise, suitable adoption is an activity sympathetic to a historic building and its context with a new use that reinforces the structure with recent changes and adds a layer to valuable layers of the building (Orbasli, 2009; Ghasemi & Ozay, 2018). In this regard, adaptive reuse may help communities, governments, and developers in the quest to reduce the environmental, social, and economic costs of continued urban development and expansion (Ball, 1999; Wilkinson and Redd, 2008; Bullen and Love; 2009). Also, adaptive reuse can transform heritage buildings into accessible and valuable places as well as provide the added benefit of regenerating an area in a sustainable manner. This practice of conservation involves converting a building to undertake a use change required by new or existing owners (Latham, 200; Minkinson et al.; 2009). Although, the new use adaptation requires refurbishment and/or complete renovation of existing buildings or structures. Next, changes to facilities can involve major internal space organization and service upgrades or replacements. Alternatively, adaptive reuse may require minor restoration works where nothing changes except the building's function. When adaptive reuse is applied to heritage buildings, it retains the structure and conserves the original builders' effort, skill, and dedication (Love and Bullen, 2009). Adaptive reuse also conserves the architectural, social, cultural, and historical values (Latham, 2000). All in all, the practical outcomes of adaptive reuse and the conceptual importance of conservation support the reuse of heritage buildings as a sustainable strategy. Cooper (2001) suggests that the effects of adaptive reuse include improvements in material and resource efficiency (environmental sustainability), cost reductions (economic sustainability), and retention (social sustainability) (Bullen & Love, 2011).

During an adaptive reuse project, the condition of the historical pattern must first be assessed, and a conservation plan must be coordinated with a management plan (Yıldırım, 2012). Adaptive reuse is a complex process that requires participants to clearly understand how to determine the most appropriate future for the building in a particular location and time (Kincaid, 2002). It can also transform heritage buildings into accessible and useable places and provide the added benefit of regenerating an area in a sustainable manner (Bullen & Love, 2011). Therefore, rather than replacing buildings, reuse is generally the most resource-effective strategy to provide accommodation, especially if a conservation strategy is incorporated into the design (Ball, 1999; Douglas, 2002). The most successful adaptive reuse projects respect the heritage significance of the building and preserve it since this project adds new valued layers in the current condition and transfers new values to future generations (Hein &others, 2008). In order to implement a reuse project for historic buildings, Fuentes (2010) proposed a method with six successive steps. This method is universal and can apply to different types of buildings, from historic industrial buildings to social, residential, etc. (Figure 1). In this diagram, an assessment of the structural condition and physical maintenance of a historic building is placed as the first step in "Preliminary Studies" to initiate an adaptive reuse project (Hussein, 2017: 26).

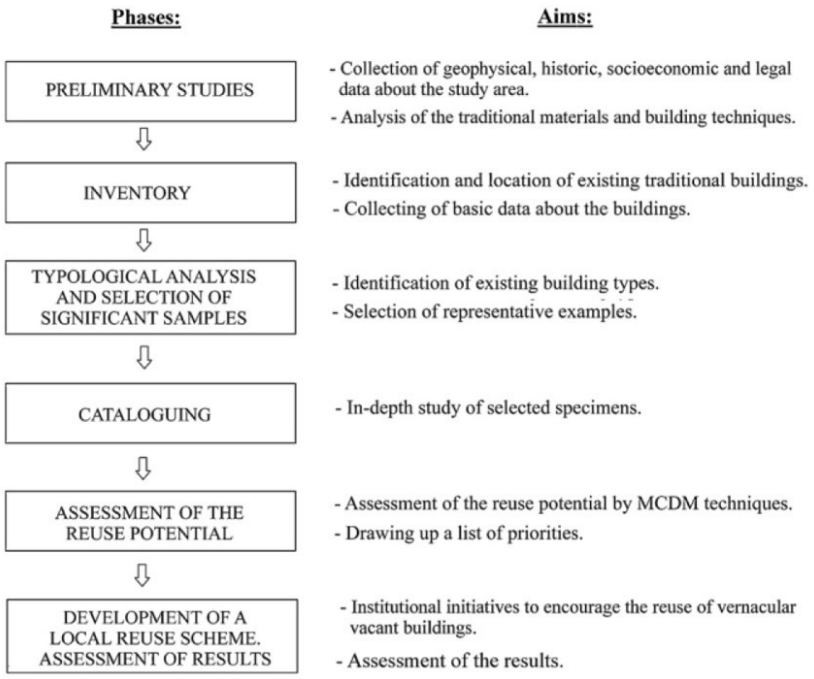

Figure 1. Process of documenting Adaptive reuse process for historic buildings, Source: Hussain, 2017.

3.1 Adaptive Reuse of Building Challenges and Opportunities

Understanding the cultural significance of a place is one of the worldwide admitted principles of heritage conservation. According to the Burra Charter (1996), to understand the cultural value of a heritage place, that place should have an adaptive use with its structure and physics. Hence, adopted functions should respond to the modern community's needs as well as maintain its cultural significance with the help of minor changes in valued structures, details, and historical place settings (ICOMOS, 1996). The result is only available with historical and structural analysis of the building. Therefore, adaptive reuse does not mean conformity with strict conservation regulations; instead, it involves extensive solutions after revealing accurate analysis, evaluation, and consistent heritage interpretation in planning challenges of the design process.

Using a historic structure or a heritage building fabric helps reduce the building's rubbish; material and man work as much as possible. Also, it helps to maintain and conserve the structural integrity and structure of the building, leading to the survival of its historical values and meanings. Thus, it helps create environmental, economic, and social sustainability in rehabilitating historic buildings and cities. While the general essence of adaptive reuse projects since they need to be confirmed with the existing structure and the necessity of conserving them, most often, these actions are more costly than destroying and rebuilding processes (Old Buildings, New uses, 2005).

One of the most critical determinations of reuse success is the structural integrity of the building. Any adaptive reuse or change in the use of a building requires a proactive look at the structure. In this case, how a building or conservator responds to the following questions straightforward the needed treatments in adaptive reuse projects:

- Will the structure experience new loads?
- Are structural modifications necessary?
- Will there be new openings and penetrations?
- What is the impact of mechanical systems, and will they force any structural changes?

Many historic buildings are designed to respond to the construction standards. Structural analysis of building materials should be completed; hence the indicators and measures confirm the minimum safety obligations in changing the function of buildings. During the adaptive reuse process, the internal space of the building is most often built from the beginning and replaced with new materials and suitable design with new function necessities. New openings on the floor, additional load bearings, and general changes in the building are prevalent. Usually, supportive, innovative solutions are necessary for continuous changes even during the project (Clarck, 2008).

According to the restoration codes and regulations, construction building standard methods are likewise utilizing temporary structures and contemporary attachments to the historic building such as handicap accesses, mechanical system installations for heat, lighting devices, etc. Besides structural challenges like evaluating foundation strength, prospering and diminishing historic building's foundation, and transformation in skeleton includes structure repairer, conservation or reconstruction of enveloping systems. These challenges are the main issues contractors confront within the adaptive reuse process (Adaptive reuse of historic structures, 2014).

As an example, in adaptive reuse projects, in envelop system of a building (including roof, windows, doors, upper and lower load-bearing walls), there are just some particular elements that can be replaced entirely, stabilized, conserved, or restored. In many cases, they cannot be seen in a project or participate unless they have significant damages or ruin. The deterioration of fallen elements or their injuries can cause many costs during construction. Yet, heritage buildings have unsafe conditions (Clarck, 2008). Design experts should do a holistic assessment and analysis of building fabric to determine an exact recipe for adopting covering components of the building. Fundamental principles in evaluating the structure encompass a useful building lifetime and ingrained value than anticipated for any construction element, preserving historical systems and components, and authenticated requirements. These principles of time duration considered by the owner for conservation of building are instances that influence structure condition (ibid). In addition to the building envelope, one main aim of a successful adaptive reuse project is to maintain structural and historical integrity. Every adaptive reuse project or alteration in building function requires an active view of a structure. Therefore, the foundation should be studied and considered for evaluating the possibilities and strength of bearing new loads. Temporary structures should also help sustain the building and surrounding buildings during reconstruction. Renewing plumbing, plumber system, ventilation system, and HVAC, lightening and communication systems require complex and delicate operations in historic buildings" existing crust and skeleton (Adaptive reuse of historic structures, 2014).

4 Case Study: The Zahir-ol-Islam Historic House

The historical house of Zahir-ol-Islam is located on the corner of Shahid Ghaedi Street (former Hedayat St.), at an intersection that adopted the house's name crossroad in Tehran city. This house is a palace built during the Qajar period, and its architecture combines Iranian and Foreigner styles with adorable plasterwork. In the early maps of Tehran, the house was located near the first-built connecting network of roads within the borders of the historic city of Tehran. During the Naser Shah Qajar period, this building was located beside the northeast defensive- the wall of Tehran in the middle of city gardens. Nowadays, this house is within the historic fabric of Tehran, which connects current Jomhouri Street and Baharestan Square. So, this house has an excellent location in the city.

Figure 2. Location of Zahir-ol-Islam traditional house in 1956 aerial photography; Source: Cartography institution of Iran

Figure 3. Location of Zahir-ol-Islam traditional house in 2016 aerial photography; Source: Google Earth

There are two separate narratives about the owner. First, it is believed that this house belonged to the '"Seyed Zein-ol-Abedi" Friday pray header known as "Zahir-ol-Isla", Naser-Eldin-Shah's son in law. The other narrative relates its ownership to the army commander, Vali Khan Tonekabon". Thereby, this place has historical, political, social, and authenticity value since it is a house related to one of the constitutionalist leaders. As an example of the Qajar period, residential houses show palaces' transmission and composition with European architecture and its location. Nowadays, this building has been listed as "Zahir-ol-Islam House" in the National Iran list of heritages in Aug,13,2013, with the number 31096 (Domehri, 1391).

Studies show that this building has no inscriptions or plates, determining the construction time. Still, regarding the composition of traditional and European architecture with the existing gable roof in this house, this building belongs to the late years of the Naser-Eldin-Shahs government period. This house has a demonstrative design, and all the places gather around the central salon of the building. Thus, this building had a big yard and a nice basin that had originated from one of Tehran's Qanats. Nowadays, just a part of the yard exists, and the bay has been demolished. In this building with a brick and plaster façade, all rooms look like a fabulous garden long ago. For its decorations, its façade has been ornamented with ample light and shade and colour differences in brick redness and plaster whiteness.

Figure 4. Current situation of Zahir-ol-Islam historic house; Source: Authors

Eskandar Mokhtari, analyzing the architectural styles of eight traditional houses in Tehran, notes the evaluation of Iranian architecture in the Qajar Period in two separate sections the first section, he notes this evaluation related to historical experiments in traditional architecture and its domination of structure sustainability and various forms that promoted and gained perfection. In the latter one, he described it as a gradual bias toward the European lifestyle as well as gradual exclusion against national knowledge in architecture practices and constructions. Also, he addressed the Zahir-ol-Islam historic house as a sample of the latter group, which is related to after the Mashrootiat revolution time. Furthermore, he admitted that the house's architecture resulted from conformity with the European cultural lifestyle, as illustrated in conjunction with the Andaroni and Birooni parts of the building in an integrated place (Hariri &others, 1394).
After all, this house consists of a yard, kitchen and two baths, a cellar and a dining room on the basement floor as Andaroni (Interior Part of the house) and living rooms, bedrooms, and a central place on the ground floor as Birooni (Exterior part of traditional houses in traditional Iranian architecture). Profited decorations in this building include Muslim design paintings on plaster context, plaster works on interior walls and some parts of the roof, and the use of brick in alabaster and faced of the yard and basement plinths of the house.

5 Analyse and assessment of Architectural structure of Zahir-ol-Islam House

During surveys, it has been acknowledged that the Zahir-ol-Islam building has three different structural systems to bear the forces building is confronted. The statical and structural analyses show that this building consists of three structural systems with various but symmetrical stability and bearing capabilities. On each level of this house, there is a unique structure. Like other houses, in the Zahir-ol-Islam traditional house, the Foundations are isolated and consist of rough stones like limestone. The structural system on the basement floor is a composition of vaults and groin with sun-dried bricks. In this level, the downcoming force and load from upper classes and lateral troops have been supported by a quadripartite vault (Taq Chahar Bakshi in Persian) in the central extent room with the help of four columns in for corner and load-bearing walls in the middle of cues. Imported forces in crossing spaces in basement floor, e.g., corridors, granaries, and cellars since of geometrical shape of the room has been covered with barrel-vaults and then with the aid of two side load-bearing walls this load transferred to the foundation and then to earth (Fig 4, second phase of structural system of building).
On the ground floor, the roof covering this level is a wooden beam and pale restrained in each other. A part of the imposed forces and loads are supported by leaning on four wooden columns in four corners of the central place other has been beard by load-bearing walls with masonry, brick, and plaster materials in for a side of the main room led to four separate parts of the house and transmit them to underline structure system. Since it uses material, this structural system has less weight than the basement floor and thus has more freedom to organize the spaces on ground level. It causes us to experience various unique structures at this level. The ground floor openings have been locked with the aid of wooden lintels between bricks and, namely, transfer coming bears to lateral elements and materials of the house (Fig 4, Seventh phase of structural system of building).
The trusses have been settled on the first floor and under the gable roof to construct the envelope skeleton. This section shows a collection of wooden trusses and columns responsible for transferring the loads and imposition forces to lower levels of the building structure. This level's structural system has the minimum weight among other groups and settles in the maximum height (Fig 4, Eighth phase of structural design of building). Generally, the structural system in this house in the primary and older sections is in a hierarchical order that from top to bottom, the load bears rise. The structure has become heavier and more massive, thus strengthening the bear load-supporting systems (Fig 6). Also, this composition with various structural systems allows more optimal exceptional accumulation in the building.
We have faced and attached part of the building in the structural analysis. These attachments that relate to a few decades after the initial construction of a building are on the north and south sides. The extensions are structurally self-independent and do not import any additional load to the original structure of the building. These attachments are on the ground level and settled on the earth; they transfer their loads directly underground. The south side roof of the extensions is a barrel vault, and the iron beam fixed on the lateral load-bearing walls of the North building here attachments is also a stair complex that associates the north façade of the ground floor to the ground and shapes the main entrance of the building in the attachments period.

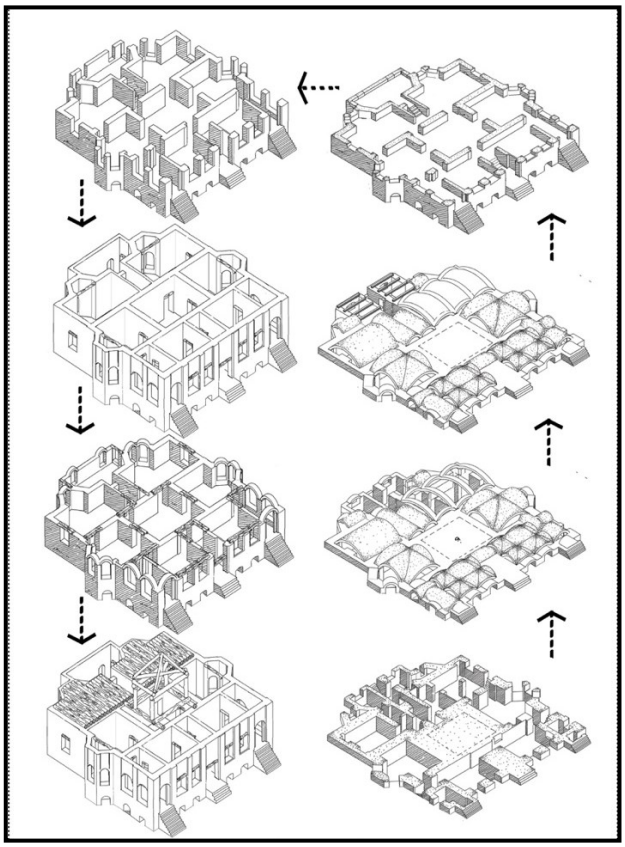

Figure 5. structural analysis procedure in Zahir-ol-Islam historic house from basement to roof; Source: Authors

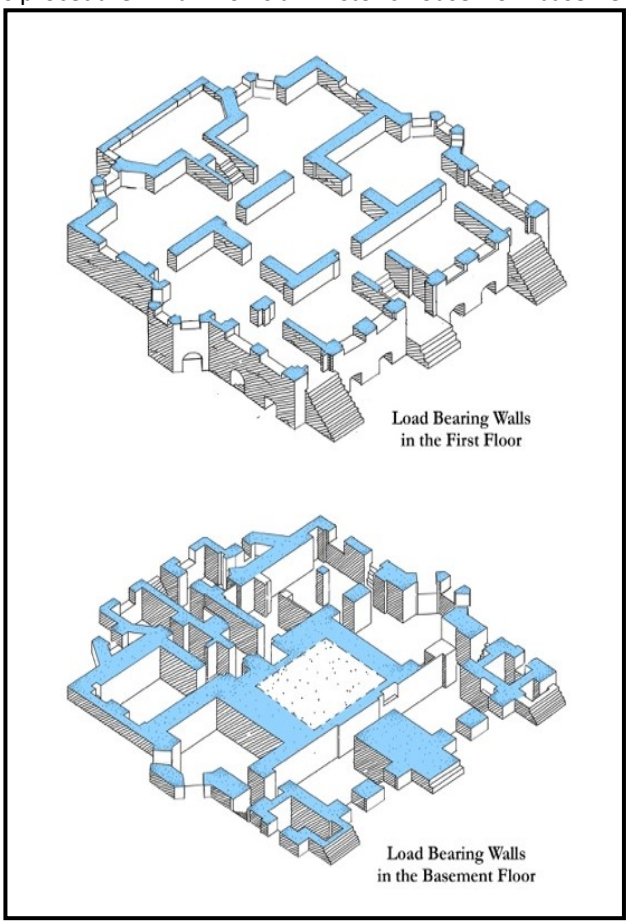

Figure 6. Load bearing and non-load-bearing walls in basement and ground levels; Source: Authors

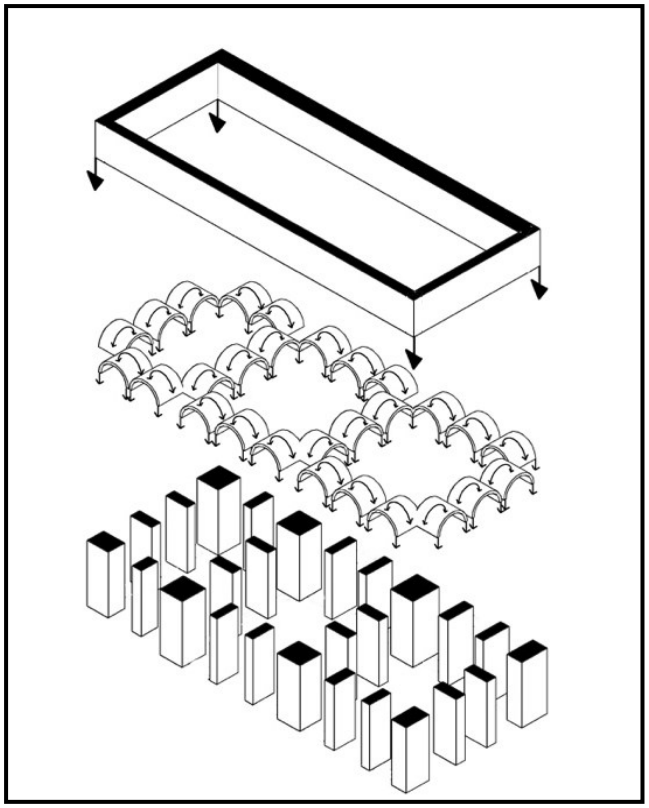

Figure 7. Hierarchical order in the transformation of forces in Zahir-ol-Islam house; Source: Authors

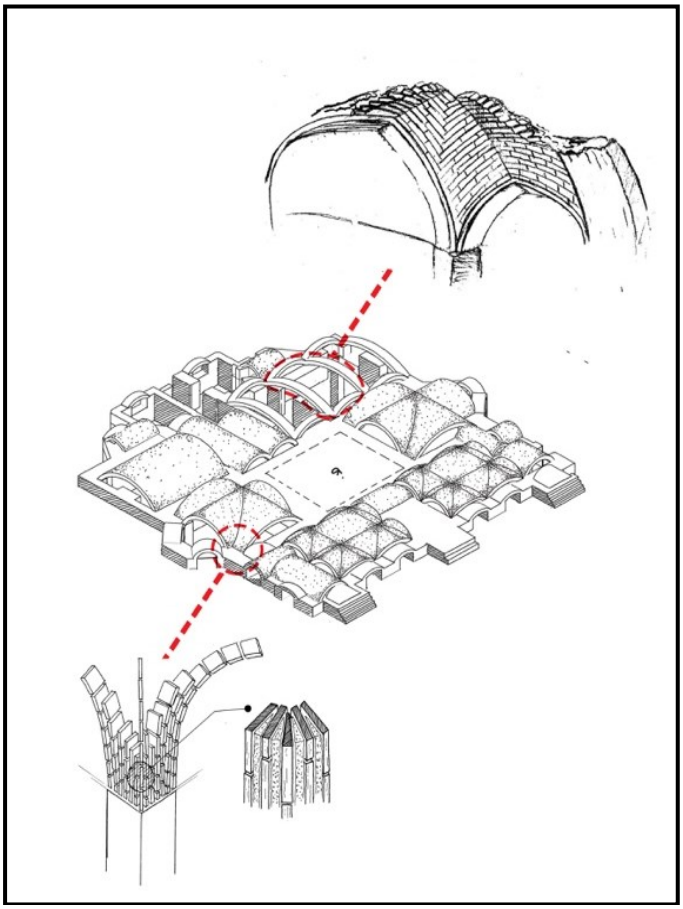

Figure 8. The junction of enveloping and load-bearing walls in basement level; Source: Authors

5.1 Evaluation of Structural System of the Zahir-ol-Islam House

Structural deficits in the Zahir-ol-Islam house constructed with brick, wood, stone, and other masonry materials are included:

- Incomplete load transferring path because of injured materials in roof and walls.
- Unsuitable shear strength of the building.
- Disability of building in maintaining the integrity during the trembling caused by an earthquake and various pollutions.
- Negation of secondary auxiliary system, e.g., systematic horizontal and vertical filature.
- Disorder in the plan after attachments; plan assessment before extensions shows that there are two symmetrical axes in the building, and their intersection is in central space.
- The absence of a suitable foundation to bear the whole loads, considering the construction of the Zahir-ol-Islam isolated foundation, shows that one of the significant damages is a result of unequal subsidence of the building.

In the historic buildings during the construction process, architects rely on their experimental acknowledgements in confronting earthquake distractive forces, as we can call it in a most traditional building. There is no tenacious system between foundation and diaphragms against lateral loads that could transfer earthquake loads from levels to earth. Also, in the case study building, the lateral load-bearing system could not sustain against additional load. Thus, we need to design a new lateral load-bearing system for the house. Regarding the shear strength evaluation of the building, the entire cross-section of walls on each level and along each linear and transversal extension is lower than standard dimensions.

Hence, the fabric of the Zahir-ol-Islam house, especially in the load-bearing and non-bearing walls, crushed mortals, and bricks, are off the wall. Therefore, the load-bearing strength of the elements diminished some tracks can be seen in the building, and therefore many load paths are incomplete.

Figure 9. Some of the damages on the roof of the ground floor in Zahir-ol-Islam house; Source: Authors

6 Discussion on Pathologies on Adaptive Reuse of Zahir-ol-Islam House

Diagnosing the tracks and damages is an important action in a restoration operation. The material spices, contiguity between building components and elements, suitable distribution of forces, foundation strength against loads, accordance between internal parties and material power, etc., are necessary factors and conditions in providing stability, life continuity, and building revival (Mohebali &Mohammadmoradi, 1393). Disturbing elements in heritage buildings can be classified into two orders internal and external factors. In Zahir-ol-Islam traditional house, based on field studies, these factors include:

Figure 10. An example of damages on basement level walls in the Zahir-ol-Islam historic house, Source: Authors

Table 1. Visible damages in the Physical Structure of the Zahir-ol-Islam historic house; Source: Domehri, 1391, p62

Factor	Environmental Factors				Statical Factors				Continental Factors			Ecological Factors
Structural Elements of Building	1 Earthquake	2 Metocamechanical	3 Acoustic Impression	4 winds and Trembling	5 Statical and Foundational structure	6 statical behavior of surrounding buildings	7 Stable pressed Forces	8 Additional Loads	9 Wheater	10 Humidity	11 Temperature	12 Environmental Pollution
Envelop-Roof	◇	◇	●	●	◇	■	◇	◇	■	■	●	●
Roof &Balcony	◇	◇	●	●	●	■	◇	◇	◇	◇	◇	■
Walls &column	●	●	■	●	●	■	◇	◇	◇	◇	◇	■
North Wall	■	■	■	■	■	■	●	●	●	●	●	■
Foundation	●	●	●	●	●	■	●	●	●	●	●	●
Coating &Floor	◇	●	■	●	●	■	◇	◇	●	◇	●	■
Stairs &Trench	●	●	●	■	●	■	■	■	●	●	■	■
Earthquake &Physical body	●	●	●	●	●	■	●	◇	●	●	●	●

■ Limited and local damages ◇ Damage to structure & Foundation ● Continual Damages

Table 2. Some of the visible structural damage in the Zahir-ol-Islam historic house; Source: Authors

Type of Damage	Picture of Damage	Location	Cause of Damage	Structural Damage	Architectural Damage
Collapsed roof		Three-door rooms and rooms in south	Humidity enters the building (caused by rain and snow)	Imbalance and loss of integrity in structure because of material erosion	Erosion in the insulation of the roof and incorrect implementation of dope
Collapsed, cracked &blowing up on plaster and mortar		All rooms in the house	Collapse on the roof and humid entrance	Imbalance and loss of integrity in structure because of material erosion	Diminishing and entrance of humid
Water sign and saltpetre on the walls		Basement level corridors	Entrance of rising and anticlimactic humid	Imbalance and loss of integrity in structure because of material erosion	Erosion in materials and mortar
Cracks on façade walls and plaster		Rooms and saloon on the ground floor	Earthquake and foundation subsidence	Imbalance in structure because of unequal subsidence and damages of the earthquake	Subsidence in-wall foundations and cracks over the walls
leaning on the walls from a vertical position		Side rooms on the ground floor	unequal subsidence of the foundation	unequal subsidence and damages of earthquake leaning on the walls from injunction point	Demolition of roof and walls

7 Conclusions

The permanence of historic buildings' life in an urban context needs a partnership as mediocre in community life. As long as historic buildings remain without a function compatible with a community's modern needs, they will confront erosion and decadence. Therefore, adaptive reuse of historic sites and buildings is a strategy that maintains the historic fabric of the structures by involving them within the contemporary life of society. Thereby, adaptive reuse helps preserve historic assets' historical, physical, social, cultural, and economic integrity. Adaptive reuse is the best choice for the conservation of historic buildings and sites when it conserves the existing values and significance while finding the best solutions for upcoming challenges. Since conservation and continuation of physical integrity and

structure respond to the new bearing loads in the building when granting new uses. However, during the practice of reuse, buildings may need to install new services considering standards and current guidelines to sustain their social, economic, and environmental durability. During the adaptive reuse process, the structural system and the physics of the building areas are the most critical factors in accomplishing changes and interventions since, as well as the effect on the building. Ipso facto, structural analysis and assessment of the condition of a historic building to adopt a new function will clear the primary precautions that must be considered prior to any interventions. By taking these measures, the integrity, historical and structural values of a historic building would be alive while it is ready to answer the modern necessities.

In the case of Zahir-ol-Islam historic house, technical analysis of the building's structures depicts that despite minor cracks, damages, and material lost on the fabric of the building, the architectural structure of the building is capable by itself to accept new multifunction and more culturally oriented use to meet its significance and current needs of the neighbourhood.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare no conflict of interest.

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