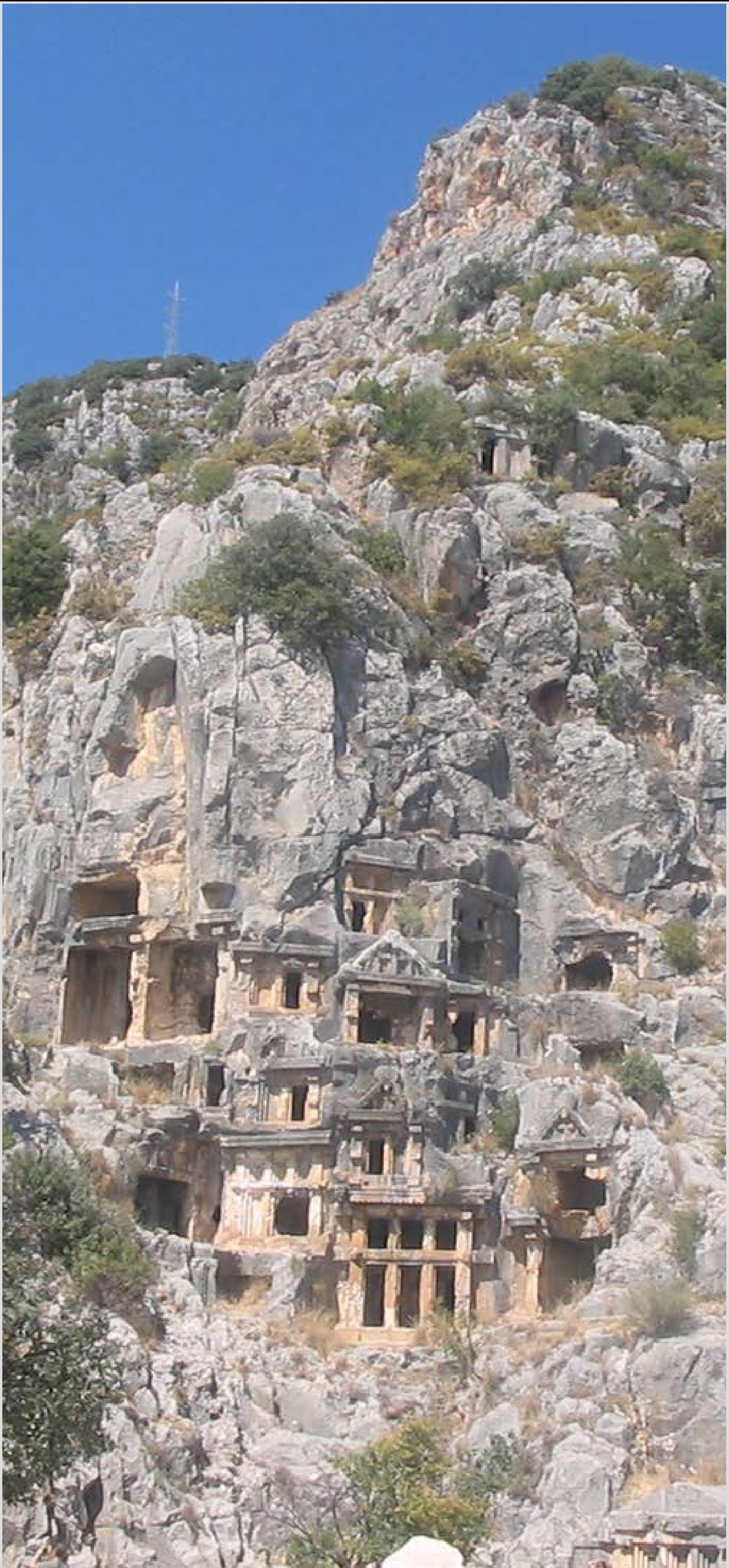
# Inter-ISC'18

## ICOMOS Inter-ISC Meeting & Colloquium

Anti-Seismic Vernacular Heritage of Anatolia and Beyond

10-13 JULY 2018 - KASTAMONU - TURKEY



# Proceedings of the Inter-ISC'18

## Anti-Seismic Vernacular Heritage of Anatolia and Beyond

Organized by ISCARSAH TURKEY
On behalf of ICOMOS TURKEY

Iscarsah TÜRKİYE

Mimari Mirasın Yapısal Analiz ve Restorasyonu Türkiye Bilimsel Komitesi

ICOMOS

TÜRKİYE

# Anti-Seismic Vernacular Heritage of Anatolia and Beyond

**Proceedings of the Inter-ISC'18**
**ICOMOS Inter-ISC Meeting & Colloquium**
**July 10-13, 2018 Kastamonu, Turkey**

Organized by
ISCARSAH TURKEY
On behalf of
ICOMOS TURKEY

Edited by
Meltem VATAN

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# PREFACE

At the Florence triennial General Assembly in 2014, several ISCs expressed interest in the concept of an inter-ISC meeting that revolves around interdisciplinary research on a building type that proliferated throughout the seismic regions of Anatolia. This building typology involves the use of a stone foundation, wood framework and mud-brick or rubble-stone infill to create anti-seismic thermally efficient vernacular structures. The ISCs that have expressed interest include ISCEAH (Earthen Architectural Heritage), IIWC (Wood), CIAV (Vernacular Heritage), ICORP (Risk Preparedness), ISCARSAH (Analysis and Restoration of Structures), CIVVIH (Historic Towns and Villages), and ISCES (Energy and Sustainability), ISCS (Stone), and CIPA (Documentation). The joint meeting would bring an unprecedented number of ISCs together and review an architectural typology from various disciplinary approaches. In addition to ISCs, certain National Committees may also be interested in participating.

Wood-framed stone and mud-brick buildings can be found throughout the Balkans, Turkey, Armenia, and the Middle East. The practice is particularly effective in seismic zones. The stone foun-dation acts as a damp course against rising damp, and the wood framework as the skeleton that supports the floors and roofs if the walls collapse during an earthquake. The wood sills/ring beams installed at regular intervals knit the vertical framework together and dampen the impact of seismic shaking. The floor and roof wood framing acts as a diaphragm

SHATIS'17 is organized jointly by the Hasan Kalyoncu University Faculty of Fine Arts and Architecture and Yıldız Technical University Research Center for Preservation of Historical Heritage. This biannually held conference provides an international and interdisciplinary forum for researchers, experts and people from application to exchange their experience and knowledge and disseminate information on preservation of timber structure. Its aim is to enhance knowledge, in-crease awareness of the current technology and methodology and encourage studies of different disciplines working on timber structures. Contributions of different disciplines from 20 countries present their own experience and ongoing research activities in an interdisciplinary way.

The following areas of research are contemplated:

- What are the historical origins of this anti-seismic typology?
- Did the Ottoman Empire affect the spread of this form or was it already prevalent?
- What are the typical characteristics and shared-built heritage of the wood-framed masonry vernacular structure?
- What are the energy-efficiencies of this type of architecture?
- How does this form behave structurally in a seismic event?
- What variations of this form have evolved for denser urban settings?
- What is the current rate survival of this vernacular construction?
- Has this form of vernacular architecture been well documented?
- What steps are being taken to raise awareness about the efficacy of this form in resisting seismic activities and in sustainability?
- Are there case studies for adaptive reuse?

It is hoped that these issues will be discussed and answered.

Dr. Görün ARUN

On behalf of the Inter-ISC'18 Organizing Committee

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# CONTENTS

## CHAPTER III: Documentation

# CHAPTER I

## TYPOLOGY, HISTORY AND GEOGRAPHICAL SPREAD

# STRUCTURAL SYSTEMS OF TRADITIONAL TIMBER CONSTRUCTION IN TURKEY

**Görün Arun**

Hasan Kalyoncu University, Gaziantep, Turkey

**Keywords:** Timber construction, Timber housing, Timber walls

**Abstract**

*In Turkey, timber dwellings were commonly constructed until approximately 1950s. The heritage of timber structures in Anatolia is immense and the oldest examples date back to 12th century, some of them still in good shape and contribute to the visual vitality of historic Turkish towns with their cantilevering jetties or upper stories.*

*Traditional timber buildings, erected using traditional methods with experience and great skill passed from one generation to the other, can be classified according to the construction of their walls as composed of block wood or framed structure with totally wood or composite with timber studs and masonry infill. The timber walls of one or more stories in height were supported on the foundation walls, on timber laced masonry walls of the ground floor or raised on cripple studs and post and beam supports.*

*The earthquakes occurred in Turkey have shown that timber buildings have performed well and demonstrated a level of life-safety during earthquakes. Traditional timber constructions with monotonous repetition of wooden joists, studs and rafters have numerous load paths and are considered structurally redundant in providing level of safety in earthquakes without loss of their integrity.*

*The paper will explain the types of traditional timber buildings used in Turkey and discuss their failures during earthquakes. Their construction technology may bear some important information both for cultural heritage conservation and construction of contemporary building*

## 1 INTRODUCTION

Wood is one of the earliest building materials used in many parts of the world. The rock reliefs, drawings, traces of timbers on stone masonry, and written sources show that timber construction was also highly appreciated in ancient Anatolia. The technical implementation of timber construction, especially in the densely wooded regions as Paphlagonia in north, Phrygia in middle and Lycia in west of Anatolia, were from the Bronze Age in all fields of structures [1]. Archaeological excavation reports of Gordion, the former capital of Phrygia, mentions that tomb chambers from 9th to 6th century BC were constructed like log houses (Fig. 1a) [2]. Traces on the stone walls show that roofs of large town halls spanning more than 15 meters, temples spanning 10 meters were of timber trusses of cedar. And tombs were spanned by simple timber purlins (Fig. 1b) [3].


**Figure 1** Ancient timber construction

Besides forming the walls, floors and roofs of timber buildings, wood has been traditionally used in the construction as piles for ground consolidation (Fig. 2a), as indirect foundations in case of poor soil conditions (Fig. 2b) and as horizontal timber lacing to tie two faces of load bearing masonry walls (Fig. 2c).


**Figure 2** Use of wood in masonry construction

The heritage of timber structures in Anatolia is immense. The Seljuks, came to Anatolia in 11th century, built many mosques, public and military buildings of timber between 12th and 15th centuries. Some of the mosques are still in good shape and perform their duties. Houses were mostly of masonry. During Ottoman period, as masonry houses have suffered numerous intense and destructive earthquakes, wooden buildings gained importance to be safe especially among rich people. As several fires wiped out thousands of houses and the districts, masonry buildings were made obligatory by law in the form of building regulations known as Ebniye Regulations enacted in the early 19th century by the Ottoman government. Later however, due to many casualties and great damage caused by repeated earthquakes, timber for building was once again allowed under the law [4]. Between the 15th and the 18th centuries, the classical Turkish dwellings known as timber framed construction with a brick filling material were developed. After the 18th century there was a decrease in the quality of work and walls with brick filling began to be plastered over.

The timber houses were constructed until approximately 1950s. Afterwards, claiming that timber is expensive and burnable, timber buildings were almost forgotten, their building masters disappeared, and these buildings were replaced with reinforced concrete. The ones still in good shape contribute to the visual vitality of historic Turkish towns.

## 2 TIMBER CONSTRUCTION

Traditionally, the wood used in timber houses was of the local predominance of species. The hard woods as walnut, oak, elm and juniper or soft woods as pine, beech tree and chestnut was used according to the structural or ornamental function. However, in the North of Anatolia, in Black Sea region, the use of oak and chestnut is predominant in most buildings. In the rest of the country the use of pine predominates.

These structures, depending on the carpenter know-how, were erected using traditional methods and rules-of-thumb passed from one generation to the other, without mathematical or predictive methods. But with experience and great skill, an impressive empirical wisdom was obtained.

### 2.1 Timber Walls

The timber walls of one or more stories in height were supported on the foundation walls, on timber laced masonry walls of the ground floor or raised on cripple studs or post and beam supports (Fig. 3). In the first two cases, the masonry wall top is first covered with a layer of lime and timber sill beam forming a level set for the timber wall. The foundations of timber walls were of masonry, later of concrete. The footings of the timber columns are either anchored in concrete or masonry foundations or placed on a big footing stone.

**Figure 3** Timber houses rise on foundation wall, on masonry wall and on columns

Traditional timber buildings in Turkey can be classified and named according to the formation of their walls. The timber walls are composed of either block wood or framed structure with totally wood or composite with timber studs and masonry infill (Fig.4).

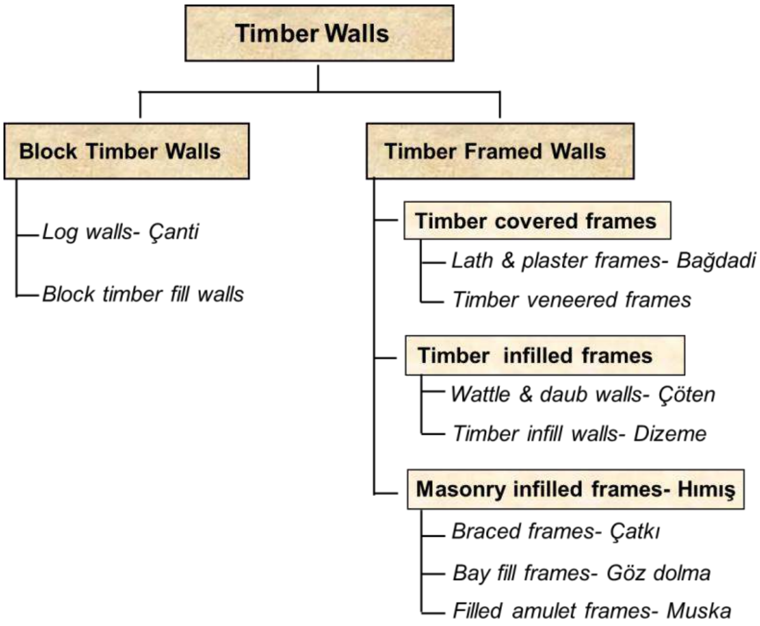


**Figure 4** Traditional Timber Wall Classification

2.1.1 Block Timber Walls

Block timber walls may be classified as log walls and columns with block timber infill.

*Log Walls*: The houses constructed with log walls are called “chanti”. According to the function of the house, the exterior and partition walls of this type are constructed with rough round logs or solid sawn lumber that laid horizontally one over the other and anchored at the ends with simple cross lap (Fig. 5). The width/height ratio of solid sawn lumber is between 1/4 -1/3. The window openings are of 3 or 4 panes.

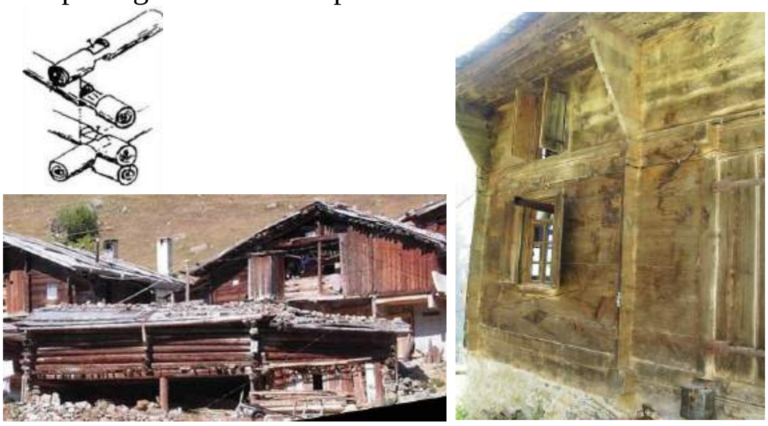

**Figure 5** Log Walls.

This type of wall construction is good in transmitting gravity loads through horizontally laid logs and the interlocking connections depend primarily on direct bearing of one member on another for their strength. The window openings and the interlocking timber connections due to the removed portion of the wood in a joint could be weak for resisting the shear forces of lateral loads.

*Block Timber Fill Walls*: The exterior load bearing timber walls are composed of columns placed at the corners and at the intersection of the partition walls and studs placed on the sides of the window and door openings (Fig.6). The space in between the columns and studs is then filled with horizontally laid rough round logs or solid sawn timber. The width/height ratio of solid sawn lumber is 1/3.

The connection of the timber fills to the columns or studs is by passing the tongue at the ends of the horizontally laid timber through the grove in the columns. The horizontal timbers laid one over the other is connected to each other by tongue and grove joint in order to avoid rain water penetrating inside. Connection of the partition wall of horizontally laid solid sawn timber to the columns is by passing timber itself through the vertical grove of the column. The width/height ratio of solid sawn lumber of partition wall is 1/4. Usually, the outer bays of the wall are diagonally braced.

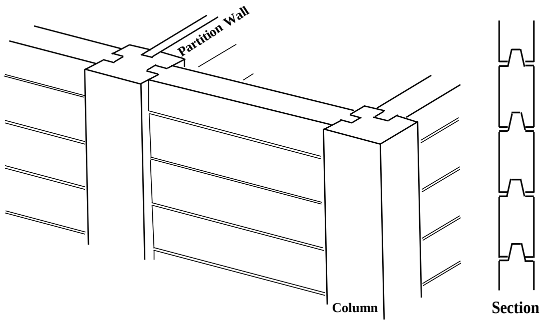


**Figure 6** Block Timber Fill Wall

2.1.2 Framed Timber Walls

The load bearing framed timber walls are composed of columns or studs placed 0.60 - 1.50m apart resting on the lower chord beam and tied with the upper chord beam at each floor level. The structural composition of the wall between the studs and columns and upper and lower chords are of wide ranging structural typologies depending on the ability of the carpenter and availability of building materials. The framed timber walls can be classified as totally timber framed and composite with masonry infill.

2.1.2.1 Totally Timber Framed Walls

The frame of totally timber framed walls is composed by either 25-60 cm spaced columns / studs or 60-150 cm spaced columns with horizontal and diagonal bracings. Closely spaced studs are covered by timber lath or planks, filled with wattle and daub. The frame with widely spaced columns filled with timber is called “dizeme”.

Timber Covered frames are composed of closely spaced columns and studs at ~40-60 cm intervals. If closely spaced laths are nailed on both sides of the frame and then plastered, the wall is called “bağdadi = lath” walls (Fig. 7a). The laths may be lined up horizontally or sometimes diagonally. Sometimes exterior of these walls are then timber veneered. In timber veneered frame, the sawn timber planks are nailed on the outer side of the frame (Fig. 7b). The inner face of the wall may be covered by lath and plaster or timber veneered. The space between the outer and inner face of the timber covered frames are usually left empty.

Timber infill frames are different depending on the space of the studs. When the studs are closely spaced, the space is woven with wattle or short rough pieces of timber that could not be used for structural elements, the wall is called “çöten (choten)” (Fig. 7c). The frame with widely spaced studs are filled with timber and called “dizeme” (Fig. 7d).

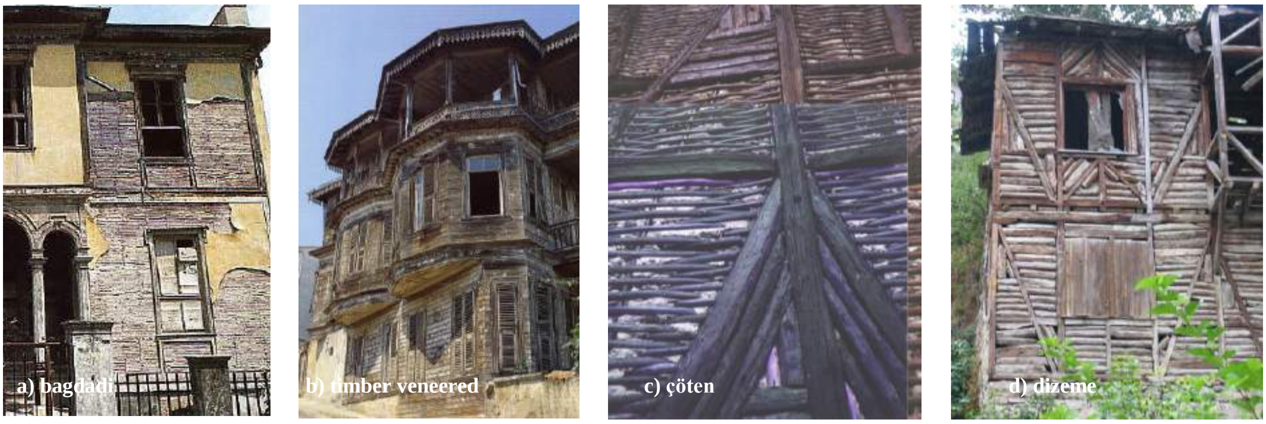


Figure 7 Totally timber frames

The houses with exterior and interior partition walls of this type are light weight and economical to build but are subject to insect attack. These houses performed well during the 1944 Gerede [1] and 1999 Marmara earthquake. Cracks in the plaster are considered a non-structural damage that dissipates a lot of earthquake induced energy.

2.1.2.2 Masonry Infilled Timber Framed Walls

The timber framed walls filled with stone, adobe or brick infill are called “hımış” pronounced as humush. Hımış system can be classified as Göz dolma (bay fill) (Fig. 8a), Muska dolma (filled amulet) (Fig. 8b) and Çatkı (braced) (Fig. 8c). Depending on the available material and carpenter’s ability, such hybrid timber framed walls of wide ranging typology are composed by either 25-60 cm spaced columns / studs or 60-150 cm spaced columns with horizontal and diagonal bracings.


**Figure 8** Masonry Infilled Timber Framed Walls

*Göz dolma*: This, typical wall construction of east Black sea region may be explained as “bay fill”. In the wall structure, columns of 10x10 or 15x15 are placed at the corners and at the intersection of the exterior wall to the partition wall. The space in between these columns is then divided with ~ 5x10cm studs placed at 20-22cm intervals that are braced horizontally at 17-20cm intervals. The connection of the columns and studs to the upper and lower chord beams and 3x10cm horizontal timber bracings to the column/stud is by mortise and tenon joints. Then these small bays are filled with stone cut to the size and lime mortar (Fig. 8a).

The interior of these walls is plastered. The window and door openings are sized according to the stud spacing. The partition walls of these houses are of horizontally laid 1/4 solid sawn timber connected to the columns by passing timber itself through the vertical grove of the column.

*Muska dolma*: This system consists of ~ 5x10 cm timber studs placed 40-60 cm apart in between the columns at the corners and at the intersection of the partition walls that are nailed to the bottom and upper chord. The space in between the studs is triangulated with ~ 5x10 cm diagonal braces nailed to the studs/columns (Fig. 8b). The triangulated space of the frame is then filled with brick or rubble stone set in lime mortar. If there are openings, horizontal bracings at the top and bottom of the opening are placed from column to column. The interior of these walls is plastered or covered with timber coverings hiding the infill and the timber frame

*Çatkı walls*: çatkı (pronounced as "chatku") wall construction can be described as a timber frame with masonry infill such as bricks, adobes or stones. According to the placing of studs in between the columns at the corners and intersecting walls, the structural system of this type can be classified as system containing bracing elements and no bracing elements.

The system without bracing didn't behave well during 1940 earthquakes and use of diagonal bracing at earthquake zones was advised for later constructions [1]. The system with bracing, horizontal bracings of the same size as studs tie the studs/columns at about mid-story height of the wall and diagonal bracings positioned at the most vulnerable to damage bays, especially at the corners (Fig. 8c). The space between the horizontal and diagonal braces and the studs are filled with adobe, brick and rubble stone set in thick mud or lime mortar. If bricks are used, they are sometimes placed to form a decorative pattern on the façade. All timber elements are nailed to each other.

Çatkı houses have good earthquake resistance. Because the timber studs subdivide the infill, the losses of masonry portions do not lead to the destruction of the rest of the wall. The closely spaced studs prevent propagation of 'X' cracks on the masonry portion and reduce the possibility of the masonry falling out of the frame.

### 2.2 Floor and Roof Framing

The timber houses are formed with a floor platform completed at each level, and load bearing exterior walls are erected upon it. Floor and roof framing consists of wood joists or sloping rafters on upper chord beams of the timber studs. According to the layout, floor joists and roof rafters are designed one way, aligning parallel to each other at about 40-60 cm spacing.

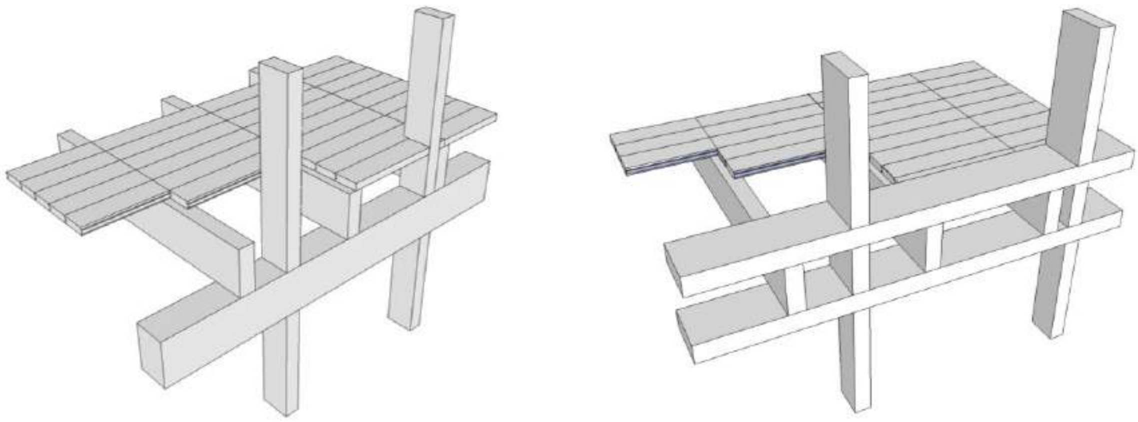

**Figure 9** Floor framing

The floor joists rest either on the upper chord beam of the lower storey which also serves as lower chord beam of the upper storey or placed in between the upper chord beam of lower storey and lower chord beam of the upper storey (Fig. 9). The size of the joists of 1/2 or 1/3 in ratio varies according to the length of the room and wooden species. The joists are then covered with timber boards nailed to the joists.

The walls having cantilevering joists projecting out about 60 cm help to give additional strength to the wall below against lateral forces. Longer cantilevering joists are supported in various ways. The upper story's wall rises from the end of the cantilever because the walls are light enough to be supported on the cantilevered timbers (Fig. 10).

**Figure 10** Cantilevering joists

Timber buildings have floor decking of solid wood boards of ~ 2 cm thick nailed on the floor joists. These boards set side by side or with joints of tongue-and- groove are laid at right angles to the joists.

The most typical timber roof structures in traditional houses are the wooden trusses. The trusses were mostly made of main roof beams, which support the purlins that supported the rafters. Timber boards supporting the roof tiles are nailed to the purlins.

## 3 TIMBER HOUSE ORGANISATION

Timber dwellings in Turkey are generally constructed as single houses. However, in cities with dense population, it is possible to encounter attached houses aligned side by side. These houses are formed with a floor platform completed at each level, and load bearing exterior walls are erected upon it. The attached buildings contain 50~60 cm thick continuous masonry walls from foundation to roof in between the houses to prevent fire spreading to neighboring buildings [5]. The first-floor framing supported directly on the masonry walled ground floor serves as storage or barn area of the structures. The ones erected directly on foundation walls or raised up on post beam frame had such service areas in their garden.

The traditional multi-storey dwellings in seismic areas are constructed getting progressively lighter both with construction material and the thickness of the wall. These are constructed with a heavy wall as stone masonry at ground floor; timber frame filled with brick or adobe masonry solid then with cavity brick walls at intermediate level and wattle or lathed wall construction at upper floors (Fig. 11). The building getting lighter at upper floors make the timber frame at top more ductile and therefore more able to meet the higher seismic demands that occur at upper levels.

**Figure 11** Timber buildings getting progressively lighter

Traditional timber building masters, being aware that moisture is a serious non-seismic threat to timber structure, have given high priority to drainage during construction. To control the seasonal and daily raise of underground water, traditional timber structures contained wells in the floor resting on soil, in basement or ground floor. The channels from the wells in underground discharged the water out of the building [6].

Timber houses were erected depending on the carpenter know-how, availability of the material and owner's financial power. In places with lots of wood, totally timber was used. If there were not enough woods, other methods using rough timber pieces or masonry was introduced.

## 4 CONCLUSIONS

Traditional timber constructions with monotonous repetition of wooden joists, studs and rafters have numerous load paths and are considered structurally redundant in providing level of safety in earthquakes without loss of their integrity. Thus, this redundancy of elements with a high level of energy-dissipating capacity leads to the good performance during earthquakes. Masonry infill falling out of the frame and cracks in the plaster are considered a nonstructural damage that dissipates a lot of earthquake induced energy (Fig. 12a).

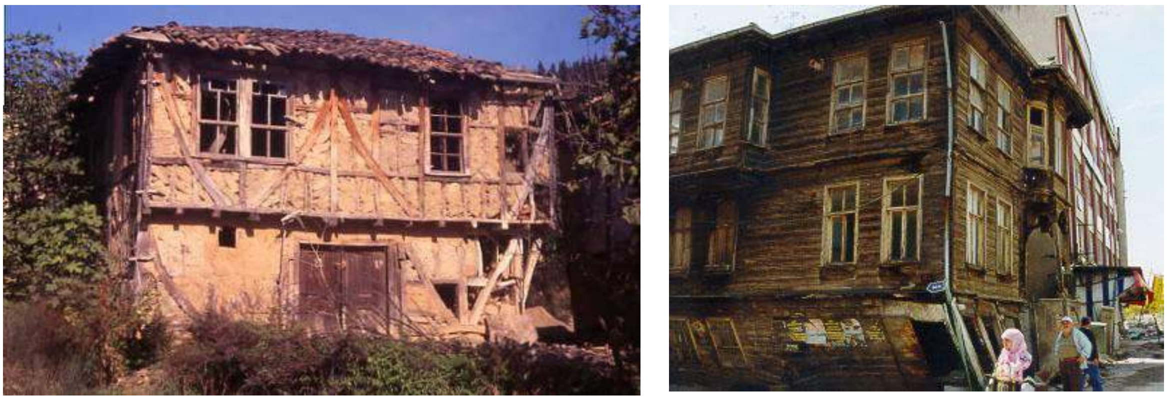

**Figure 12** Earthquake damages

Structural integrity of timber frame buildings under seismic forces also depends on the connections to provide ductility and energy dissipation and the configuration of the building and its structural layout. The most common type of structural damage in timber buildings results from lack of connection between the superstructure and the foundation and lack of connection between the floor diaphragm and walls. The timber constructions that had changes in the structural layout due to the necessities of modern life sometimes end with soft storey irregularity (Fig. 12b). If these flexible buildings are on soft soil, because of the reduction in their strength and increase of their natural period under cyclic loading, they suffer severely.

The early design rules of traditional timber constructions and their load distribution through joints were built upon with empirical knowledge transmitted and improved through generations. Designing the building getting progressively lighter at upper levels provides seismic enhancement in many ways: the greatest mass is found at the base, the structure becomes exceedingly lighter at the upper reaches, and thus the center of gravity of the entire structure is closer to grade. This shows that besides economy and availability of building materials and craftsmanship, risk from earthquakes was also concerned by the building masters in shaping the form of traditional construction.

Traditional timber constructions with variety of materials and techniques in Turkey have suffered from continuous changes and repair of past works, and abundance during their lifetime. The timber architectural heritage to be preserved today necessitates architects and structural engineers for proper inspection, structural analysis, repair and monitoring and public awareness for maintenance.

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# MASONRY INFILLED TIMBER FRAME CONSTRUCTION TECHNIQUE IN ISTANBUL BEFORE MID 19$^{TH}$ CENTURY

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**Keywords:** traditional Istanbul house, masonry infilled timber frame (*hımış*), rationalized timber frame without infill

## Abstract

*The timber heritage buildings of Istanbul that survived today are timber framed constructions with thin vertical braces without any infill. However these constructions do not represent "the traditional" building method prevalent in the city before mid-19$^{th}$ century. Similar to many regions in Anatolia and the Balkans traditional residential architecture of Istanbul for centuries was timber frame with adobe or brick infill (known as dolma or hımış). The Western influence on science and technology affected newly emerging engineering discipline in Istanbul and caused the gradual change in timber frame design and the emergence of timber frame with thin vertical braces without infill. This paper traces the structural characteristics of traditional hımış technique in Istanbul and its impact on the newly emerging in the 19$^{th}$ century timber frame with thin vertical braces. Istanbul hımış technique was documented in the architectural surveys of Sedad Hakkı Eldem done in the first half of the 20$^{th}$ century. Moreover, building materials and construction techniques are well recorded in Ottoman archival sources (such as building cost registers or photographs). The documentation and description of traditional Istanbul hımış technique is of major importance while identifying the evolution pattern of the thin vertical braced timber frame in the second half of the 19$^{th}$ century.*

## 1 INTRODUCTION

The “traditional” Istanbul timber house is depicted based on 19th century examples that survived throughout the city today: Timber houses (*yalı*s) on the Bosphorus, relatively modest timber houses in Zeyrek and Süleymaniye neighborhoods and timber houses from the late nineteenth century built in Western styles (Art Nouveau, Art Deco, neo-classic, neo-gothic, Victorian or eclectic) in Yeşilköy, Bakırköy, Kızıltoprak, Göztepe, Erenköy, Bostancı and Prinkipo Island. **(Fig. 1)** However, those residential buildings constructed with thin vertical braced timber frame are the products of Western influence on architectural styles, engineering science and woodworking technology [1].

Prior to 19th century adobe or brick filled timber frame (*dolma* or *hımış*) was the only way of constructing a timber framed building in Istanbul. However the technical developments in the field of carpentry and construction engineering in the Western World affected deeply Istanbul’s cityscape. Trussed partition walls without infill, depicted in 18th century carpenter manuals as self-supporting structures, and later the publications of engineer Thomas Tredgold in Great Britain, together with the industrialization of woodworking sector caused the rationalization of timber frame design in the Western world [1]. Tredgold proposed the lightening of brick filled timber frame partition wall by constructing the wall with thin vertical timber braces, which have to be from well-seasoned and precisely sawn wood in order to distribute the load through the wall properly [2]. The Western influence on architectural styles and engineering education in Istanbul was the main motor behind the gradual change in timber frame design and the construction of timber frames with closely placed thin vertical braces, without infill [1]. Initially applied around mid-19th century in the dwellings built for the Ottoman Imperial family members, this construction technique took the place of traditional *hımış* frame in Istanbul [1]. Being cheaper, lighter and easy-fast built the timber frame without infill soon became the prevalent building technique in many neighbourhoods of the city.

**a)** **b)**

**Figure 1:** Timber buildings in Istanbul **a)** Beşiktaş and **b)** Beylerbeyi, 2016 (Photos: D. Acar)

This paper traces the characteristics of traditional *hımış* construction, which was the only method of constructing a timber framed building in Istanbul prior to mid-19th century, through

Ottoman archival sources and survey drawings. The effect of traditional *hımış* technique on the newly emerging rationalized timber frame with thin vertical braces is another focal point of this study.

## 2 STRUCTURAL FEATURES OF MASONRY INFILLED TIMBER FRAME (*HIMIŞ*) IN ISTANBUL

Istanbul houses were depicted in travel accounts as timber framed buildings with adobe or brick infill since the very beginning of the 17th century **(Fig. 2)** [3]. Local sources from the 17th century, such as Ottoman judicial records or cost estimates use the term **infilled wall** (*dolma duvar*) or only the word **infil**l (*dolma*) in order to describe the construction technique of a timber framed building [4, 5]. The word **framework** (*çatma*) was another term used in the 17th century pious foundations' records, to specify the infilled timber frame construction technique of a one or two storey Istanbul houses [6]. Very few of the *hımış* Istanbul houses have survived today. Most of those are in ruinous state with many inappropriate additions. **(Fig. 3)** Sedad Hakkı Eldem had a chance to record the structural features of 18th century *hımış* houses in Istanbul or in nearby towns during the first half of 1900s. Köçeoğlu mansion and Yasinci mansion built on the Bosphorus in the 18th century were two of the masonry infilled timber framed buildings recorded by Eldem. **(Fig. 4** and **5)** Masonry infilled timber frame was not applied only in the constructions of grandiose mansions, the timber framed buildings constructed in poor neighbourhoods of the city prior to mid-19th century were also built with masonry (stone or adobe) infilled timber frame. (**Fig. 3** and **6**)

*Hımış* houses have principal timber studs (dim.app. 26 x 26 cm) resting on the timber sill or directly on the stone foundation wall. Principal studs were placed 1,5 - 2 meters apart from each other. Heading connected with a simple tenon-mortise joint was nailed to the principal stud using wrought iron nail. The timber sill of the upper floor was laid down on those headings, which help transferring the load to the principal stud. Principal studs were supported with same size diagonal braces and the space between the studs and diagonal braces was filled with adobe, brick or rubble stone wall. The simple joints between timber sill, studs and diagonal braces were done with hammering the wrought iron nails, without applying any tenon-mortise connection. The masonry filling was divided by horizontal timber laths/braces (dim.app. 12 x 20 cm) placed on every 50 cm between the adobe or brick infill. [8, 10] **(Fig. 3** and **7)** The horizontal timber laths strengthen the masonry filling against the lateral forces, i.e. earthquake.

*Hımış* houses constructed in poor neighbourhoods used adobe (*kerpiç*) or rubble stone built with earthen mortar as an infill, whereas in more prosperous houses the infill was built with brick and lime mortar (*horasan*). Brick was a relatively expensive material and mostly the mortar joints were done wider than the brick layer. **(Fig. 3** and **4)**

This construction technique was in use until the mid-nineteenth century, after when it gradually changed and completely disappeared at the end of the century. The evolution of infilled timber frame into a timber frame with thin vertical braces did not happen at once, the buildings constructed during this transition period had characteristic features that affected their static properties.

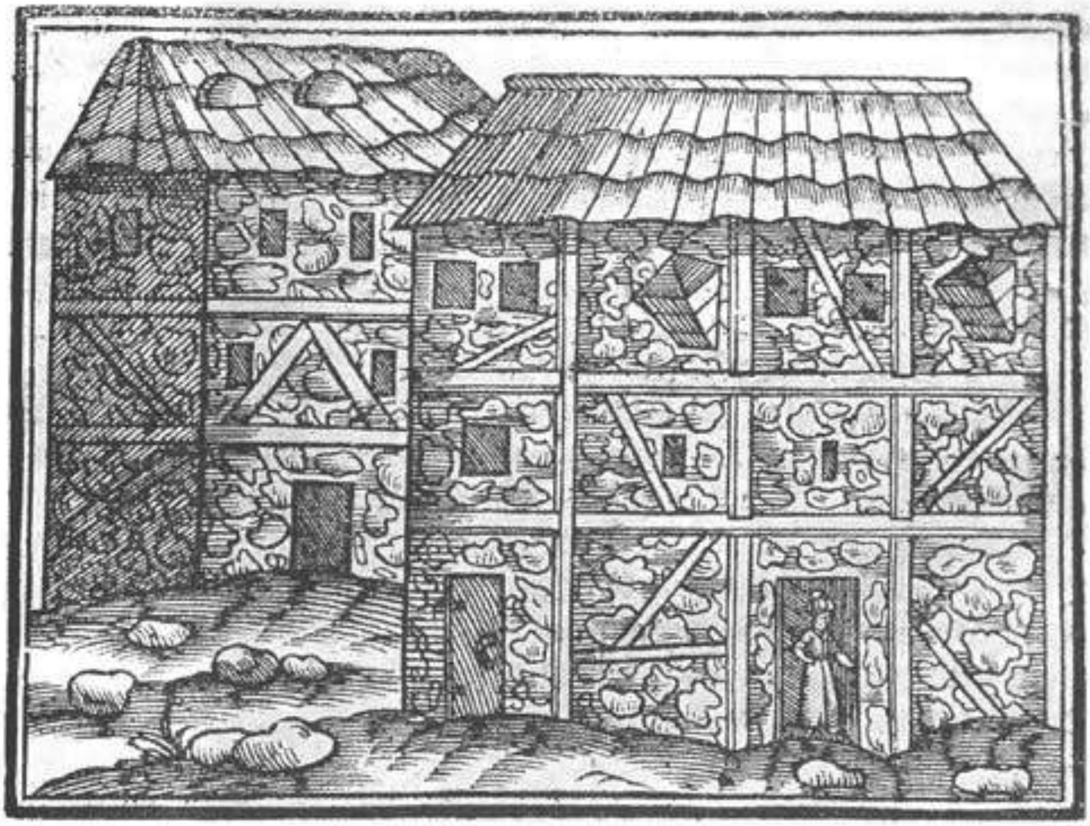


**Figure 2**: 17th century *hımış* Istanbul house depicted in the Salomon Schweigger's travel book. [3]

**Figure 3**: Timber frame with brick infill from the beginning of the 19th century in a demolished house in Prinkipo Island/Istanbul (2014) (Photo: D.Acar).

**Figure 4:** Masonry (brick) infilled timber frame of Köçeoğlu mansion built in the 18th century in Bebek/Istanbul and pulled down in 1941 (Photo: Sedad Hakkı Eldem) [7]

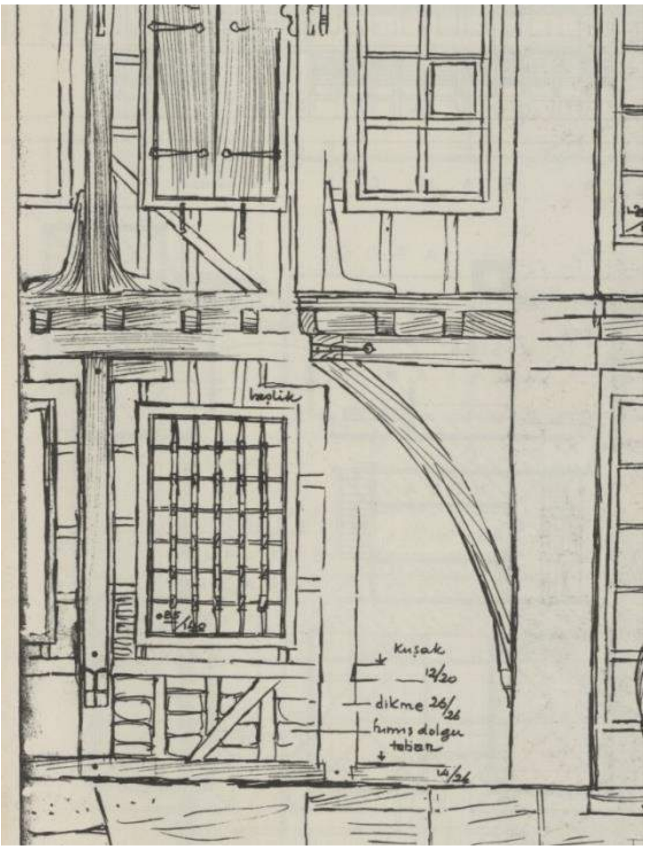



**Figure 5:** Drawing of masonry (adobe) infilled timber frame of Yasinci mansion built in the 18th century in Anadoluhisarı/Istanbul and pulled down in 1940s (Drawing: Sedad Hakkı Eldem) [8]

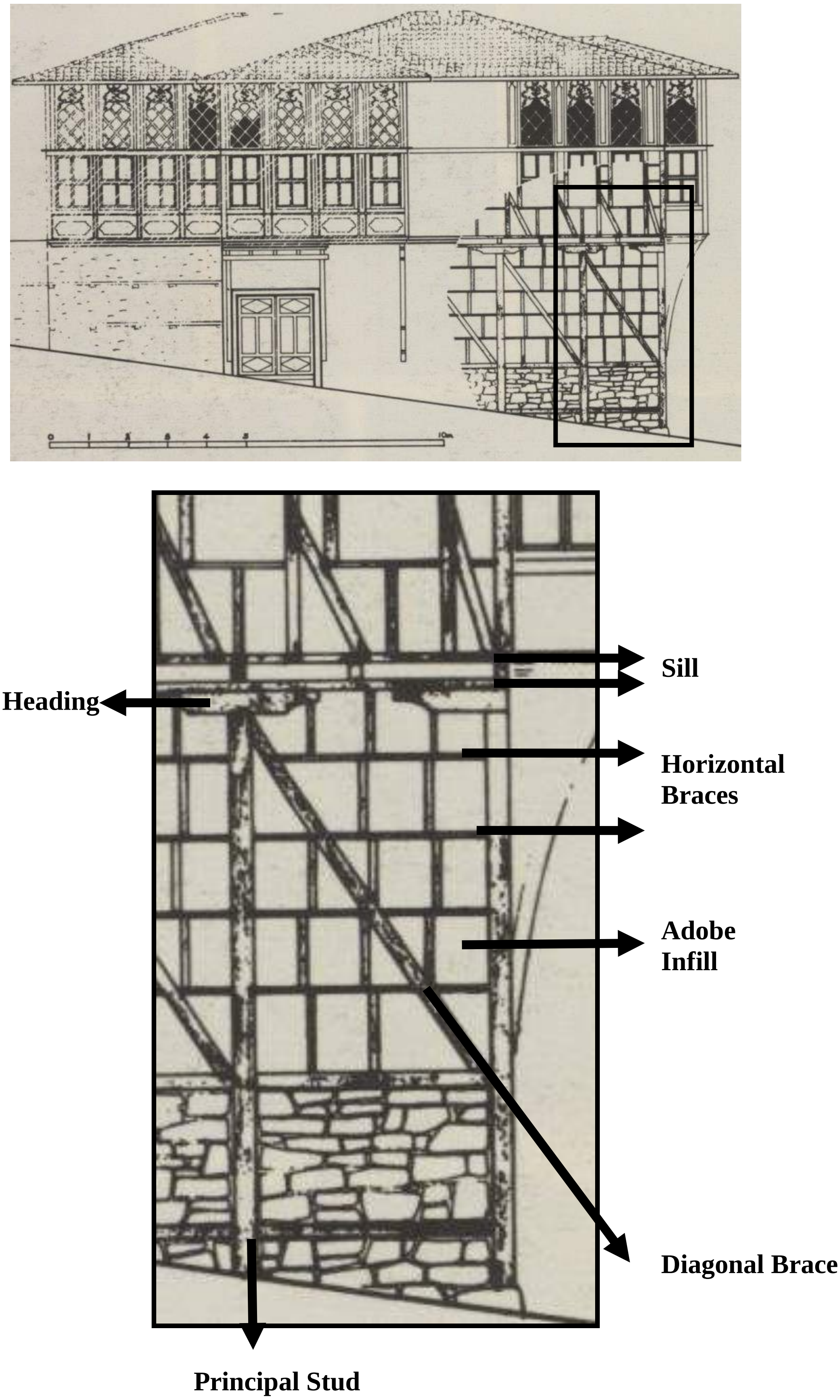



**Figure 7**: Timber framed house with adobe infill in Izmit (near Istanbul) constructed in 18th century. [10]

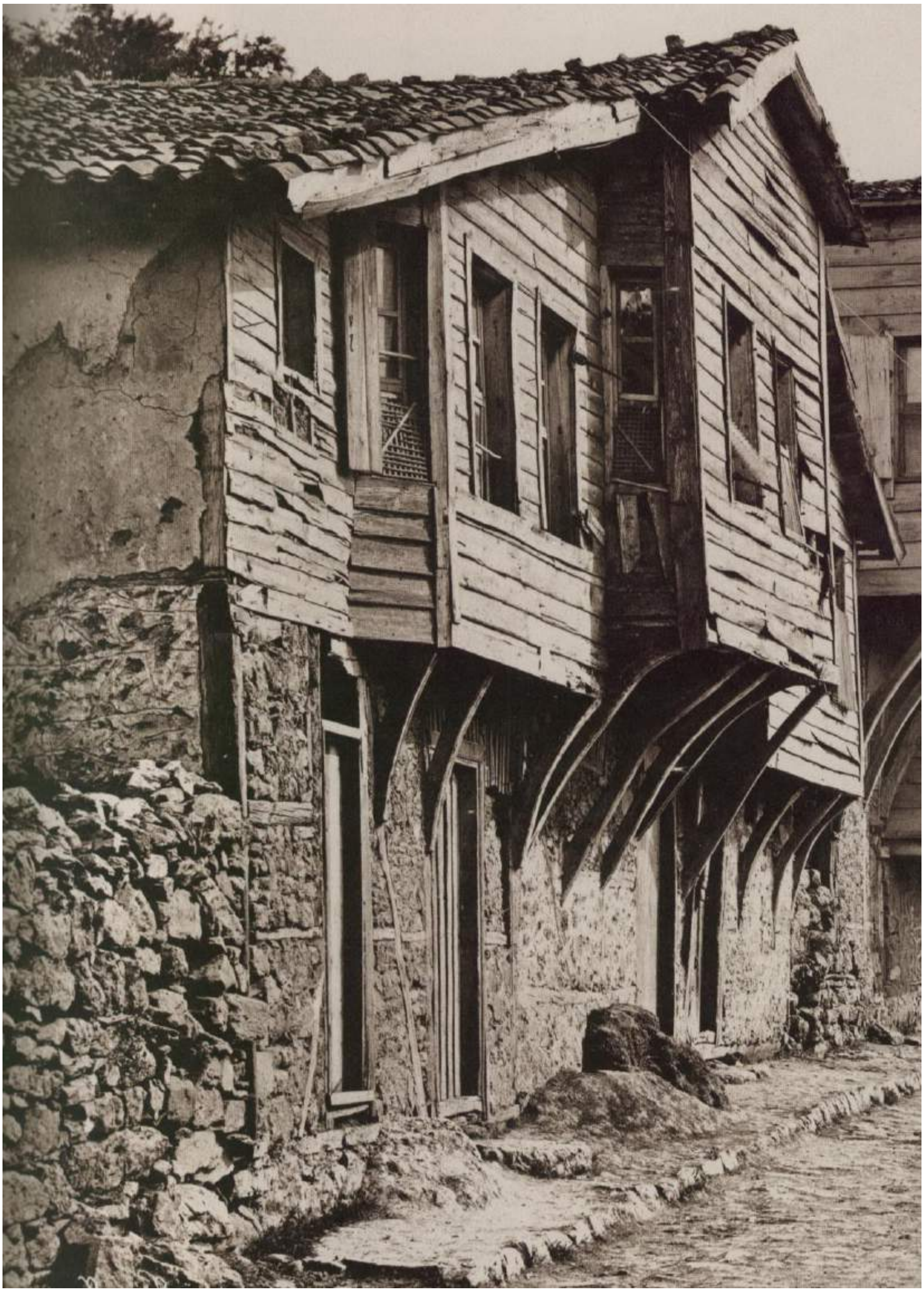


**Figure 6:** Masonry (stone and adobe) infilled timber frame of a house in Beykoz/Istanbul built in the first half of the 19$^{th}$ century (Photo:Pascal Sebah, 1865-70) [9]

## 3 IMPACT OF TRADITIONAL *HIMIŞ* TECHNIQUE ON THE RATIONALIZED TIMBER FRAME WITHOUT INFILL

Western timber frame design principles entered Istanbul through the newly established modern schools (Imperial Naval Engineering School/*Mühendishane-i Bahr-i Hümayun* established in 1781 and Imperial Military School/*Mekteb-i Harbiye* found in 1834) and were first put into practice by the civil engineers employed in the constructions of Imperial buildings [1]. From the mid- 19th century onwards signatures of military engineers could be recognized under the preliminary cost estimates of Imperial constructions [11]. By the beginning of 1880s kalfas (master-builders who usually had not any formal education) employed in the Imperial Building Department (*Ebniye-i Seniyye İdaresi*) had to work together with civil engineers while preparing preliminary building cost estimates. The civil engineers contributed to the rationalization of building techniques, but the diffusion of those techniques in all neighborhoods of Istanbul was realized by carpenters employed in the on-site construction of Imperial buildings.

Ottoman engineers educated in Imperial Naval Engineering School put into practice their knowledge on timber frame design during the construction of Çağlayan palace in 1862-63. Çağlayan Palace is one of the first buildings built with vertically braced timber frame without infill. **(Fig. 8)** The cost estimate of the building reveals that all sills, principal studs and diagonal braces of the timber frame were sawn at the Imperial Dockyard (*Tersane-i Hümayun*) [11]. The sills, principal studs and diagonal braces were cut into square cross-section rafters (25 x 25 cm for the ground floor and 22 x 22 cm for the upper floor) from oak logs. **(Fig. 9)** At that time Imperial Dockyard and Imperial Arsenal (*Tophane-i Amire*) were the only places in Istanbul which had steam powered parallel blade saw in their carpentry shops. However, the capacity of the steam powered saw in the Imperial Dockyard was not adequate and the thin vertical braces, which were considered of secondary importance, were roughly hand shaped on site. **(Fig. 9)** Moreover, the habit of placing horizontal timber laths in adobe/brick filled timber frame could be clearly observed in Cağlayan Palace structure. **(Fig. 9)** Instead of placing the monolithic vertical braces, which shall transfer and distribute the loads through the wall, horizontal braces were placed uninterrupted. Vertical braces were used only to support horizontal laths, a practice typical of *hımış* structures. The vertical braces unable to transmit the loads caused an out of plane failure and breaking occurred along the horizontal braces. **(Fig. 9)**

The timber frame of Çağlayan Palace was lightened by the elimination of infill in the structure; **(Fig. 10/ B)** however the design principles of the timber frame with closely placed thin vertical braces were violated. The timber frame was constructed as if a masonry wall would be built as an infill. Moreover, the mechanization of the woodworking sector in Istanbul was not at a level to meet a large-scale demand for standard structural timber members for the market, even for the construction of Imperial buildings. However, the building technique with vertically braced timber frame quickly spread to neighborhoods of the city due to its low cost and ease of construction. The constant migration from the Balkans to Istanbul, especially after the Russian-Turkish War (1878) caused a huge demand for new housing, for which the new technique offered significant advantages. However, hand shaped (with axe or frame saw) principal studs and carelessly placed thin vertical braces caused the uneven distribution of load through the frame and the emergence of a “loose and unstable” in Bachmann’s terms, timber frame [1, 12]. **(Fig. 10/C)** Additionally, the usage of non-standard wrought iron nails in the vertical braces’ connections caused cracks in thin vertical braces, which weakened the joints. Thus, those structures needed frequent maintenance without which they could not survive for a long time.

**Figure 8**: Çağlayan Palace at the end of the 19th century (Photo: Istanbul University Rare Sources Archive).

**Figure 9**: Çağlayan Palace staircase hall timber frame, 1940 (Photo: Istanbul Protection Board Encümen Archive)

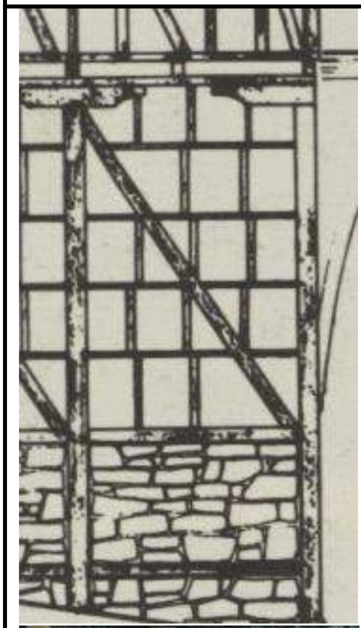
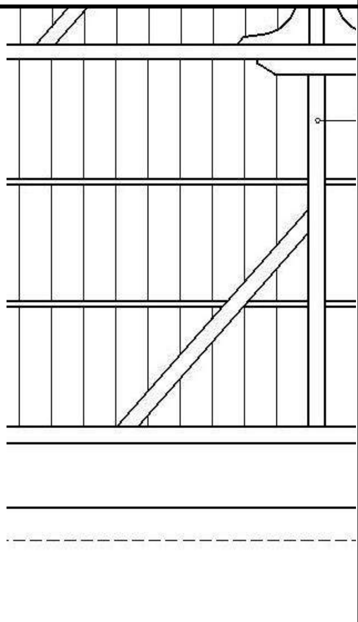
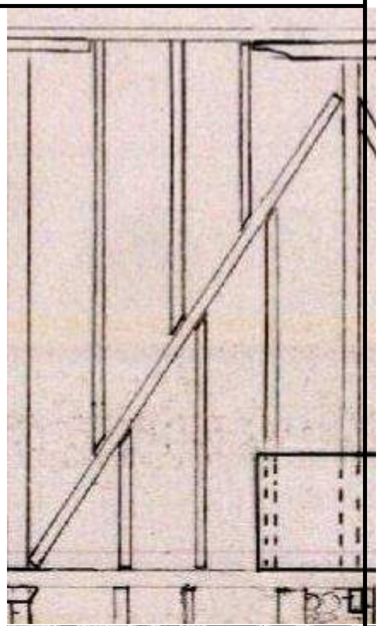
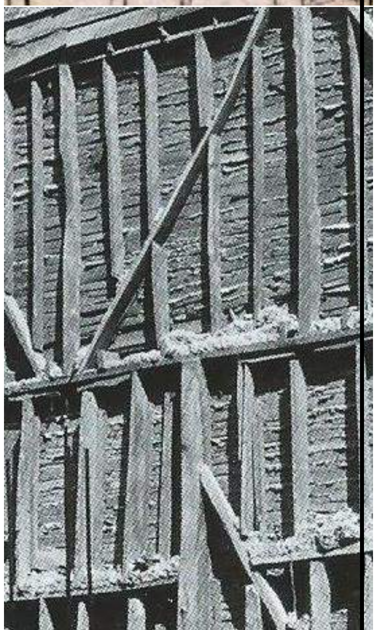
| A:<br>TIMBER FRAME WITH ADOBE/BRICK INFILL | B:<br>TIMBER FRAME WITHOUT INFILL WITH HORIZONTAL BRACES | C:<br>TIMBER FRAME WITH HAND CUT VERTICAL BRACES |
|---|---|---|
|  |  |  |
|  |  |  |
| Wall thickness:<br>20-26 cm | Wall thickness:<br>22-25 cm | Wall thickness:<br>10-18 cm |

**Figure 10**: The evolution of timber frame in Istanbul before the industrialization of timber sector. [1]

## 4 DISCUSSION AND CONCLUSION

There are very few *hımış* constructions in Istanbul today, mostly in ruinous state. However knowing that they are the only three dimensional evidence of the traditional building technique in the city they should be preserved with utmost care. Identifying the structural features of *hımış* buildings help us to understand the evolution of timber frame without infill in Istanbul and to distinguish the reasons behind the structural strengths and weaknesses of the newly emerging timber frame with thin vertical braces.

The standardization of timber frame elements in the neighbourhoods of Istanbul did not happen until the establishment of Ahırkapı Timber Factory in 1893. Until that date the cost estimates point out that vertical braces were occasionally supplied from ruined timber constructions (*enkaz kerestesi*), which show that the thin vertical braces of the frame were mostly neglected and considered as non-structural elements. This practice could be associated with the habit of building *hımış* houses, where it was not necessary to use standard vertical or horizontal timber elements. However, the usage of non-standard vertical braces violated the even distribution of the load through the wall, which was one of the main principles of the thin vertical braced timber frame. Moreover, the hand-cut short vertical braces divided with horizontal laths could not transfer the load to the sill and caused structural failure of timber frame. The usage of standard posts and vertical braces after 1893 made possible the construction of the multi-storey timber frame buildings in Istanbul like the five storey tall Prinkipo Island Orphanage designed by Vallaury and constructed in 1898.

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# TYPOLOGY AND CONSTRUCTIVE ANALYSIS OF THE TRADITIONAL OTTOMAN HOUSE – THE CASES OF KAVALA AND OHRID

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**Keywords:** Ottoman houses, Vernacular Architecture, Typologies, Plan typologies, Building materials

## Abstract

*As part of the Inter-ISC'18 conference within the theme of "Typology, History and Geographical Spread", this article will try to give an outlook of the architectural and constructive panorama that shared influences and experiences in the domestic architecture in the Balkans presented through two specific case studies of Ottoman towns: Kavala and Ohrid. Historic Islamic cities show a variety of origins and growth patterns that are visible in the two examples mentioned above. In general, those Ottoman towns were conditioned by external factors such as pre-existing settlements, deliberate choices of location and prevailing dynastic evolutions and changes. Practically all of the most important Eastern Mediterranean cities were a product of many simultaneously urban activities where multi-cultures and multi-religious systems coexisted together for centuries. Beyond the very significant and ancient historical stratifications, virtually everywhere in their long forming, they acted, cohabited and lived together. The two towns, Kavala and Ohrid were both part of the vast Ottoman Empire, positioned in the lands of the Ottoman territory of Rumelia for almost five centuries. Both towns had long urban history rooted deep down in the ancient times but the traces of the previous eras were "covered" with the Ottoman presence, evident especially in their domestic and vernacular architecture. This article will try to give an outlook to the Ottoman patterns appearing in both case studies, showing similarities and resemblances.*

## 1 INTRODUCTION

The Ottoman town of the Balkans is more often an adaptation of the Byzantine, or rather Hellenistic city, according to scholars like Cerasi, that later went through transformations or extensions.[1] Speaking of Ottoman cities in the Balkans on one hand means attempting to identify the diverse origins of these cities before the Turkish conquest but on the other, means to describe and interpret the developments that happened from the beginning of the conquest around the end of the $14^{th}$ century till the beginning of the $20^{th}$ century, when the Ottoman Empire collapsed as a consequence of World War I [2].

Both Kavala and Ohrid, today respectively in Northern Greece and Republic of Macedonia, were towns that within the borders of the Ottoman Empire were part of the same regional architectural milieu. Topographical similarities can be found in both the towns, positioned along the important land route called Via Egnatia and built on a hill, beside a mass of water; in the case of Kavala on the shores of the North Aegean Sea and in the case of Ohrid by the homonymous lake. Both towns possess long historical continuity going as far back to neolith: the ancient Neapolis, later known during the Byzantine Empire as Christoupolis that in Ottoman times was renamed Kavala and the ancient Lichnidos that later became known as Ohrid. In the Ottoman times both the towns reached their peak in the urban and house development and if we take them as case studies, through a comparative research approach, it is possible to find common denominators in their architectural expression, both in the house plan typology and in the building-systems and constructive materials.

The spatial development of the Balkan towns, especially those in the European territory of the Ottoman Empire once called *Rumelia*, has its roots in Ottoman concepts, including the public institution of the pious foundations (the *imaret* or *külliye*) and the private and civic quarters and neighborhood systems (the *mahalle*). Typically, the physical shape of a town was consisted of an organic and almost unsystematic accumulation of these quarters around specific and important centers or landmarks and the house appearance was thus influenced both by the formation of neighborhoods, the organic disposition of streets, and the morphology of the terrain. All these common elements can be easily seen in both the aforementioned towns confirming the continuity and the regional Ottoman architectural influences and realizations as well as climate, geographic and historical circumstances under which both have been developing their physical appearance. In order to investigate in the following chapter the history of the urban settlements of Kavala and Ohrid, we will briefly discuss about the characteristics of a typical Ottoman town

### 1.1 Formation of the Ottoman town

It is an accepted truth that the art and culture of every nation are affected by those of earlier and neighboring civilizations and the Ottomans, even the Seljuks before them, were not exceptions[3]. The Ottoman town, as it is defined according to Cerasi as a commixture of Levantine and preexisting elements together with the traditions and innovations brought by the new Turkish rulers,[4] cannot simple be ascribed and encompassed in the main historic categories of the generic 'Islamic city' or 'Oriental city', but it should be analyzed through the differences or the boundary's limits that we can refer to the studies on the comparative cultural geography. Moreover, far from old interpretations about the generic Islamic city, the research on the Mediterranean area, especially considering the Eastern Mediterranean and the lands close to it - as in the case of the Balkan peninsula - had always been effected by a sort of multiculturalism, related to the multiplicities of several population living in those areas and the coexistence of several religions as well [5].

The wooden pitched roof house, the domed mosque, the peculiar layout of the urban texture, the market (or *çarşı*), the neat separation between economic and residential functions, the urban composition open towards the nature are all together rarely denied rule of what we can call the typical Ottoman city that has ruled the Anatolian region (with the exception of the oriental and partially the central plateau areas), the Thrace region, Macedonia, Epirus, Thessaly, Albania, Bosnia-Herzegovina, the big cities in Serbia and, in a minor and limited way, the south and the coasts of the nowadays Romania [6].

The lands of Rumelia - which included today's Turkish Thrace and the whole Balkan region, have always enjoyed great importance in the past, thanks to their geographical and strategic location and their function as a link between Asia and Europe. In every historical period, these lands have always been used by the most diverse populations and civilizations as an obliged passage between the West and the East. In the Ottoman era, three large main roads to the west connected the capital Istanbul with the Balkans, with the regions north of the Black Sea and with central Europe. These road systems therefore played a fundamental role in all relations with the Western powers, both in terms of commercial exchange or military and strategic purposes [7].

The western highway of the Rumelia road system, the so-called 'Left Road' or Sol Kol in Turkish, was the road to Greece and to Italy. Starting from Istanbul continuing until the coast of Ionian Sea. The road, which in ancient times was named Via Egnatia, was mainly a military road built and used by the Romans, and was for a long time the commercial road that directly connected - through the lands of today's Greece, Republic of Macedonia and Albania - the two capitals of the Roman Empire, Rome in Italy and the new "Rome", Constantinople (Figure 1).


**Figure 1:** Via Egnatia and the settlements on its route, with indications of Kavala and Ohrid (re-elaborated from Cerasi, M. 1988).

The Ottomans, upon their conquest of the territories of north-west Anatolia and the Balkans, faced an already existing culture and developed towns so they did not need to build new ones. Following this case, it was more adequate to speak about Ottomanisation rather than Ottoman cities in a strict sense, mostly regarding the urban forms that were mostly inherited and rarely reconstructed. The Anatolian cities shaped during the Ottoman period with both their Islamic - Arabic counterparts and medieval cities of Europe were compared by a detailed analysis by Pinon in terms of streets, parcels (lots) and housing units [8]. He proposed a typology of urban texture based on, for example, street pattern, density of different grid types, and built density. First morphological specific of the early Ottoman towns following the creation of the Empery was the absence of walls. The consequences of these openings were numerous. City plans were no longer conditioned by an imposed frontier that limited extension and implied that the layout of the streets had to pass through gates.[9] However, this was not in the case of the Balkans where in many towns and cities we actually follow the pattern of development of the street and urban layout within the city or town walls entered through gates positioned towards the main land roads leading to the bigger administrative capitals (Thessaloniki, Kavala, Ohrid, etc.).

The Ottoman town was essentially a formation consisting of morphological structures and urban fabrics organized of quarters, road layouts and urban facilities and residential fabric within it, as well as secondary layouts and parcel divisions. It was also a multicultural town. The Ottoman urban morphology was dictated by the high density of the settlements, the constant quest for a view, good sun orientation and the position of the house on the street front. This morphology was a result of garden lots set along the isometric curves of the site 10]. The protection against fire was complied with set conditions as cantilevered floors open to the street. Following these laws, similarities in urban neighborhoods and housing were created. Developing a full adaptation to the topography of the city, neighborhoods included extending roads, varies in width required by the lack of space. The narrow streets of the neighborhoods created interesting perspective with the houses located on their both sides [11].

### 1.2 The core of the Ottoman town and the system of *mahalle*

The two most important social institutions in the Ottoman time were the family and the religion (mosque). These two were the poles of attraction of social life of the common man. The *mahalle* (quarter) as an entity was directly in relation with the family life and its conjunction with the religious structure (mosque, mesjid) created the most important unity of the town. The mosque or mesjid were the spiritual center of the neighborhood whereas the house was the foundation of the family life giving the socio- religious aspect of the town. The *mahalles* were usually divided according to the religion and the ethnicity of its inhabitants, but there were also neighborhoods inhabited by various religious and ethnic groups cohabitating to-gether. This was most noticeable in the commercial districts of the towns [12].

The appearance and the form of the houses were directly influenced by the *mahalles* and their formation within the organic disposition of the streets as well as the role of the woman in the Ottoman society.

The wooden residence, with its light structure, a height limited to two or three stories and a certain overall dynamism, given by the movement of the flaps and the projections of the bay windows (*cumba*), was, due to its extension on the urban territory, the element dominated by the Ottoman city and constituted the base from which the monumental buildings emerged, by contrast, and were distinguished by solid masonry ashlars stonework or stone alternating with brick courses and the stereo metric shape of the volumes that were surmounted in the mosques from lead-covered domes.

The Ottoman urban culture, in a very short period between the end of 16$^{th}$ and beginning of the 18$^{th}$ century, spread over a large area of the Ottoman Empire expressing many elements of its society. The town's society culture and its housing persisted and spread their influence up to the first decades of the 20$^{th}$ century and the Turkish-Ottoman house included many Slavic, Macedonian, Armenian, and Greek ethnic elements due to the numbers of ethnic artisans coming from these communities. It is still unknown if the Turkish-Ottoman house imposed itself on the Balkan communities that were not of Turkish origins or if it was a product of agglutinations of the multiethnic society [13].

## 1.3 The Ottoman house

There is a regional classification of the Ottoman houses that emerged as a result of the different geographical, topographical and climate conditions. The foundations of the Ottoman house are believed to originate from the regions of Marmara and Rumelia and then further were influenced in the nearby zones of the regions. The Marmara region had its impact on Rumelia whereas Istanbul influenced the lands of Anatolia. These two regions, Marmara and the town of Istanbul have special importance among the other six main house types divisions related to the geographical location. It is widely accepted that Istanbul house was a typical Ottoman house while the houses in the other regions are classified as provincial types with regional influences [14].

Sedad Hakkı Eldem was the first to pioneer the studies of the Ottoman house through its typological aspect. His researches resulted with classifications and schematic drawings based on the classification of the plans of the house's main floors, and the position of the so-called *sofa* (or hall) within the houses architectural layout.

According to Cerasi the Ottoman house was defined by the concept of the room. This space later continued to develop and had other necessary features added that also became its elements. The storey of the house is one of the elements that are particular in the Ottoman house. The house has the ground floor, built in stone with an entrance door and small or no windows at all. The first floor, or in some cases the last floor, in case of two story houses, was the place where the life was conducting [15].

Another important element of the Ottoman house is the Hall called in Turkish *sofa* ( or *hayat, chardak*, hall). The rooms always open into the hall. If the room was compared with an individual house, then the hall can be compared with the street and all the houses open onto it [16]. Depending on the position of the hall and the way the rooms open onto it we can determine the types of the Ottoman house [Figure 2]. This is how the four types of Ottoman house floor types distinct: 1. House without a hall (*sofasız*); 2. House with an outer hall (*dış sofalı*); 3. House with an inner hall (*iç sofalı*); 4. House with a central hall (*orta sofalı*).

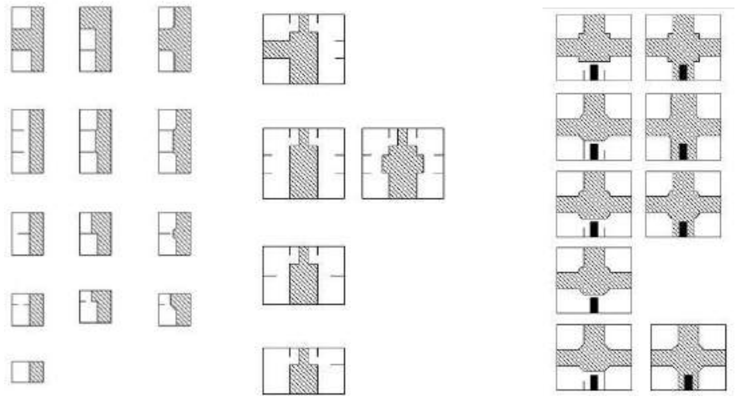

**Figure 2:** House plan types with 1. outer hall; 2. inner hall; 3. central hall (redrawn from Eldem, S. H. 1984).

The four-floor type plans further on develop by adding different functional architectural elements such as *selamlık*, harem, *eyvan*s or *köşk*s, but still kept the fundamental typological classification based on the position of the hall [17].

The Ottoman house plan types went through several phases of transformation and development and renovation of the inner space is presented passed three stages corresponding to three floor plan types. These three phases influenced Istanbul and then spread its influence over the whole region of Marmara and had also secondary influences in more far geographies of the Ottoman Empire. In some areas house plan types from previous periods continued to exist together with the contemporary style ones. This was more specific for the houses built in the Ottoman provinces. Because of this cohabitation of the plan typologies, especially in the provinces, the three period's division of the house plan type development by centuries is only applicable to Istanbul.

Before analyzing in details the cases of Kavala and Ohrid, from historical, economic and social point of view and regarding the domestic architecture and its features, we should underline that the similarities found in the house typology of both the towns, has been effected also because they belong to the same geographic region. Beside in fact a common practice in which – especially in the literature about architecture in the Balkans – prevails a sort of 'nationalism' to differentiate the architecture of each country, the substantial truth is that the common factors that unite the domestic architecture in this vast area between North Greece, Republic of Macedonia, and Albania are much more numerous than the distinctive ones.

According to Tomasella in his research about the vernacular architecture within the Slavic population from South [18].

> Very often the studies carried out on the architecture of tradition insist on specific regional typological peculiarities without emphasizing the overall linguistic unity of the whole study area. [...] What makes the prevailing typology in a city peculiar is the ability of the skilled teams of masons and master builders grouped in the *taife* to rework, in a very personal way, rich schemes and styles derived from other experiences in combinations well integrated into the urban or rural context in which they were placed.

The Ottoman house in the Macedonian region presents a variety of typologies due to the climate and territorial conditions but in general those houses are quite modest and in the above-mentioned cases of Kavala and Ohrid the climate conditions as well as the site's morphology are quite much similar.

Usually the residential house in these regions is based on two or three storeys, with compact plans and asymmetric formal shapes. The ground floor consists of a stone base of good work interspersed with wooden curbs; the upper floor in a wooden structure (*bondruk*) shows accentuated projections and generally has a double order of wide and regular windows. The pavilion roof is adorned with eaves, characterized by regular or curved tympanums connected to the façade walls [19].

## 2 THE URBAN SETTLEMENTS OF KAVALA AND OHRID IN OTTOMAN TIME

### 2.1 The penetration of the Ottomans in the Greek and Macedonian provinces

The Ottomans started relatively early the conquest of the lands towards Europe and even the capital of the Ottoman Empire moved soon as well from Bursa to Edirne, in Thrace, before finding the last destination in Constantinople. Beginning from the era of Sultan Murat I (1362-89), the Ottoman army, starting from the banks of the river Maritsa (Meriç) in Thrace, conquered all the Macedonian and Greek territories, including centers like Komotini (Gümülcine), Serez (1383), Thessaloniki (1387) and later Drama and Kavala. During the years 1372-95 Northern Thessaly was also seized and towns like Verria (Karaferiye), Neapolis (Yenişehir), Aksios (Vardar) joined the Ottoman lands. Thessaloniki (Selanik) and Halkidiki (Halkidikiya) were seized in 1392 and in 1397 and the Sultan Yıldırım Beyazıt entered Athens descending the Attica Peninsula. The entire Mora Peninsula was also incorporated in the Ottoman newly seized territories, but only in 1430, under Murat II (1421-1451), the city of

Thessaloniki was finally recaptured by the Ottomans. By this time, Macedonia became an Ottoman province and entered the administration of the Beylerbeyi of Rumelia [20].

## 2.2 Kavala

The port town of Kavala is situated by the shore of the Northern Aegean Sea, facing towards south the Island of Thasos and towards West the Chalkidiki Peninsula and Mount Athos. Its location is in a mountainous region near the sea and the town lays on a rocky peninsula. Since the ancient time, it was a small port used for trades by the ancient Greek populations called Neapolis and during the Byzantine domination was known as the city of Christ, Christoupolis. The town lays at the point where Via Egnatia was coming down to the shore because of the high mountains to the north. The caravans that were commuting along this route were at constant attacks by the corsairs lurking along the coast (Figure 3) [21].

**Figure 3:** View of the historical peninsula of Kavala from the port and its fortress at the top (Ivkovska, 2016)

The conquest of Byzantine Christoupolis occurred in 1387 and the scholars generally agree that ancient Neapolis (later the Byzantine Christoupolis and in Ottoman time Kavala) does not confirm an unbroken continuity of the settlement [22].

According to a codex from the monastery of Panteleimon on Mount Athos [23] "In this year (1391), the city of Christ, the city of Christoupolis, was destroyed by the incredible Mohammedans, and destroyed by the foundations, with speed, and the inhabitants were distributed to various districts and places".

All that remained was the castle, where the Ottoman guard settled in order to control the most important sea passage in north Aegean Sea, the strait between Thasos and Kavala, and the semi-mountainous passage north of the city's port [24].

Kavala's growth was namely thanks to Sultan Selim I who had completed the construction of the fortress of Kavala at the peak of the peninsula (see Figure 3), on the site of the earlier Byzantine fortifications [25]. Under the Suleiman the Magnificent Grand Vezier *Pargalı* Ibrahim Pasha Kavala started to grow into an important settlement on the coast of the North Aegean and continued its development under the five centuries of Ottoman rule.

## 2.3 Kavala's house plan typology

A typological and morphological examination of the buildings in the historic peninsula of Kavala makes it possible to assess their particular qualities and characteristics. A research conducted by the University of Aristotle lead to certain conclusions about the typology of the houses. By a close examination of the plans three basic types were set: types A, B and C. These plan types show a development of the space depending on the size of the plot and it's adaptation to the terrain as well as the needs of its users. Starting from the simplest plan with two rooms; one closed one semi-open. with two storey and closed balcony- sitting room and a vertical access in a form of a staircase (Figure 4).

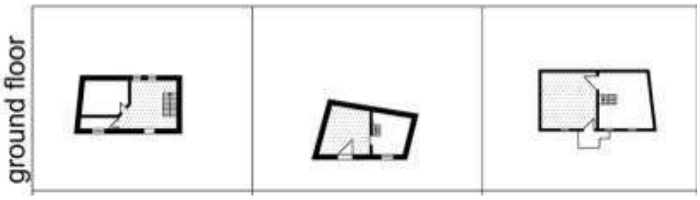


**Figure 4:** The type A house (redrawn from Kavala Intra Muros, 1992).

This balcony is actually the outer hall that we find in the first period of the Ottoman houses in Istanbul and is also referred as *chardak* in the houses from the territory of the Republic of Macedonia. Later this simples plan developed by broadening its front and adding more rooms to the hall, and an enclosed area (balcony-sitting room) where the stairs are located. This type A of a plan that is used by the Greek scholars when determining the traditional house plan typologies in Greece, corresponds with the house with an outer hall which is closed and from which we access the room or the rooms. The stairs are placed inside this hall. Type B is essentially a product of evolution of the parceling system and successive division of urban land. The buildings are two storey, narrow-fronted structures presenting a limited area towards communal spaces (Figure 5).

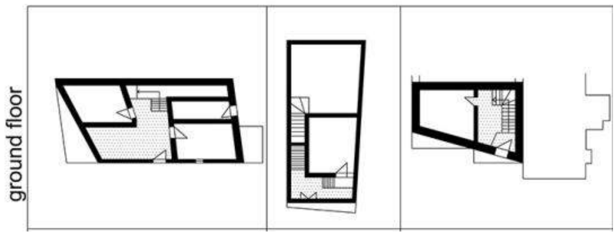


**Figure 5:** The type B house (redrawn from Kavala Intra Muros, 1992).

In this case, the sitting room which gives access to the other rooms does not have the major role that it has in the A type but sometimes can be so narrow that the rooms are positioned on either side of it and that way does not receive any direct light. In this type of a house we notice a transformation of the hall into some type of a corridor since it space became so narrow that only hosted the stairs and allowed access to the rooms. The term that is used for the hall here is the sitting room that in the B plan type lost its function. The stairs lead to a smaller enclosed room that is sometimes at the center of the house but its dimensions and position do not suggest a function of a hall since its very small dimensions and no functions in it at all [26]. The last type, C is probably more recent and is more urban in character (Figure 6).

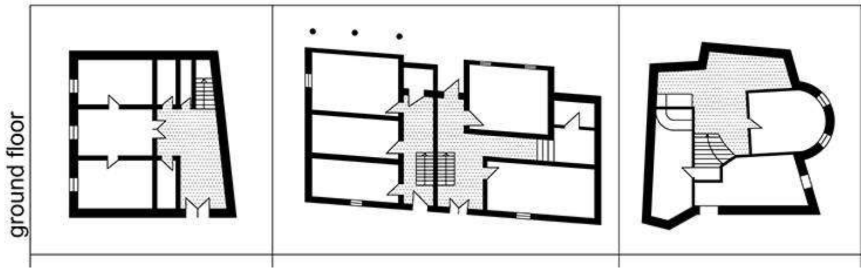


**Figure 6:** The type C house (redrawn from Kavala Intra Muros, 1992).

It comprises two storeys, is box shaped and can have a wide front. Some additional morphological features are visible. One feature that is in common to all variations of this type is the internal central sitting room with the rooms positioned symmetrically on either side of it [27]. There are usually two rooms on either side and they all open into the sitting area which runs through the length of the house with the stairs usually at the back. The type C presents the inner hall floor plan. The long inner hall spreads in the middle of the house and the position of the stairs is sometimes at one end of it or in the middle. This type of house plan corresponds to the split belly floor type (*karnıyarık*) which is a modification of the house with an inner hall that corresponds with the type B that is used by the Greek scholars and sometimes provides wider front (Figure 7). Given the examples from the plan types in Ottoman Kavala we notice that the central hall plan does not appear in the typology of the houses in the town. If the style itself presented nobility and social development, then we can conclude that the town kept its provincial character.

**Figure 7:** Double house in Kavala (Ivkovska, 2015)

## 2.4 Ohrid

Situated on the shores of Lake Ohrid, the town of Ohrid is one of the oldest human settlements in Europe built mostly between the 7th and 19th centuries. The town was already known in the ancient time as Lichnidos and in the 4th century BC, under the domination of the Kingdom of Philip II of Macedon was an important center that continue to be important even in Roman time [28].

The particular position of the town that goes from the 10th century military fortress built by the Tsar Samuil on the top of the hill - where the citadel called Gorni Saraj is located - down to the shores of the homonymous lake, makes Ohrid a truly unique place (Figure 8).

**Figure 8:** View of the Old town of Ohrid from the lake with the fort at the top of the hill (source: wikipedia.org)

Ohrid's architecture represents the best preserved and most complete ensemble of ancient urban architecture of South Eastern Europe. Slav culture spread from Ohrid to other parts of Europe and seven basilicas have thus far been discovered in archaeological excavations in the old part of Ohrid. These basilicas were built during the 4th, 5th and beginning of the 6th centuries and contain architectural and decorative characteristics that indisputably point to a strong ascent and glory of the town (whc.unesco.org). The structure of the city nucleus is also enriched by a large number of archaeological sites, with an emphasis on early Christian basilicas, which are also known for their mosaic floors. The convergence of well-conserved natural values with the quality and diversity of its cultural, material and spiritual heritage makes this region truly unique (29).

The old centre of Ohrid is a distinctively preserved, authentic ancient urban entity, adjusted to its coastal lake position and terrain, which is characterised by exceptional sacred and profane architecture. The architectural remains comprising a forum, public buildings, housing and sacred buildings with their infrastructure date back to the ancient town of Lychnidos (the former name of the town). The presence of early Christian architecture with the lofty basilicas from 4th to 6th centuries, together with the Byzantine architecture with a great number of preserved sacred buildings of different types from 9th to 14th centuries, is of paramount importance and contributes to the unity of the urban architecture of the city.

The overall coherence of the property, and particularly the relationship between urban buildings and the landscape, is vulnerable to the lack of adequate control of new development.

Special emphasis regarding Ohrid's old urban architecture must be given to the town's masonry heritage. In particular, Ohrid's traditional local influence can be seen among its well-preserved late-Ottoman urban residential architecture dating from the 18th and 19th centuries. The limited space for construction activities has led to the formation of a very narrow network of streets.

The town of Ohrid is reasonably well preserved, although uncontrolled incremental interventions have impacted the overall form of the monumental urban ensemble as well as the lakeshore and wider landscape. These are also vulnerable to major infrastructure projects and other developments.

The originally residential function of some buildings has changed over time, as have some of the interior outfitting of residential buildings, which were altered to improve living conditions. While reconstructions often used materials identical to those used at the time of construction, new materials have also been used on occasion, which presents a threat for the authenticity of the property.

## 2.5 Ohrid's house plan typology

The traditional house in Ohrid can be considered as a real building prototype for the entire regional area, where the usual building elements, such as stone and wood, which constitute the structural part of the house, generate an informal free plan in the interior that goes beyond the simple appearance as picturesque to become a real building type [30]. The Ohrid's vernacular architecture represents the traditional civic architecture of the town presented with the Ohrid house. This house can be characterized as a regional variant of the Ottoman type of urban house with specific indigenous characteristics, which are specifically related to the spatial plan and structural details. The climate imposed this house's spatial organization separated in two spaces - a winter and a summer apartment [31]. The house elevations were organized in such manner that every level received enough light, air and vista (Figure 9).

**Figure 9:** Robevci house, double house in Ohrid (Ivkovska, 2015)

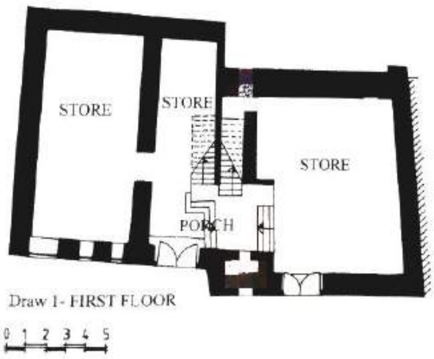


**Figure 10:** Floor plans of the Robevci house (split belly type)

The house had its ground floor typically encroached by the streets and the lot (Figure 10). The vertical distribution of the space was made through stairs positioned in the ground floor that lead to the upper floors onto a space called *chardak* (*sofa*, *hayat*, hall). This was the space from where other rooms were accessed. This hall allowed different distribution of the space around it with adjunctions of spaces creating different plan typologies (Figure 11).

The hall that is also called *hayat*, or *chardak*, is an element that prevails in the domestic architecture of the Ottomans and was used as an element in all its territories. *Rumelia* and its towns was not exception [32].

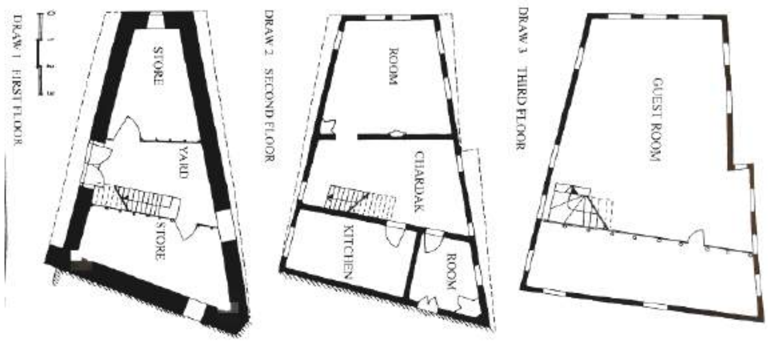


**Figure 11:** Kanevche house plan with inner hall and distribution of the space on both sides of it

As a result of the Ottoman domination in the Balkan region, typological analysis of the spatial organization of the 19th century urban house in Macedonia and those of the neighboring countries pointed out the presence of different basic types throughout the territory. The only exception are the very numerous "L" type houses in Macedonia, which was the most frequently used house type in Ohrid's civic architecture. The type resulted from the urban milieu of Ohrid and different conditions of the lot, the position to the neighboring dwellings, etc. The features of this type are result of different shapes and dispositions of the balcony (*chardak*) [Figure 12] and the porch in the different storey. Another typical solution for Ohrid residential architecture is the placement of the so-called winter kitchen on the mezzanine level but its most specific feature is its development through three or four storey.

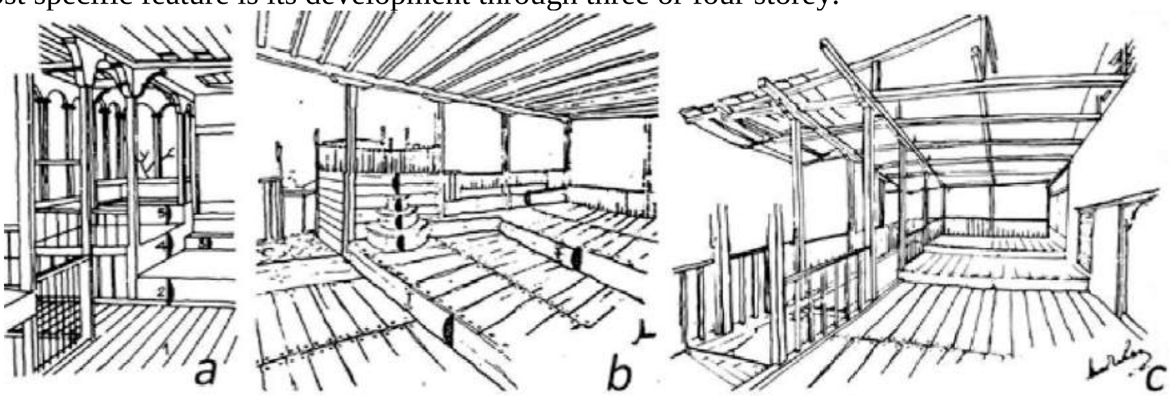


**Figure 12:** Multi-level floor of the balcony (čardak): a) Debar house; b) Muslim house in Ohrid;c) Christian house in Ohrid. (source: Хаџиева Алексиевска, Мерки, Антропоморфност и модуларнипропорции кај старата македонска куќа, Скопје: Студентски збор, 1985.)

The Ohrid house is often a building that grows in height, due to the lack of frontal space. Its house plan types are usually asymmetric as a result to their ground floors adjusting to the terrain.

**Figure 12:** View of the Kanevche house (Ivkovska, 2014)

A particular architectural expression of the house included a specific treatment of the yard, which became a part of the interior of the house, while the ground floor level of the house was closed towards the street. In this way, the cellar and the summer kitchen remained in the yard, and the winter residence was on the mezzanine level. The floors of the summer residence were opened to the street, towards the sun and the Ohrid Lake [33].

## 2.6 The constructive system and building material

Regarding the applied building techniques, the Balkan authors believe that material and technological base of a traditional Balkan house is found in the Byzantine masonry techniques, as well as in the Slavic techniques of building with wood. Besides, a great similarity can be found between the houses from Greece (Kastoria, Veria) and those from Galičnik in Macedonia, where we can search for the origin of the Macedonian rural house [34].

The traditional houses of Kavala and Ohrid share various traditional building materials. The structures were built of two main materials, stone and wood. Stone was used for the massive structural system in the ground floors and the wooden construction, the so-called *bondruk* system [Figure 13] was used for the upper floors of the house [35]. In this way the houses responded in the best way to the yearly climate changes [36].

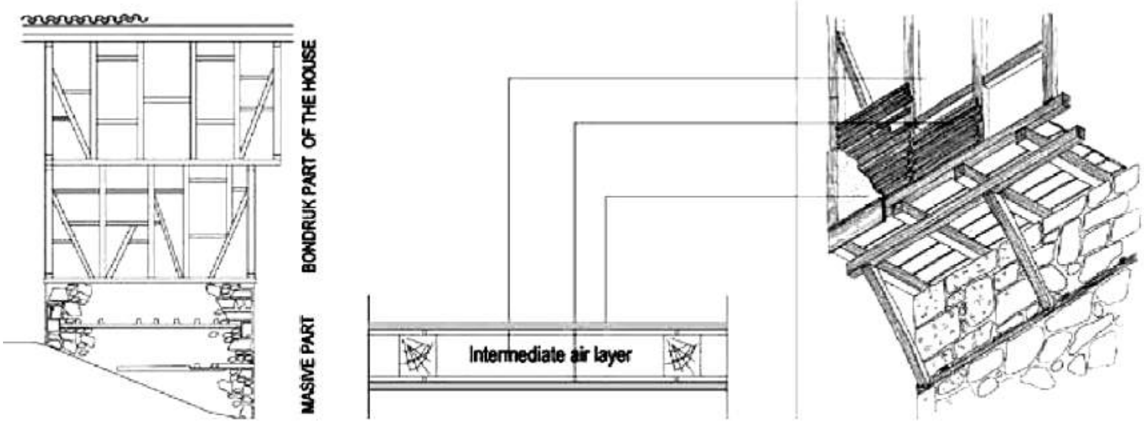


**Figure 13:** The wooden structural system of the houses (Tomovska, Radivojevic, 2016)

Plaster was applied to the exterior surfaces of the wooden (*bondruk*) wall frame that was covered with wooden lattices as a surface for applying the plaster (Figure 14). This plaster was made of different materials: hydrated lime or dry pulverized lime, river sand, and a small amount of a material with pozzolanic features (ground volcanic stone, powder dust from clay tiles or pozzolanic earth) [37]. Glass was used for closing the windows after this material be-came commonly used in the Balkans during the 19th and at the beginning of 20th century.

**Figure 14:** Wooden lattices applied over the wooden frame in the houses in Kavala (Ivkovska, 2014)

The massive system was constructed of stone walls, built of stone blocks and bonded with mud which was the most common binder, although there are examples where lime mortar was also applied. It represented a very durable structure. On the other hand, the *bondruk* wall which was constructed of basic timber frames consisting of post and beam structures with trusses or braces supporting at the corner points. This type of timber frames were widely applied, since it allowed the houses to be built quite quickly and the timber material did not have to be of a top quality [38].

## 3 CONCLUSIONS

Both Kavala and Ohrid, being towns of what was once known as *Rumelia* share more than just common history under Ottoman rule. Both towns have strong continuities in past starting from the Neolithic times passing through the Hellenistic, Roman, Byzantine, up to the Ottoman eras, when both sites underwent drastic physical transformations un-linked to those from the pre-Ottoman times. Both towns are located on a hill, with forts built before the Ottoman arrival on these lands. Both towns, especially Kavala, underwent major changes in the time under Ottoman rule, since there was no material evidence in situ from the previous eras. However, this was not the case with Ohrid. Even beside that both towns under Ottomans had their specific urban development that strictly followed the morphology of the terrain in creating the circulation of the urban space. Even though on the hill of Kavala Muslims lived, whereas in Ohrid the Christians were settled on its hill, the physical manifestations of the dwellings are very much alike. This had a lot to do with the specific of the terrain the dwellings were built on. The organic distribution of the streets ending with the typical dead ends, the perpendicular secondary stair like street network connecting the major arteries were typical Ottoman elements in the urban development of both towns. The street patterns directly influenced the house plan typologies, having limited space in the ground floors that also influenced irregular ground plan layouts and upper floors with attempt of creating more geometrically defined spaces with the use of cantilevered eaves over the ground floors. The hall that is also called *hayat*, or *chardak*, is an element that prevails in the domestic architecture of the Ottomans and was used as an element in all its territories. *Rumelia* and its towns was not exception.

In terms of constructive material, the dwellings in both settlements follow same pattern, ground floors built in massive stone masonry with mortar, and upper floors build in light wooden structure frames covered with plaster.

In both settlements, the feeling of similarity and spatial equivalency is more than visible and palpable. Both towns even today keep the Ottoman appearance, and even though scholars tend to take sides on whether these dwellings had Hellenistic, Byzantine, Ottoman, Greek, Macedonian etc. routs, one is certain, both settlements' civic architecture that we have in evidence today was built in Ottoman times, by local builders, using local materials, suitable for the climate which in both towns was very much alike. We definitely can draw parallel between these two towns in sense of appearance, spatial distribution, organic float of space, floor plan typologies and building materials and constructive techniques.

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# A TALE OF TWO CITIES: MYTILENE AND AYVALIK

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**Keywords:** Lesvos, Turkey, Wood-Frame, Vernacular, Rubble Stone, Ashlar, Mud Brick

**Abstract**

*Separated by a narrow strait, Mytilene, capital of the island of Lesvos, and Ayvalik, across the way on the coast of Turkey, are sister cities. The commercial buildings and houses are almost identical. The churches have the same unusual typology in both cities and the mosques could be interchangeable. Mytilene faces the Turkish mainland and is located on the extreme eastern coast of the island, as far as possible from Athens.*

*The connection between the two cities is unmistakable, and so is the method of construction. Both places are in active seismic zones. The construction technology involves ashlar or rubble-stone exterior walls. Interior load-bearing partitions are framed with wood studs and X-braces infilled with mudbricks. Projecting bays at upper stories consist of wood studs and lath with mud plaster coated with lime plaster. Wood-framed hip roofs are waterproofed with terra-cotta tiles. Along with the horizontal wood framing of floors, the roof plates act as diaphragms. The stone walls also contain wood studs and cross braces along with wood ring beams. Their purpose is to maintain the floors and roof in place in the event of an earthquake, which could cause the rubble-stone walls to collapse. This anti-seismic system of construction was common throughout the Ottoman world and minimizes loss of life.*

## 1 INTRODUCTION

The Greek island of Lesvos in the northern Aegean is situated a short distance from Turkey. A narrow body of water, the Strait of Mytilene, separates the capital city of Mytilene and its sister city across the way, Ayvalik, Turkey. Known as Kydonies in ancient times, Ayvalik was an Aeolian port serving ancient cities such as nearby Pergamon. Under the Ottomans, the city remained predominantly populated by Greeks. In fact, Mytilene is on the eastern-most side of the island, more closely connected with the Turkish coast than to Athens.

According to Homer, Mytilene dates to 1054 BCE [1]. Originally, it was located on a small island of its own, separated by a narrow canal from the rest of Lesvos, but the canal eventually silted up and the city became a peninsula attached to the rest of the larger island. Throughout history, Lesvos was known for its intelligentsia. The ancient Greek poets, Sappho and Alcaeus, and in modern times, Odysseas Elytis, were all from Lesvos. So was Pittacus, the ancient Greek statesman. Aristotle resided in Mytilene for two years. The city prospered during the Roman period. At various points in time, Lesvos was under the control of the Byzantines, until 1353 when the Byzantine emperor John V Palaiologos gave it to the Genovese Francesco Gattaluci who married his sister. In 1462, the island fell to the Ottoman sultan Mehmed II [2].

Ayvalik in ancient times was part of the territory Aeolis. In addition to Pergamon, it is also close to Assos and Troy, as well as Mount Ida, well known from ancient Greek mythology. The city came under the influence of the Ottomans in the 13$^{th}$ century. Following the Treaty of Lausanne's exchange of populations in 1923, the Turks who moved to Ayvalik were mainly from Mytilene, Macedonia and Crete [3]. On both sides of the strait, religious buildings were converted or abandoned, churches to mosques and mosques to churches.

## 2 ANTI-SEISMIC VERNACULAR CONSTRUCTION

Vernacular construction embodies architecture without architects. It is the know-how of the builders and long-term traditions that guide its construction. Local and readily available building materials are used. The selected materials and the design of the buildings are typically well adapted to the climatic conditions of an area [4]. If a region is prone to earthquakes, the structural durability of the buildings will depend on their capacity to withstand seismic activity. Vernacular construction develops over the ages through trial and error. Improvements come about by learning from past failures. This system of intangible heritage is perpetuated by the knowledge of the local carpenters and masons.

In the case of the anti-seismic vernacular heritage of Anatolia and beyond, the system relies on timber framing. Walls are constructed of rubble stone or ashlar or mud bricks bedded in weak mud mortars and finished with pozzolanic lime mortars, also relatively weak. This method can be found throughout the Balkans and across Asia. In Kashmir, in the 2005 earthquake, the anti-seismic vernacular, known as *taq*, which follows these principles, held up well in comparison to other types of construction [5]. As Gulkan and Langenbach point out, "In Bam [Iran, 6.6 $M_w$] in 2004, and in Turkey [Izmit, Kocaeli, Gölcük, or Marmara earthquake, 7.6 $M_w$] in 1999, it was the failure of contemporary buildings, not historic ones, which resulted in the high death toll" [6]. In the Bam earthquake, over 26,000 people died, and in the Izmit earthquake, 17,000. A few months later, in 1999 the Düzce earthquake (7.2 $M_w$) occurred, 100 km to the east of Izmit, but also with a strike-slip movement. Again, traditional wood-frame masonry buildings fared well [7].

During earthquakes, buildings must undergo deformation without loss of vertical load-bearing capability. The more rigid a building, the stronger it has to be to withstand shaking.

Therefore, in the context of anti-seismic vernacular construction, it is the flexibility that the wood framework provides that allows the structures to remain standing [8].

In both Turkey and Greece, anti-seismic vernacular construction involves the insertion of horizontal wood beams (*hatil* in Turkish, and *σανατζ* (sanage) in Greek), as well as studs with horizontal braces and X-bracing that are infilled with masonry, *himis* in Turkish. The bands of sanage behave like belts [8]. This method enhances the bearing capacity of the heavy stone ground floors, while providing tensile resistance [9].

The 2017 earthquake (6.3 $M_w$) in Vrisa, Lesvos, where nine out of every ten houses in the village were severely damaged and one woman died when her house collapsed [10], would seem to disprove this theory. However, Vrisa, as its name implies in Greek, is founded over ground hollowed out by natural springs. And in nearby Plomari, where serval houses also collapsed, the buildings were constructed on a soil-filled ravine. Furthermore, the houses of Vrisa are not timber reinforced, and this is not the first time the village was wiped out by an earthquake [11]. The author, who experienced the substantial aftershocks of this earthquake (up to 5.5 $M_w$) inside two different timber-laced houses on Lesvos, one in the village of Vatousa and the other in the city of Mytilene, can attest to the flexibility yet sturdiness of these types of buildings. With multiple aftershocks continuing for several months after the primary earthquake, the former house suffered minor damage in the form of vertical crack in the brick-dust lime-based mortar, and the latter, with volcanic-ash lime-based mortar, remained completely intact. Both houses are of load-bearing rubble-stone construction with ashlar cornerstones.

### 2.1 Architectural style

In 1839, the Ottoman Empire began to modernize in order to recover from an economic crisis. This led to equal rights being granted to all of the empire’s subjects, including the abilty to develop or sell real estate. Non-Muslims had already established relationships with Europeans and were in a better position to exploit these new rights. Architecture thrived in the Greek Orthodox communities, particularly on the coast, with a new types and styles of structures. Neoclassicism was popularized, being the architectural style of the new Greek capital, Athens. From its formal expression it was incorporated into local tradition. The first areas where it was adopted was Izmir and Ayvalik.

Prior to the changes to modernize the Ottoman Empire, the urban housing was either fortified (post-Byzantine and Frankish) or the older style of Turkish houses with low ceilings and latticed windows. Ayvalik, by the start of the 20$^{th}$ century, was considered a model Greek town. As Vasilis Colonas notes, “as far as architectural continuity is concerned, there does not seem to be a dividing channel of water between the islands and the coast of Asia Minor” [12].

### 2.2 Mytilene-Ayvalik vernacular typology

The vernacular buildings in Mytilene follow a very similar typology to those in Ayvalik. Townhouses tend to be square or rectangular in plan. The houses are generally two stories tall, rarely three. Layouts include an entry hall off of which are two rooms. The front room is a reception room (*living room*, *σαλονι* – saloni) and the back room is often a root cellar (*kiler*, *κατωι* - katoï) with soil floor. In larger buildings, the entry hall is centrally located and there are rooms to either side. The second story is accessed by a staircase located in the hallway. The upper floor will also have two rooms off the hallway. The front one tends to be a piano nobile, whereas the back one functions as a bedroom. The second-floor hallway is generally large enough to fit a day bed (*sedir*, *ντιβανι* - divani) at the opposite end.

The upper stories of townhouses frequently have cantilevered bays (*çıkma*, *σαχνισια* - sachnisia) supported on diagonal braces (Figure 1). The bays are often lightweight, constructed with lath and plaster (*bagdadi sıva*, *μπαγδατη* - baghdhati) or finished with wood siding [13], and the jetties help restrain the lower masonry wall [6] (Figure 2).

**Figure 1:** The Vareltzidena house in Petra, Lesvos is a fine example of Ottoman-era architecture constructed in the first half of the 18th century exemplifying the use of sachnisi. Note also the exposed sanages.

**Figure 2:** Typical baghdhati construction in Ayvalik, Turkey.

The construction materials are based on local availability, but the typology of construction also has to do with climate. Both Mytilene and Ayvalik have very similar climates: hot and humid in the summer and cold and wet in the winter. The lower story is constructed with thick stone walls; for a two-story building the thickness is 60 cm minimum. The upper floor's stone walls are 40 cm. The mud mortar and interior mud plaster serves, along with the thickness of the stone walls, to regulate the climate within the houses [13]. Buildings are also oriented to take maximum advantage of sunshine in the winter and shade in the summer; overall the effect is that of passive design [14]. Townhouses provide a continuous wall, particularly in the commercial districts, along relatively narrow streets producing shade (Figures 3 and 4). In more residential neighborhoods in Mytilene, the house can be set back from the street with a small garden in front that sometimes wraps around the back as well. In Ayvalik, the gardens tend to be at the back of the house.


**Figure 3:** Townhouses along a narrow street in Ayvalik.

**Figure 4:** Townhouses along a narrow street in Mytilene.

Townhouses sometimes also have doors leading to small balconies that project from the front façade. Typically, there is only one, sometimes centrally located in a reflection of Neo-classical aesthetic. Roofs are hip-style with terra-cotta tiles. The attic space between the wood-paneled ceiling and the roof tiles, also serves to regulate interior climate (Figure 5).

**Figure 5:** Typical roof framing of a Mytilene house before the *plywood*, *καπλαμαδες* – kaplamades (planks) are installed that will support the terra-cotta tiles.

## 2.3 Construction Technology

The vernacular buildings of Mytilene and Ayvalik have relatively shallow foundations, approximately 50 cm. The exterior stone walls are load bearing and laced with timber. The significance of the horizontal beams in the Mytilene-Ayvalik style of vernacular construction cannot be overlooked. During seismic activity they absorb some of the movement, allowing the load-bearing masonry buildings to behave in a less brittle manner. The weak mud and lime mortars permit slight deformations during earthquakes between wood frame and stone-work. The weight of the masonry keeps the timber in place while the wood framework contains the masonry [5]. In addition, at the floor and roof levels, the wood plates which frame joists and hip roofs act as ring beams [13] and behave as diaphragms during seismic activity [9].

Interior partitions are also load-bearing and anti-seismic in design. These are framed with woods studs, discontinuous horizontal members and X-braces, and infilled with mud brick (Figure 6). This is also typical of *dhajji dewari* construction in Kashmir, referred to as half-timbered by the British and *himis* in Turkish [8] and *τσατμας* (tsatmas) in Greek. Window openings tend to be long and narrow [13].

In this way, the timber framework serves to support the upper stories and the roof, so that even if the rubble masonry collapses, the houses remain standing and the occupants are not killed as a result of pancaking of the buildings. This behavior can be observed in abandoned buildings as well, where lack of maintenance has allowed the tile roofs to cave in, and rubble stone walls show signs of bulging as a result of the wash out of the mud mortar and associated displacement of chinking stones, yet the wood framework is still intact. Corners generally survive too, because even in load-bearing rubble-stone construction, this type of vernacular technology uses ashlar stonework to knit corners and tie the walls together (Figure 7). In exposed rubble-stonework, the sanage are not concealed, thereby providing surface area for the wood to dry when wetted and permitting any rot that occurs to be readily seen (refer to Figure 1).

**Figure 6:** Wood framework of an interior partition in an abandoned house on Lesvos. Interior partitions are load bearing and anti-seismic in design.

**Figure 7:** Townhouse in Mytilene with stonework exposed showing the corner quoins which knit the exterior walls together.

Townhouses are often stuccoed, considered superior weather protection for the façades (refer to Figures 3 and 4). This was traditionally a lime stucco but is more likely to be composed of a lime-cement stucco in current times. When stonework is left exposed, it is pointed with lime-based mortar that has pozzolans added. These can be volcanic ash (*volkanik küller, θηραικη γη* – thiraïki ghi) or ceramic dust (*horasan, κουρασανι* – kourasani). Pozzolanic mortars are considered soft and have large pores, permitting evaporation of trapped moisture. The same applies for lime-based stuccos [15].

The aspect ratio of the thick walls to the height of the buildings also helps during seismic activity. In addition, the continuous construction along streets allows the buildings to act in unison during shaking events.

## 3 CONCLUSION

Over the course of the centuries, traditional builders learned to cope with seismic activity, ensuring that buildings survived earthquakes with repairable damage and without huge loss of life. Across the Balkans, Anatolia and beyond, that system involved lacing wood framework into load-bearing stone construction in such a way that even if the stonework partially collapsed, the floors and roof remained standing, supported on the wood framework. There is some evidence, that this system may "have followed patterns of migration and cultural influence over centuries, such as the spread of Islamic culture from the Middle East across Central Asia" [8]. Certainly, it is well represented within the former Ottoman Empire.

The ductility provided by the wood framework combines with the rigidity of the masonry to resist the horizontal movement of an earthquake. The brittle masonry may crack, but the wood maintains the vertical load-bearing capacity while containing the masonry. There is adequate flexibility to permit movement, while the friction between masonry and wood produces a damping effect, dissipating the energy produced by the earthquake. However, this can only occur if the mortar is weak, either lime-based or mud [8].

As is evidenced by earthquakes in the past 20 years in the countries of Greece and Turkey, this type of construction performs robustly during seismic activity. The same cannot be said for contemporary buildings, probably due to shoddy construction and lack of knowledge about and experience with newer forms of building materials like steel and reinforced concrete [6]. Therefore, in earthquake zones, a concerted effort should be made to preserve and reuse this type of vernacular construction, and consideration should be given to adapting the lessons learned to contemporary architecture. By doing so, the craftsmen who are still familiar with this method of construction can be encouraged to pass on their knowledge to the next generation, so that the ability to repair and maintain these buildings is not lost. Speaking from experience on Lesvos, where the author has restored four of these style buildings, as well as assisted others in maintaining their own, this traditional knowledge still exists there even though routinely, lime-based mortars and limewash have been replaced by cement-based mortars and commercial paints. However, there is a willingness to learn, and the author successfully trained local masons in the mixture and use of both brick-dust and volcanic-ash lime-based mortars, as well as lime-based plasters and limewashes.

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# THE OTTOMAN RESIDENCE RECOGNITION IN ALGERIA, JUNCTION AND VARIANCE. ILLUSTRATION OF CONSTANTINE BEY'S PALACE

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**Keywords:** traditional architecture, ottoman, Algerian heritage, template definition.

## Abstract

*From the 16th century, the North African region was annexed to the Ottoman Empire, remained so for more than three centuries. Located at a significant distance from the Ottoman radiation center "Istanbul", and its cradle "Anatolia", these Arab provinces, by their cultural and politico-militarian entity were about to experience a profound transformations in both urban and architectural development, we casted the shadow on the Algiers regency. The question was: what was the Turkish architectural contribution into the Algerian traditional model?*

*Many researches noticed that the sighted architecture in the Ottoman Maghreb, reflected a specific situation, which evolved around the quasi-independence. Owing to this observation, we investigated a study, to identify this form relating to historical evolution, and the reference style. We provide a work of documentation, followed by a practical part about architectural analyses and sampling. As a result, we collected, categorized and modeled all the required data characterizing this model. As an illustration, we chose the Palace of Ahmed Bey in the province of Constantine, this master-piece (built between 1826-1836), although it has undergone some consolidation, the building has resisted through time, climate and use. This vast palatial overall, intended to be the residence and the center of government of the last bey of the Turkish era in Algeria, is composed of several buildings. Distributed on three levels, its constructive aspect indicates that the building lies on mixture of systems and materials, provided from different places, varying between the timber frames, the stone walls, and on columns system.*

*To sum up, this palace formed a vernacular model, combining local constructive techniques of the millennial city of Constantine, fused with the Mediterranean roots, and elements of Turkish influence; all of them were translated together to give this unique heritage model.*

## 1 INTRODUCTION

Algeria conceals diverse architectural and urban heritage, it forms a patchwork of properties and styles; that we would like discover more and more. For the millennial metropolis of Constantine[1], the Ottoman period was only a chapter[2] in its long and tumultuous evolution. In this nest that spreads over the "old rock", where radiated several civilizations, we find the traditional medina, which inaugurated a new phase of its history in 1522[3], by its setting under the Turkish protectorate. This episode officially ended December 15th, 1837 with the downfall of the province and the rebellion of its leader[4].

We were interested by the architectural legacy of this period, which included a summary of the transformations that have occurred on the city morphology. Where Constantine like most Maghrebian medinas presented a complex and compact urban fabric; drained by a bundle of streets and alleys. Houses, resulting from juxtapositions, then characterized by their central courtyard, with round tile roofs. It is at the heart of this composition, where the provincial political power center was imposed (see Figure 1).

Therefore, this palatial ensemble called the *bey's palace* exhibit for us a synthesis of the ottoman architecture in Algeria:

"*Artists and travelers have often mentioned it as one of the most beautiful and curious Arab monuments that can be found in Algeria*"[5].

### 1.1 Research subject

During the time of the last bey in the history of the Ottoman era in Algeria, Hadji Ahmed Bey a persona who marked the turning point6; that was built this monument, the most completed model of architecture[7]; considered as the last palace built in Algeria during the turkich

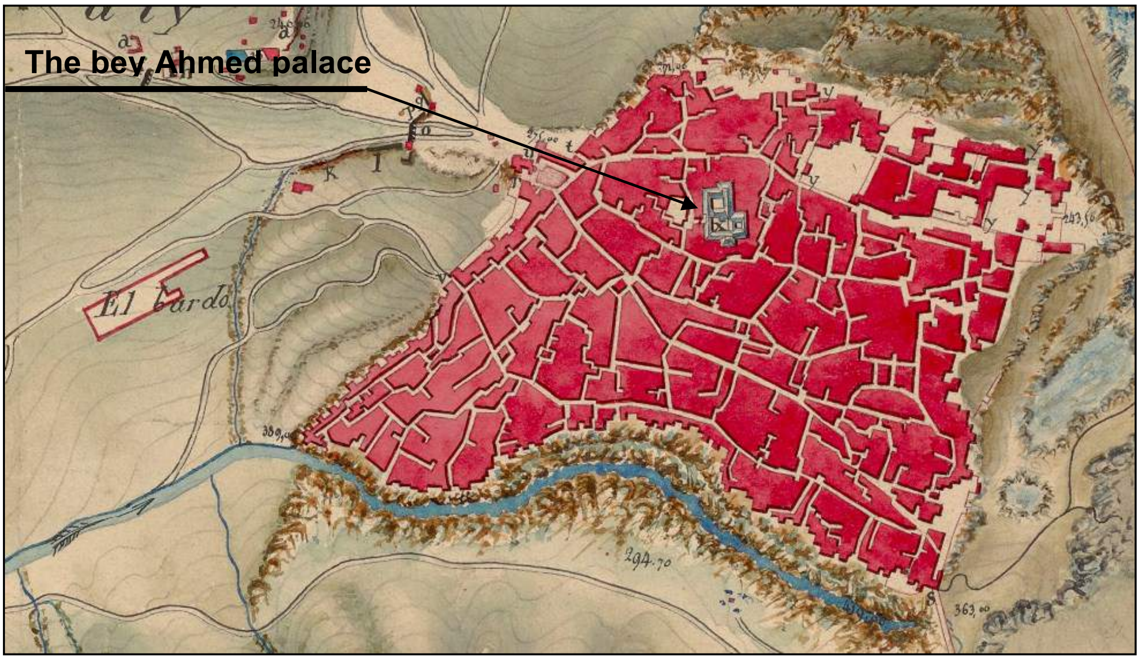


**Figure 1:** Constantine between 1836 and 1837, the rock and the situation of the bey's palace.
Source: Constantine and its surroundings, raised and drawn by the undersigned engineer's lieutenant SCHETTLER, http://gallica.bnf.fr/ark:/12148/btv1b530293773/

presence. Therefore, it possesses eminent archaeological importance[8] .To this day it is a complete and, probably most significant artwork that this heritage conceded in the North African region. What set up a building that responded at once and with logic, to the imperious necessities of manners and climate of the country.

This monument[9] in question is the object of our research program; it represented the emblem of the power at the time of its construction and even during all the period of French colonization in the Constantine's province.

It is at this level where we have shed light on the following problematic, indeed, how is characterized architecture of this palace?

Of course, any architectural analysis must take a reference in the temporal and cultural framework; so, is there any common expertise that we can find between this Algerian architecture and the other Ottoman types of the same period?

On the other hand, our investigation focused on a critical process; thus, can we go back on a principle of transmission or architectural influence, which has crossed the North African provinces, with the arrival of civilians and militaries from all other Ottoman territories?

## 1.2 Research objectives

In this paper, we target to provide an illustration of this local architectural model, but considering it in the overall context of the Ottoman Empire. For that, our study focused on highlighting this heritage not well known, and showed its characteristics.

In addition, we hoped determine the place of this architecture in relation to others Ottoman models. Moreover, we tried to elaborate an iden-tity card of this architecture as being a vernacular model.

**Figure 2:** aerial view of the bey's palace of Constantine.
Source: Yann Arthus-Bertrand, *Constantine vue du ciel*, filmography [on line], realized on august 2013, published by GILARD Serge, on February 12th, 2014. Accessible from the URL : https://www.youtube.com/watch?v=LrsZ-MbEZ64

### 1.3 Methodology approach

Several studies had found the specifici-ty of the fragment of Ottoman architecture in Algeria; indeed, we could detect its de-tachment from the Ottoman imperial mod-el[10]. In this paper we are conducting our reflection towards a prospection, which made it possible to recognize this form re-ferring to two scales, the first dimension is temporal (which we call historical), and the second one is artistic (making a stylistic at-tribute).

To do this we went through two succes-sive levels, we started analytical documen-tation work, and then we moved on to the practical, like sampling and architectural survey; from synoptic analysis of different cases[11], which allows to establish a charac-terization of the initial model.

Consequently, we were able to establish a file summarizing the different influences that this type of Algerian architectural style had during the time of Ottoman protectorate. In addition, to distinguish the existence of the turquising influences, exceeding several European, Asian, and African countries; in what way does this geographical extension affect the architectural design?

It is through an application on our cho-sen case that we expose our contribution; this monument illustrates many specific characteristics, because of its conservation state, in spite of the successive arrange-ments occurred, but it still offers a complete interpretation of its genesis by its almost 200-year-old architecture.

## 2 ANALYSIS

The example we have considered for this study is the palace of Bey Ahmed in Constantine, capital of the Turkish beylicat of eastern Algeria. This old Mediterranean city has seen coexist and superimpose on its land several civilizations. In this paper, we presen this case study according to the fol-lowing aspects:

- spatial configurations;
- The constructive aspect;
- The employed materials.

**Figure 3:** view under a simple gallery, bey's pal-ace of Constantine.
Source: BOUNOUIOUA Ferial, 2016.

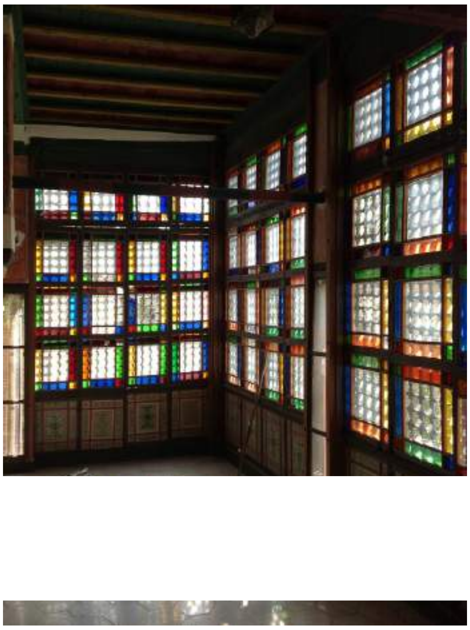

**Figure 4:** moucharabieh in colored glass, bey’s palace of Constantine.
Source: BOUNOUIOUA Ferial, 2016.

The residence of the Bey of Constan-tine is a vast palatial ensemble, was intend-ed to be the residence and the center of government of the last Turkish chief in Al-geria, it consists of several buildings, orga-nized around two spacious gardens (see figure 2&3), and two others courtyards. In-cluding the Bey' kiosk, and his private house; the divan apartment; the courthouse (see figure 5). We find also, the harem apartments (see figure 6), and various pavil-ions and several other service dependencies.

From the constructive view point, the whole monument is distributed on three levels. On the ground the building rests on the large cut stone blocks recovered from the Roman sites (see figure 7), without for-getting that in large part it is superimposed on other visible vestiges in the basements, which gives an exceptional archaeological stratification. The structure was based on a mixed carried system, the first using marble monolithic columns to support the porticoes (see figure 3), to create a set of single and double in arcature galleries. Maintained by horizontal wooden tie-rods where arcades are executed in solid brick (see figure 8). In addition, there was a second type of struc-ture, supported by the load bearing walls (see figure 10), which apparatus was found-ed on a stone base, and executed in rubble intertwined with a solid brick, than covered with a mortar of sand and lime (see figure 11). These two described bearing systems ensure the function of carrying the floors (see figure 9), which in turn, rely on a sys-tem of wooden beams (see figure 12). The roofs taking a slight slope, it rest on wood-en frames, and the whole is covered with tiles.

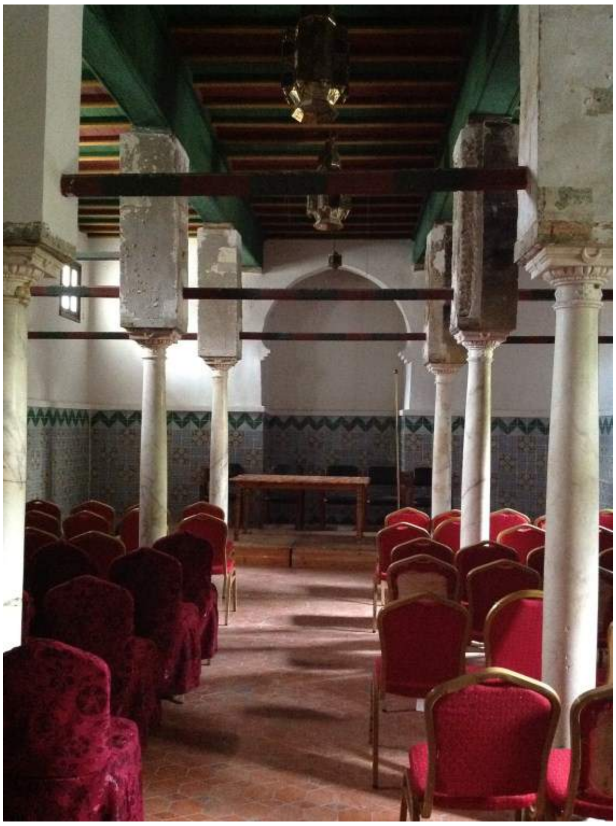

**Figure 5:** inside a room of the tribunal, bey's pal-ace of Constantine.
Source: BOUNOUIOUA Ferial, 2016.

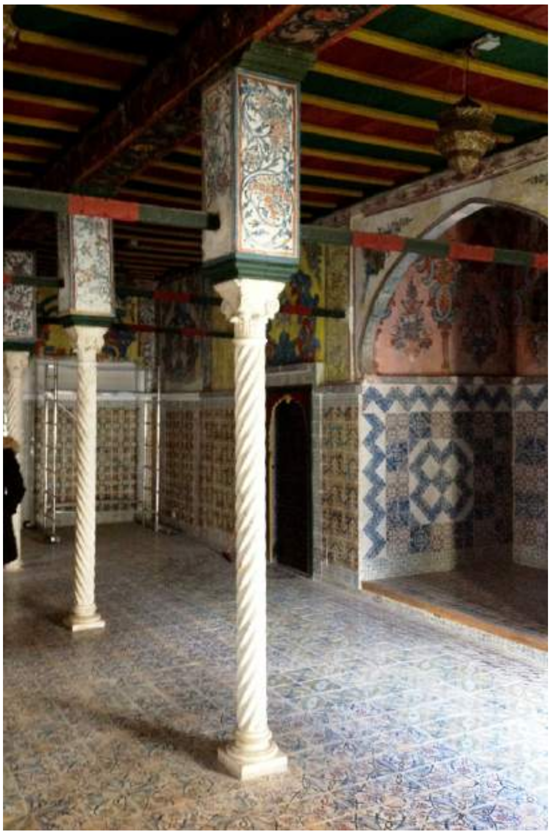

**Figure 6:** the bey's Ahmed daughter pavilion.

In a general overview, this palatial resi-dence is an exhibition of the of power and financial capacities of its founder, it was also, an adaptation of art and construction to the local conditions of the Medina of Constantine; in terms of its location, in-stalled on a sloping terrain, which appropri-ate solutions have been employed. Equally for the management of the climatic speci-ficities that dictated the spatial and material configurations. Given the vulnerability of the old constructions to the aggression of time we already, especially during the earthquakes that hit the city; the palace has certainly been appeared by some degrada-tions, we already mentioned the main inter-ventions[12] on the monument, where the first consolidation's operations occurred around 1856, than another in 1861, and again in 1919. Moreover, various rehabilitation ac-tions followed by restoration took place be-tween 1982 and 2007.

## 3 ARGUMENTATION

In this research program, we tried to see better e on one model generated in the palace of Ahmed Bey in Constantine; where we opened the parenthesis on its vernacular consideration. Actually, the building has been developed over time with taking care about the conditions of its particular site, by transposing them on local architectural and urban traditions. It is very important for us to explain that the monument incorporates many elements reused, recovered from the bourgeois houses of the city, and from an-tique sites located around. It is also interest-ing to note that the construction of the palace was initially conducted on the old buildings rearrangement, which date back to different eras prior to the 19$^{th}$ century[13].

**Figure 7:** ancient stone blocs as a base, bey's pal-ace of Constantine.
Source: BOUNOUIOUA Ferial, 2016.

**Figure 8**: the use of wooden tie between the arcs.
Source: BOUNOUIOUA Ferial, 2016.

**Figure 9**: floor covered with wooden ceiling,
Source: BOUNOUIOUA Ferial, 2016.

It is also good to return to the point where this monument has similarities with other buildings elsewhere, with which we had the opportunity to find the reference to other exogenous types, developed in other Ottoman zone during a near time to our ex-ample. We took two cases, the model of the Çakiragha bourgeois house (see figure 13 )in Izmir dating back to the 19th century (Turkey). Again, the model of eastern Ara-bia as the palace el Azim (see figure 14) in Hama of the 18th century (Syria). However, how the link was established with these ge-ographically and culturally distant refer-ences, still in search of a developing.

The study of this example as a local variant of Ottoman architecture had demon-strated the existence at least of three com-bined references:

- The first molding was of Islamic architecture, a common root already developed further under the Ottomans;

- The second was about the permanence of artistic traditions and local know-how, influ-enced by the Mediterranean plural position;

- The third concerned the contribution of the influence of Ottoman Anatolian architecture, oc-casioned by the arrival of the Turks in the coun-try and the exchanges due to these circumstances.

**Figure 10**: apparent composition of a mixed bearing wall, bey's palace of Constantine Source: BOUNOUIOUA Ferial, 2016.

**Figure 11**: bearing walls relieved by arches, Bey's palace of Constantine.
Source: BOUNOUIOUA Ferial, 2016.

## 4 CONCLUSIONS

During this study, we have been able to dis-cern some junctions and variances present in the palace; that explains its hybrid character was the convergence of various currents. This has shown us, that it presents a model developed according to the local living of its medina. Where this traditional city persisted face of mutations of time and of use, and maintained the model of its development, which was reflected in the reference of the palace of Bey Ahmed. The oeuvre that decisively closed the end of the Ottoman period in Algeria, gave evidence of a social, cultural and artistic reality as well as local techniques to reconsider.

At the end of this paper, we can suggest that this monument of architecture forms a prototype that deserves to be valued and preserved in the image of its richness. Indeed, going beyond the temporal and con-ceptual scale that can be found in the sharing of architecture history. It is important to recommend that this architecture merits to be recognized according to its own attributes. It has all parameters of patrimonialization ,that go outside the local levels of the Constantine's city or the Algeria's country. A vernacular art of building rooted in Mediterranean traditions that have been transmitted between several civilizations. Therefore, we have the responsibility to keep this affluence as an added value to the universal heritage.

**Figure 12**: wooden beams support.
Source: BOUNOUIOUA Ferial, 2016.


**Figure 13**: courtyard view Çakiraga house.
Source:http://www.discoverislamicart.org/database_item.php?id=monument;ISL;tr;Mon01;32;fr

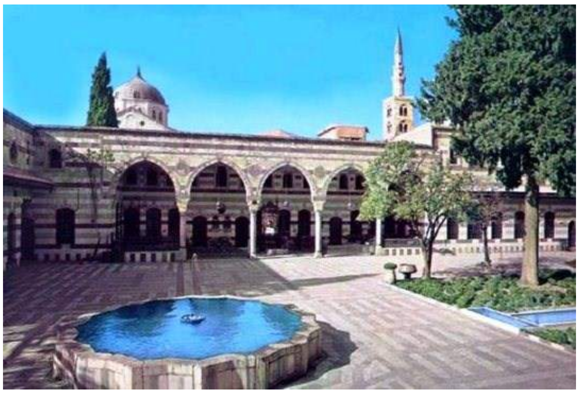

**Figure 14**: courtyard view of al Azim kasri. **Source:** http://adm180.blogspot.com/2011/06/adm-ou-azm-historia-da-origem-da.html

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# IMPORTANCE OF LOCAL BUILDERS ON THE SUSTAINABILITY OF ROCK-CUT STRUCTURE TECHNICS IN CAPPADOCIA REGION

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**Keywords:** Rock-Cut Structure, Material Characterization, Local builders, Cappadocia, Sustainability, Traditional-Modern Technics

## Abstract

*Cappadocia is a region where man-made carvings are integrated with naturally shaped landscape. Rock-cut structures of this region were built since Hittites. Local builders conveyed their knowledge to the next generation for thousand years and these buildings survived. Today, rock-cut structures especially warehouses of various fruits are built by using modern tools and technics, but some of them cannot survive more than 10 years. In this study, architectural examples built in Cappadocia were analyzed to understand the local builders' traditional construction technics and methodology. Data obtained through in-situ and laboratory tests and shared knowledge by local carvers are combined. The role of builders, the effect of their knowledge on sustaining of rock-cut structures and how this sustainability saved buildings from lateral loads like earthquakes were found out and shared.*

# 1 INTRODUCTION

Many civilizations have lived for thousands of years in Anatolia, and Anatolia is a home to many historical monuments and settlements that these civilizations left for future generations. Historical buildings and natural sites, thousands years old in Cappadocia Region, were taken to the World Heritage List in 1985 by the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Anti-seismic settlements and monuments were constructed with traditional technics with traditional tools for centuries. The hesitation of transferring the knowledge and skills that constitute the anti-seismic cultural heritage of Cappadocia causes serious problems in heritage conservation. To solve this problem, it is necessary to integrate traditional techniques with moderns. In this study, the compressive strengths of the 9 samples taken from four different areas in the region and the outputs of the knowledge and expertise obtained by 2 builders and stonemasons of Cappadocia Region were compared. The purpose of this comparison is to gain information about the correlation of builders' rock definitions and results of compressive strength tests, and to combine the knowledge gained by the local masters with modern technical building and carving methods. Thus, the techniques used in structures that have survived disasters for thousands of years in the region can be sustained.

# 2 CAPPADOCIA AND ROCK-CUT STRUCTURES

Cappadocia is located in the Central Anatolia, Turkey. Cabinet Council of Turkey identified the region as "The Privileged Region for Touristic Development" in 1973 and borders of the region were determined as the whole area of Nevşehir and Soğanlı Valley of Kayseri (Figure 1).

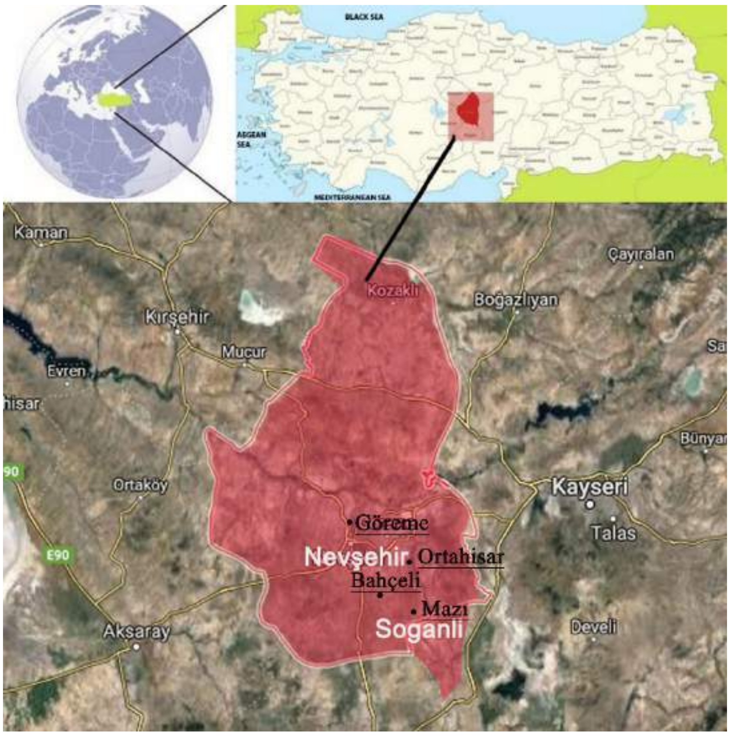



**Figure 1**: Cappadocia Region's approximate borders and places of sample

There are three types of structures according to construction types of buildings’ structural systems. These structures are masonry, rock-cut&masonry and rock-cut [1].

Rock-cut structure is a massive rock, which is formed by carving it in place, on the ground or underground for the purposes of making space [1] according to the Earthquake Risk Management Guide for Historic Buildings [2]. Historical rock-hewn structures in Cappadocia are categorized according to their usage intend into three group. These are religious, military and civil architecture buildings (Figure 2). Hundreds of civilizations left many kinds of rock carved structure heritage in Cappadocia.

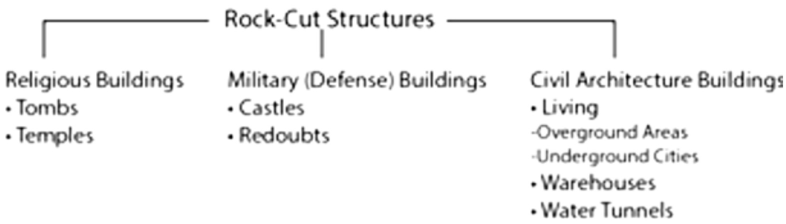



**Figure 2:** Types of rock-cut structures according to their usage [1]

In general, volcanic eruptions existed in the thousands of years of disaster history of the Cappadocia Region. The volcanic activity of Erciyes, Hasan, Develi, Melendiz, Göllü and Keçiboyunduran mountains which are in or around the region continued until 10 thousand years ago [3]. The region is generally located in the third and fourth degree seismic zone [4]. Although there are fault lines in various lengths in the region, they are not active. The largest earthquake occurred in 1940 in the Cappadocia Region and its magnitude was 5,2 [5].

## 2.1 Carving Techniques in Cappadocia

Because of the volcanic activities in the Cappadocia Region, thick layers of tufaceous rocks that are constituted by molten lava and basalt flows covered an area of 10000 square kilometres [3]. Many of these tufaceous areas provided opportunity for the formation of fairy chimneys, natural rock formations, and constitution of various man-made rock-hewn and masonry structures.

The rock-hewn structures in the region were carved traditionally by using hand-made tools for more than thousands of years (Figure 4, Figure 5). Figure 3 shows the construction stages of rock-cut and masonry building by hand carving. The rock-cut units that are created according to the space requirement can be formed horizontally or vertically. In addition, when the rock is being carved, not carved but fallen rock parts can be used as a stone to build the masonry structure (Figure 4c).

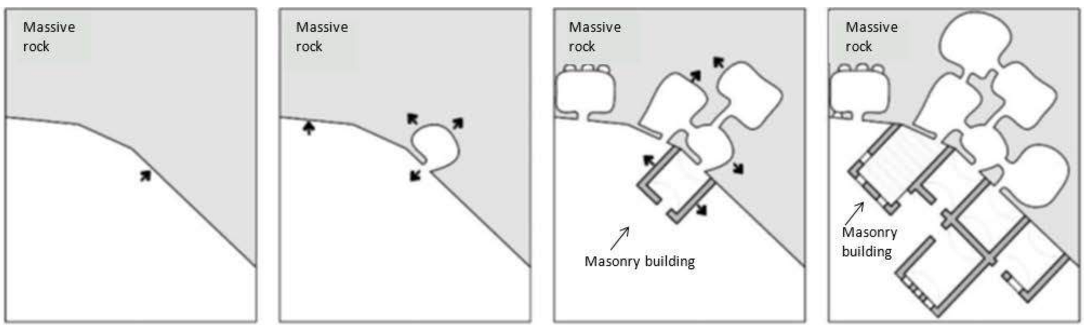



**Figure 3:** The construction stages of rock-cut and masonry building [1]

When rock is being carved by hand, tools like pickaxe, bellow, spike and sledgehammer are usually used (Figure 4a). The rock can be directly carved, or a part of the rock can be notched and fallen as a whole (Figure 4b). Stones can be formed from the entire fallen rock part for using in the masonry buildings (Figure 4c). In large rock carving areas, the airshafts are opened to allow the space to vent. (Figure 4d). A building master or stonemason can carve approximately 0.5-1 $m^3$ with 8-9 hours of work per day.

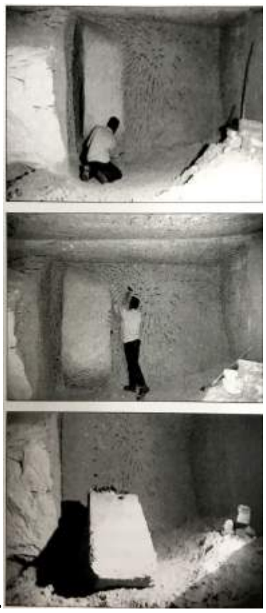
a.  b.  c.  d. 

**Figure 4:** Steps of carving by hand a. carving tools- pickaxe, bellow, spike b. Notching and rock falling c. Constituting stone from rock d. Drilling air shaft [6]

a  b. 

**Figure 5:** Rock-cut building carved a. by hand b. by an excavator

Rock-cut warehouses, which are civil architecture buildings (Figure 2), are the most common rock-hewn structures in the region nowadays. These warehouses are generally used for storing thousand tons of potatoes of Central Anatolia and citrus fruits grown in the southern part of Turkey (Figure 5a and 5b) for climate condition advantages. While productions are conserved in rock-cut warehouses, electricity is not made use of to preserve them and their weights increase by 25% [6] thanks to the natural material characteristics of rock formation. Thus, traditional and manual carving technics are not sufficient to satisfy increasing demand of rock-cut warehouses. As a result, the first mechanical carving experiments in the region were made with a tunnel-boring machine in the 1970s [7]. Mechanical carving started to be used generally to carve rocks by construction companies in the region 30 years before and is continued by modern excavators currently. In addition, mechanical carving is 40% more economic than hand carving according to Erguvanli and Yüzer [7].

Fast rock carving demand and the inexpensiveness of mechanical carving reduced local builder demand and the number of masters has been decreased year by year. Any rock-cut building code or standard was not created until 2017 [8]. While millions of cubic meters of rock hewn structures are built with mechanical carving, collapses and instabilities are observed in the newly constructed places, as no help was demanded from the master. However, even in the case of disasters, the local masters did not encounter these kind of structural problems. Builders generally know which rocks can be carved or not to constitute a place since they have years of experience.

## 3 MATERIAL CHARACTERIZATION OF CARVED STONES

In 2009, various conversations were made with 2 local builders who are 45 and 50 years old and in 2014 laboratory tests were made for understanding and explaining the material characterization.

### 3.1 Local Builders' Material Characterization

Local builders grouped region's rocks with the knowledge and skills they have acquired for hundreds of years, taking into account of the features such as stiffness, colour and content of rocks. Some features were identified according to these classification and some generalizations were reached. For instance, according to the local master, as the stiffness of the rock increases, the internal cracks increase and creating a place in the rock becomes risky [6].

The material characterization and classification made by the local masters are as follows:

- <u>Stone rock (Taş kaya):</u> This type of rocks is the most difficult type to carve. They have too many cracks especially intrinsic. Generally, Ortahisar rocks are in this type. It is suitable for home or warehouse construction, but it takes time to carve [6].
- <u>Yellow rock (Sarı kaya):</u> It is defined as a rock that is difficult to carve, resistant to erosion and cracked. Such rocks are stated to be suitable especially for house construction. Because of its colour, it is called yellow [6].
- <u>Clayey rock - White rock - Magnific rock (Killi kaya-Muazzam kaya):</u> This type is the most suitable type for rock-cut warehouses. It contains high amount of moisture in itself. Due to its low erosion resistance, carving houses in this rock is not recommended or external plaster is required to save building from erosion. Rocks of Uçhisar, Göreme and Kavak are generally in this group [6].

There is also ash rock. Crushing of ash rock is easy and its loading capacity is low. This rock is not incorporated into the classification as no space was built in it.

### 3.2 Result of Uniaxial Compression Strengths and Material Characterization

Rock samples of some rock-hewn structures in the region were collected to determine whether there is a correlation between the classification, which was done by of local masters according to stone stiffness and the compressive strengths of the rocks.

For the uniaxial compressive strength test, the fallen parts of rocks were collected from nine different places in four areas (Figure 1). These places are a church in Göreme Town (MHK-1), three different places of a castle in Ortahisar Town (OK-15-20-23), inner part (MA-02) and outer part ( MU-01) of the underground city in Mazı Village, a warehouse (DE-01) and two places of a house (EO-03, EA-04) in Bahçeli Village.

Uniaxial compression strengths were determined with the methods defined in TS EN 1926 [9]. Values of them are on the Table 1.

Table 1. Uniaxial compression strength values and classification of rock

| Sample | Sample place | Building function | Construction Year | Compression strength, MPa | Rock type[1] |
|---|---|---|---|---|---|
| **MHK-1** | Göreme Town | Church | 3-6. century | 22,21 | Semi-hard rock |
| **OK-15** | Ortahisar town | Castle | 2. century (BC) | 9,55 | Weak rock |
| **OK-20** | | Castle | 2. century (BC) | 31,77 | Semi-hard rock |
| **OK-23** | | Castle | 2. century (BC) | 14,23 | Weak rock |
| **MA-02** | Mazı Vil-lage | Underground city | 5-1. century (BC) | 4,06 | Very weak rock |
| **MU-01** | | Underground city | 5-1. century (BC) | 15,90 | Weak rock |
| **EA-04** | Bahçeli Village | Barn | 20. century | 3,32 | Very weak rock |
| **EO-03** | | House | 20. century | 3,95 | Very weak rock |
| **DE-01** | | Warehouse | 20. century | 3,13 | Very weak rock |

According to Yıldırım and Gökaşan's [10] classification of rock compression strength, compression strengths of the rocks of Cappadocia Region are between 3,13 and 31,77 MPa. And, there are three type of rock, which are very weak, weak and semi-hard rocks in the region.

## 4 CONCLUSIONS

As indicated in the Charter on the Built Vernacular Heritage [11], traditional heritage embraces not only the physical form and fabric of buildings, structures and spaces, but the ways in which they are used and understood, and the traditions and the intangible associations which attach to them. The building masters are the only people who transfer the knowledge of traditional building culture and tradition of architecture from generation to generation. They do not generally write about their knowledge and expertise, but usually transfer and sustain them within the master apprentice relation [12]. As Hill [13] stated in his article, stonemasons and builders are generally uncommunicative about their trades at the best of times, felt no such need, and it was left to other interested parties (like researchers) to write on their behalf. Unfortunately, much of the knowledge and skills linked to traditional craftsmanship are in danger of disappearing due to declining numbers of practitioners and growing disinterest of young people [14, 15]. Much information is missing if masters or third parties do not write about builders' knowledge or find a way to combine modern and ancient techniques.

Sustainability of knowledge and skills of building masters is not the only problem encountered in the preservation of Cappadocia in Turkey. It is the problem of world's many historic areas, too [12, 16, and 17].

[1] Rock types are classified according to Yıldırım and Gökaşan's (2013) [10] classification.

In this study, the correlations between the knowledge of the masters about rock-cut structures and the compression strength values of the samples taken from the region were evaluated and presented in Table 2.

Table 2. The correlation between local builders' rock characterization and rock types

| **Sample** | **Sample place** | **Compression strength, MPa** | **Rock type** | **Classification of local masters (definition of masters)** |
|---|---|---|---|---|
| **MHK-1** | Göreme Town | 22,21 | Semi-hard rock | Stone rock (difficult to cut, many cracks) |
| **OK-15** | Ortahisar town | 9,55 | Weak rock | Yellow rock (difficult to cut) |
| **OK-20** | | 31,77 | Semi-hard rock | Stone rock (difficult to cut, many cracks) |
| **OK-23** | | 14,23 | Weak rock | Yellow rock (difficult to cut) |
| **MA-02** | Mazı Village | 4,06 | Very weak rock | Clayey/Magnific rock (easy to cut) |
| **MU-01** | | 15,90 | Weak rock | Yellow rock (difficult to cut) |
| **EA-04** | Bahçeli Village | 3,32 | Very weak rock | Clayey/Magnific rock (easy to cut) |
| **EO-03** | | 3,95 | Very weak rock | Clayey/Magnific rock (easy to cut) |
| **DE-01** | | 3,13 | Very weak rock | Clayey/Magnific rock (easy to cut) |

According to Table 2, as the masters have stated, the church in Göreme was carved into semi-hard stone rock and has intrinsic cracks. The rocks taken from Ortahisar are stone rock and yellow rocks, which are weak rocks and they have cracks. The inner part of the Mazı underground city is carved into clayey/ magnific rocks that are not resistant to erosion, very weak rocks and the outer part is erosion-resistant yellow rock. Cracks of the outer yellow rock are more than the clayey / magnific rocks' cracks of inner parts. The warehouse in Bahçeli village were carved into clayey / magnific rock for its moisture holding capacity and part of houses were built in the same rock. This rock is a very-weak rock.

Cappadocia rock formation does not constitute only natural and cultural heritage but also geological heritage [18]. The UNESCO-registered "outstanding universal value" sustainability of this region will be continued by combining the knowledge of local builders who have experienced many disasters, recovered buildings from earthquakes for hundreds of years by knowing the rock character and the data provided by the modern techniques.

Although the experiences and knowledge of the masters are tried to be conveyed to the next generations by collecting, writing and sharing data, local building mastery is also a very significant intangible heritage that needs to be maintained and sustained on its own.

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# CHAPTER II

## STRUCTURAL BEHAVIOR – EQ RESISTANCE & SEISMIC RETROFIT

# TIMBER SEISMIC BANDS: CORRELATING THEIR CHARACTERISTICS WITH LOCAL SEISMIC ACTIVITIES AND UNDERSTANDING THEIR EFFECTS UNDER SEISMIC LOADS

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**Keywords:** Masonry building; Timber insertions; Seismic shear band; Energy dissipation

## Abstract

*Masonry buildings are one of the most commonly found structures throughout the world. In seismic areas, people developed several techniques and practices to make them safer in case of earthquakes. One of the most wide-spread techniques, used for centuries in several countries of Asia, Middle East, Europe, Central and South America, is the insertion of horizontal timber seismic bands into the load-bearing masonry walls. This paper first describes the variation in the timber bands disposals and how it correlates with local seismic activities in different regions of the Alpine-Himalayan belt. This research is based on a literature review and on several on-site surveys. Then, an analysis resulting from post-earthquakes observations, some experiments and a literature review allows for a global understanding on how these timber bands may contribute to a good behaviour of masonry buildings during earthquakes: by tying the building together, by preventing the propagation of diagonal shear cracks on the in-plane walls and flexural cracks on the out-of-plane walls, by dissipating energy, etc. The third part of the paper deals with two experimental campaigns conducted to better understand the mechanical impact of the reinforcement. The first one is based on two adobe walls (with and without horizontal timber reinforcement) submitted to lateral quasi-static cyclic load. It allowed for the estimation of the lateral strength, the stiffness degradation and the dissipated energy of both reinforced and unreinforced masonry walls and for the comparison of their failure modes. The second experimental campaign focuses on the energy dissipation that occurs at the interface between the seismic band and the masonry depending on the materials used and their disposals. To this purpose, seismic bands in concrete, timber and bamboos of different configurations are submitted to lateral quasi-static cyclic loads and the energy dissipation occurring is calculated.*

## 1 INTRODUCTION

In seismic-prone areas, traditional architectures often reveal a great deal of ingenuity about the use of local resources and the development of techniques and practices that are thought to reduce the vulnerability of built structures [1] [2]. The relevance of these solutions remains marginally documented and validated by scientific communities, and the organizations involved in post-disaster reconstruction prefer not to include them in their programs. Hence, much damage is often inflicted on vernacular heritage during relief and reconstruction phases and the replacement of traditional habitat by ‘modern’ ‘imported’ solutions speeds up the disappearance of traditional skills and knowledge [3]. Moreover, in many cases, it is ineffective in terms of Disaster Risk Reduction (DRR) [1] and it deprives inhabitants of DRR solutions that are often the only one they can implement by themselves [4]. Studying existing structures and how people can repair or retrofit them make it possible to empower them and support them in doing informed choices during reconstruction processes, and finally improve their resilience in the long run. Besides, studying historic structures is necessary to avoid improper interventions that often turn disastrous when submitted to an earthquake [5].

An example of these traditional techniques developed to reduce the building vulnerability is the regular insertion of horizontal timber bands in masonry structures. Referring to the theory of local seismic cultures development [1], this study first describes the variations observed in order to understand how it correlates with local seismic activities in different regions of the Alpine-Himalayan belt. This step helps us in better understanding how these timber bands may contribute to a good behaviour of masonry buildings during earthquakes: by tying the building together, by preventing the propagation of diagonal shear cracks on the in-plane walls and flexural cracks on the out-of-plane walls, by dissipating energy, etc.

An experimental campaign was carried out by LMDC laboratory to compare the behaviour of reinforced and unreinforced masonry walls when submitted to in-plane shear loads. It allowed for the comparison of their failure modes and the energy they could dissipate and for the assessment of their lateral resistance and their stiffness evolution. Moreover, a second campaign was carried out by 3SR in order to better understand the dissipation of energy at the interface between the timber bands and the masonry and more specifically the influence of the materials used and of the design of the seismic bands on it. It was based on the reconstruction guidelines currently enforced in Nepal.

## 2 TIMBER BANDS CHARACTERISTICS IN THE ALPINE-HIMALAYAN BELT

In disaster-prone areas, inhabitants usually developed local building cultures to cope with the risks they face. In earthquake-prone areas, Ferrigni et al [1] observed different approaches of local seismic cultures depending on two parameters: the usual intensity of the local seismic activity and its frequency. Following on from this work, the study presented here focuses on a specific technical aseismic feature: the regular insertion of horizontal timber bands in masonry structure. This research focuses on the Alpine-Himalayan belt, though this practice is observed in many locations around the world [6]. It is based on a literature review and on several on-site surveys performed in Italy, Balkan countries and Turkey between 2012 and 2014 and in Nepal in 2016 and 2017.

In areas where wood is relatively scarce, a balance had to be found between the mechanical advantages of timber and the difficulty to access it. In the documented sites, the masonry itself is either in stone or in sun-dried bricks, with lime and / or mud mortar. Lower stories are in masonry with regular horizontal insertions, while upper stories are commonly (but not systematically) built with a load-bearing timber structure and masonry infills.

Continuous and numerous exchanges between populations throughout the Alpine-Himalayan belt resulted in a wide geographical dissemination of aseismic technics and practices (Figure 1). More specifically, the most famous masons and craftsmen corporations were asked to build major constructions in broad areas whose delimitations were highly connected to the prevailing political domination, from the Byzantine Empire to the Ayyubid domination, the Mongol Empire, and finally the Ottoman Empire. In some cases, local corporations were then influenced by the work of these famous corporations, thus contributing to a dissemination of aseismic features at all society levels; this dissemination was even sometimes directly supported by political authorities through legal tools or the organization of trainings [6]. But these exchanges did not prevent local variations of these technics.

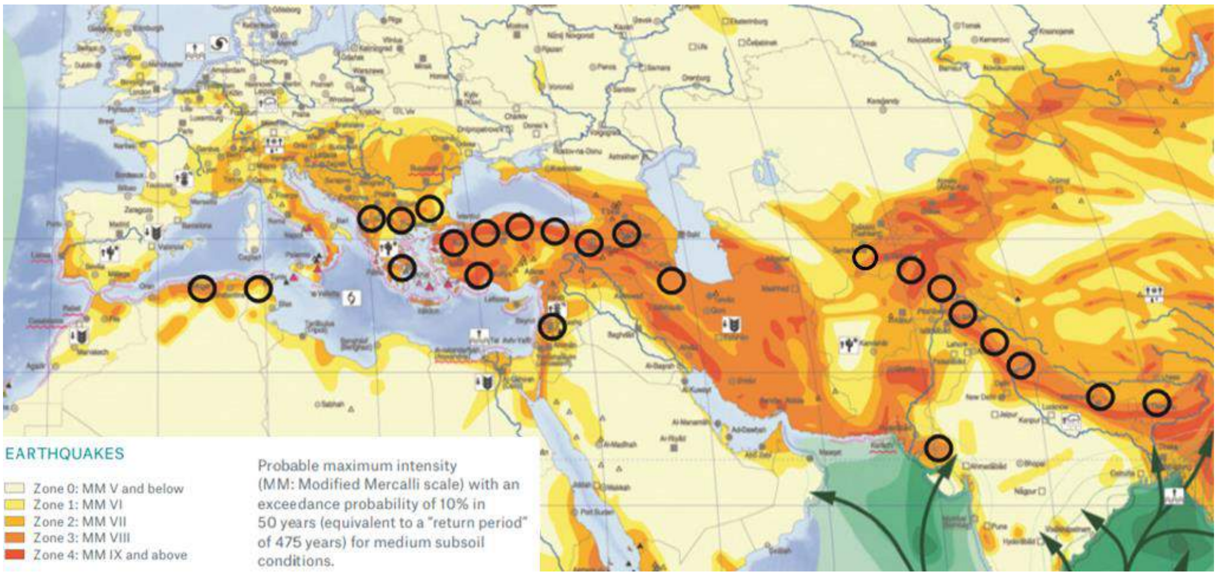



**Figure 1: Map of the ladder-like timber bands technique geographic distribution and its correlation with seismic probable maximum intensities. This map results from the research carried out by M. Hofmann [6], background map by Munich Re Group.**

This study does not refer to structural systems mixing horizontal and vertical timber elements, as the authors assume that this mixing often entails major changes in the seismic behaviour of the structure. It thus focuses on horizontal timber insertions, and three main technics were documented in masonry load-bearing walls:

a. A massive timber log embedded into the wall and connected to metallic anchors in façade;
b. Ladder-like timber bands inserted at regular spacing;
c. Several planks or logs placed next to each other on the whole wall section.

**Figure 2: a) massive timber logs embedded in a partially collapsed masonry wall at Poggio Picenze (Italy); b) ladder-like timber bands inserted at regular spacing in Cumalikizik (Turkey) and c) planks insertion in a masonry wall in Kastamonu (Turkey) (Credit: Hofmann)**

And for each of these technics, variations were observed regarding the connections in-between the elements themselves, the dimensions of the timber elements and the vertical spacing between the insertions.

A focus on the North Anatolian fault – whose cultural and historical background is rather similar but recent local seismic activity (from 1800 to 2011) slightly differs – helps us understanding the correlation between the local seismic activity and these variations. The whole research leading to the results synthesized below was part of a PhD thesis [6].

Regarding the type of insertions, in more seismic prone areas, ladder-like timber bands are very commonly found, whether horizontal planks are more frequently observed in less seismic prone areas.

Timber insertions are usually located at the top of the wall, at doorsills and lintels, and, in case of lower vertical spacing, at windowsills. This vertical spacing is highly correlated with local seismic activity: for example, this vertical spacing is relatively low (40 to 70cm) in the city of Erzurum, Turkey, where ladder-like insertions are very common and the recent seismic activity high. In neighboring areas of lower recent seismic activities, this vertical spacing is up to 150cm (especially in case of planks insertions).

Moreover, connections between elements are very interesting to compare. Planks are usually connected by overlapping and basic nailing, while in case of ladder-like insertions, connections are more sophisticated: halved or chamfered joints, and in case of recent high seismic activity, dovetail joints were more likely to be observed.

**Figure 3: a) a chamfered joint in Vevçani (Macedonia) and b) a dovetail joint in Erzurum (Turkey) (Credit: Hofmann)**

Regarding their dimensions, timber planks are usually 2 to 4cm thick, but they can be as thin as 0.1cm, as observed in Safranbolu, Turkey, an area whose recent seismic activity is slightly lower. Further documenting this wide range of value would be very interesting to better understand its correlation with local seismic activity and wood availability. There are fewer variations regarding ladder-like insertions dimensions.

This research's first results support the hypothesis that technical variations are correlated to the availability of timber and the seismic activity. Next section focuses on the analysis of the mechanical effects of these horizontal insertions and their variations, in order to better understand why they are correlated to local seismic activities.

## 3 REDUCING STRUCTURES VULNERABILITY BY USING TIMBER BANDS

Several experimental campaigns and post-earthquakes observations surveys allowed for a better understanding of timber bands roles in the reduction of structures seismic vulnerabilities [6]–[11].

Both ladder-like and planks insertions (referred respectively as techniques b and c in previous section) have several common effects providing a better behaviour to structures submitted to earthquake solicitations. They act as lintel in case of partial failure of the masonry (Figure 4a). Thanks to timber ability to resist traction, they prevent vertical and diagonal cracks from spreading (Figure 4b). Moreover, they confine the masonry elements, thus giving the wall extra resistance to out-of-plane solicitations (Figure 4c), while it is thought that they allow for movement between the wall portions and thus maintain a relative flexibility of the structure, which is of major importance to reduce the building vulnerability. Moreover, this confinement changes the structural behaviour of the wall, dividing it into several smaller portions embedded at both ends and thus changing its slenderness and resonance frequency. This confinement also increases the static compression resistance of walls [6].

**Figure 4: a) ladder-like insertions acting as lintels when partial collapse of a masonry wall occurred; b) preventing cracks propagation and c) restricting bending deflection (Credit: Hofmann)**

Besides, planks insertions increase the global compression resistance of the wall by inducing a better spreading of compression forces through the whole section of the wall [6]. Finally, they allow for the creation of a fuse interface where cracks, sliding and energy dissipation are more likely to occur. This last effect explains why some planks insertions are as thin as 0.1cm and why the wood roughness is of high impact on the insertion behaviour.

Ladder-like insertions are even more efficient as confining devices of masonry elements – providing the wood and connections are resistant enough to traction – thus increasing compression resistance [6] and restricting bending deflection (Figure 4c). However, this confinement of walls subdivisions does not prevent movements between them and thus dissipation of energy, and may be an interesting balance between a relative stiffness of walls subdivisions and a relative flexibility of the whole building. Moreover, it was noticed that two-leaf walls without proper bound stones or corner stones are more likely to be found with ladder-like insertions: this observation supports the hypothesis that ladder-like insertions improves the connection between the different vertical leaves of a masonry wall – but authors would nevertheless recommend the use of bound stones to connect properly the masonry layers. As explained in next section, ladder-like insertions improve the wall resistance to shear solicitations. Moreover, the timber elements composing these insertions usually are well connected enough to act as a belt preventing corner separation and spreading the solicitations to the building as a whole, while maintaining a relative flexibility. Finally, contrary to planks insertions, ladder-like insertions do not create water stagnation zones in the walls– accelerating wood decay and rotting – and may thus be more adapted in areas where the timber mechanical properties are affected by frequent seismic solicitations.

# 4 COMPARING REINFORCED AND UNREINFORCED MASONRY WALLS SUBMITTED TO IN-PLANE SHEAR LOADS

In order to better understand the mechanical effects of the ladder-like timber insertions and their contribution to the vulnerability reduction of the building, two walls – one reinforced with an insertion and the other not – were submitted to in-plane lateral, cyclic, quasi-static loading in order to study their structural behavior.

## 4.1 Setup

Two adobe masonry walls (1.3x1.3x0.34 $m^3$) were built: one was not reinforced (UM), the other one (RM) was reinforced with a ladder-like horizontal timber insertion. The longitudinal elements had dimensions of 75x45 mm², and the transversal ones of 50x45 mm², as recommended in the Nepalese design catalogue [12]. Longitudinal and transversal elements were connected with screws (diameter 5 mm, length 70 mm) to limit the energy dissipation in the wood-wood connections in order to ease the analysis of the global energy dissipation mechanism.

Displacements were measured through digital image correlation (DIC) thanks to a stereo-camera system, completed by three LVDT (Linear Variable Differential Transformer) sensors, and a wire sensor. To simulate permanent loads and the presence of stories in such structures, a constant vertical load of 0.2 MPa – corresponding to 10% of the compressive strength of the masonry – was applied on top of the walls. The lateral load was applied under imposed displacement, which was designed to follow recommendations of the standards ASTM E2126-05. Indeed, the control displacement curve was made of series of 3 cycles at a constant frequency (0.013 Hz), with a constant magnitude inside a series, but with increasing magnitude between two series.

## 4.2 Results

Figure 5 shows the horizontal displacement field in the reinforced and unreinforced masonry walls before failure. In the case of the unreinforced masonry adobe wall (UM) (Figure 5a), contours show a typical diagonal crack pattern. The contours of the reinforced shear wall (RM) (Figure 5b) show the apparition of a friction plane along the bed joints. Two types of failure can be observed here. The unreinforced wall experienced shear failure as shown by the presence of diagonal cracks in the joints and through some adobe units. During the first cycles of the quasi-static test, the horizontally reinforced wall showed a behavior similar to the first wall: diagonal cracks appeared at the corners of the wall. However, when the lateral force magnitude increased, a horizontal failure plane developed two beds of bricks below the timber insertion, and sliding occurred along this plane. Additionally, very few cracks appeared above the reinforcement.

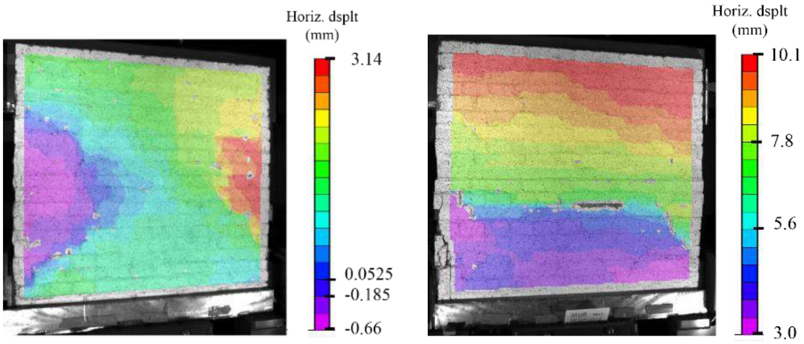



**Figure 5: Horizontal displacement field obtained with DIC: from left to right; (a) UM, (b) RM.**

The hysteresis curves lateral force VS displacement, corresponding to the quasi-static cyclic tests on UM and RM, are presented on Figure 6. The envelope corresponds to the points of maximal force and maximal displacement for each series of three cycles of same magnitude.

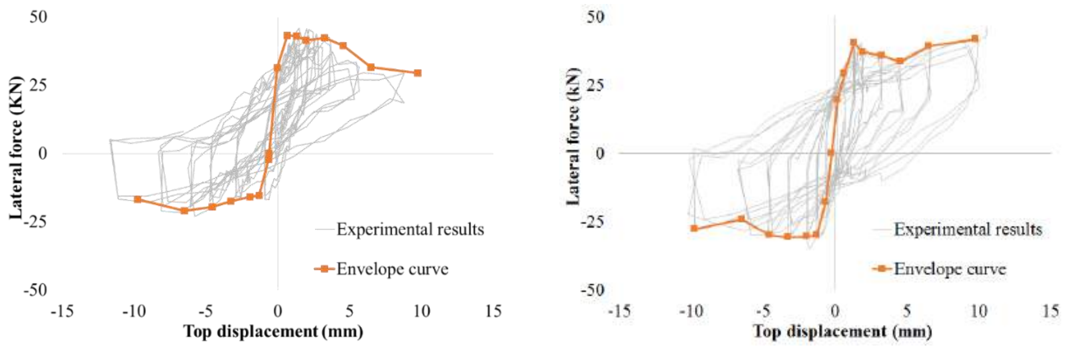



**Figure 6: Hysteresis curves lateral force VS displacement for quasi static cyclic tests on: from left to right; (a) UM (b) RM**

The stiffness degradation of the walls was evaluated by computing the slope between two points of maximal force and displacement of two loading series, which corresponds to the slope between two points of the hysteresis curves. The stiffness degradation curves (Figure 7a) illustrate similar responses for the two walls. Most of the degradation happens during the three first loading cycles, and then the stiffness stabilizes. It can be noticed that the stiffness of the reinforced shear wall degraded more progressively, which fosters the hypothesis of a more ductile behavior of reinforced masonry pointed out by the hysteresis curves.

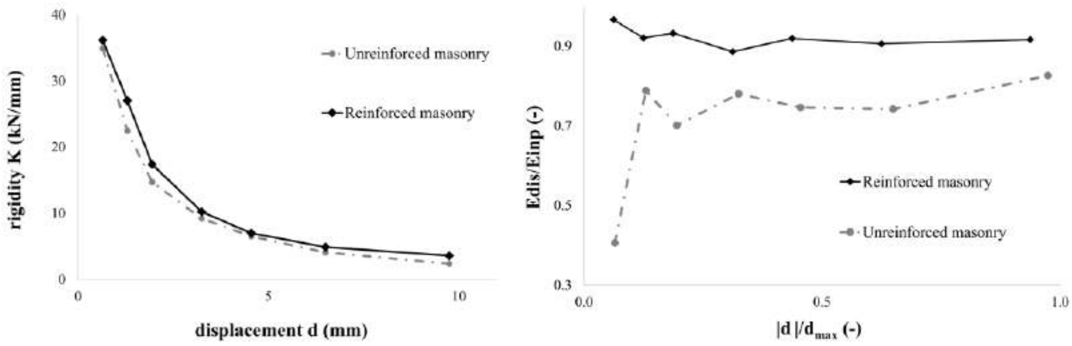


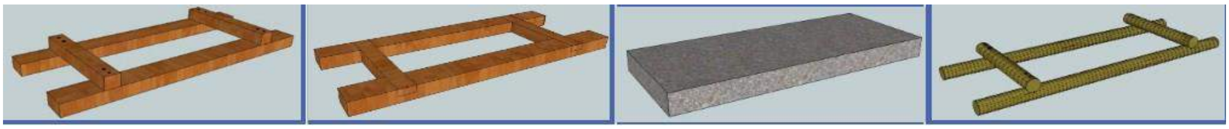

**Figure 7: From left to right; (a) Stiffness degradation, (b) Energy dissipation.**

The hysteresis curves also reveal some information about dissipated energy in the system. The dissipated energy $E_{dis}$ is defined as the area inside a cycle of hysteresis. The input energy $E_{inp}$ is defined as the area under the curve, down to the x-axis. Figure 7b presents the variation of the ratio $E_{dis} / E_{inp}$ depending on the displacement, normalized with the value of maximum displacement during the test $d_{max}$. The plot shows more significant energy dissipation in the case of the timber reinforced masonry wall (90%) compared to the unreinforced wall (80%). This could be explained by the friction phenomenon which is probably more important for the crack pattern depicted in Figure 5b. This dissipation of energy due to the ladder-like timber insertions is the subject of the second experimental campaign that is further explained in next section.

## 5 THE IMPACT OF USING DIFFERENT MATERIALS ON THE ENERGY DISSIPATED BY SEISMIC BANDS

Seismic bands are recommended in the design catalogue for reconstruction housing by Government of Nepal using different materials [12]. A quasi-static cyclic shear test experiment was carried out at 3SR laboratory to find the impact of those materials on the energy dissipation.

Four types of shear band were prepared following the Department of Urban Development and Building Construction (DUDBC) guidelines [12], using timber, concrete and bamboo (Figure 8).



Timber Shear Band Type 1 (TSB1) | Timber Shear Band Type 2 (TSB2) | Concrete Shear Band (CSB) | Bamboo Shear Band (BSB)

**Figure 8: Different types of shear bands as recommended in DUDBC guidelines for reconstruction**

Two specimens of each type of band (900x350 mm²) were tested using a Schenck Machine at a displacement rate of 0.4 mm/sec. The aim of these tests was to apply loading directly on the shear band and obtain the hysteresis curves allowing for an analysis of the energy dissipation at the interface of the shear bands. To set the limit of displacement for the test, the maximum limit of 20 mm for each specimen was selected except for the first TSB1 specimen that was tested up to 10 mm displacement to see the behaviour at the interface and confirm that the designed experimental set up works correctly.

The obtained data from the experiment was the displacement and the corresponding force needed to reach that displacement. A hysteresis curve is obtained by plotting the data. The area under the hysteresis curve provides the value of the energy dissipated during each cycle. The dissipated energy was measured using OriginPro 2017 software (http://www.originlab.com/2017), taking the average between the results obtained from the similar shear bands. Comparison of energy dissipation by various type of shear band is shown in Figure 9.

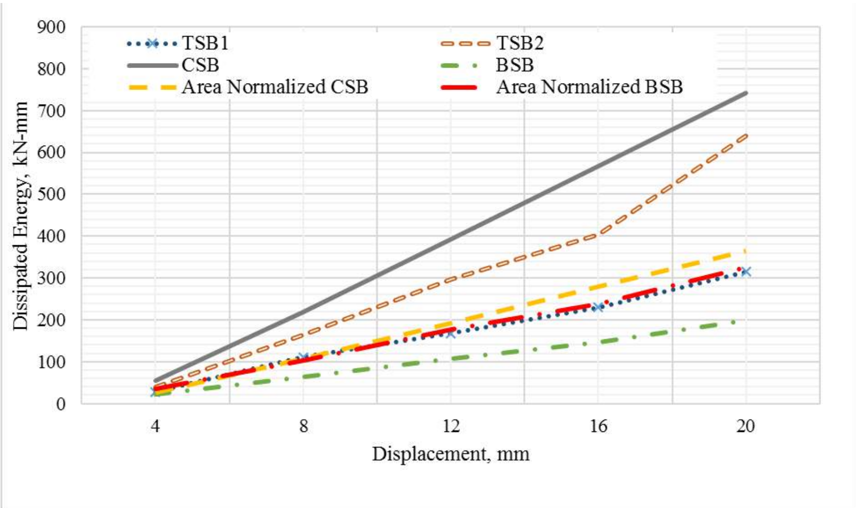



**Figure 9: Comparison of energy dissipations by various types of shear band**

From the comparison, we can notice that more energy is dissipated with CSB compared to other materials and least energy is dissipated by BSB. The amount of energy dissipated also differs depending on the connections between timber elements. TSB2 could dissipate more energy than TSB1. In order to observe the significance of the contact surface area, the results for the CSB and BSB were normalized taking the contact surface area of TSB1 and 2 as the reference. The energy dissipated by the normalized CSB and normalized BSB are similar to that of TSB1. The energy dissipation patterns obtained tend to follow linear form for each of the shear band materials.

The effective stiffness of each specimen was calculated considering a loop from the first compression to tension values and from tension to compression loading again. After separating the results for each of the loops, linear regression was done to obtain gradient and intercept for the best fitting curve. The gradients obtained give the effective stiffness of shear band against sliding for each specimen as given in Table 1. Likewise, the elastic limit of loading and the corresponding displacement, energy dissipated within elastic limit and maximum energy dissipated was obtained (Table 1) from the hysteresis loop as explained earlier. As observed in the tabular value, the average stiffness and the plastic energy dissipated (which could be used as information about ductility behaviour) of TSB2 and CSB are comparable, and that of BSB is the least which means a small amount of force can make large displacement with bamboo used as a shear band. These values of stiffness and energy dissipated can be used in development and validation of numerical simulation code for carrying out the parametric analysis for shear band using different materials.

| S.No. | Name of specimens | Elastic | | Effective Stiffness, k (N/m) | Energy dissipated | | |
|---|---|---|---|---|---|---|---|
| | | Force, kN | Displacement, mm | | Elastic, kN-mm | Maximum, kN-mm | Plastic, kN-mm |
| 1 | TSB1_1 | 12.4 | 6.3 | 1.61E+06 | 75.32 | 109.5 | 34.18 |
| 2 | TSB1_2_dry | 11.45 | 8 | 1.33E+06 | 112.3 | 314.76 | 200.46 |
| 3 | TSB2_1 | 10.78 | 8.08 | 1.35E+06 | 167.46 | 298.9 | 131.44 |
| 4 | TSB2_2 | 14 | 7.87 | 2.61E+06 | 201.53 | 639.5 | 437.97 |
| 5 | CSB_1 | 18.09 | 10.95 | 2.63E+06 | 406.25 | 877.71 | 471.46 |
| 6 | CSB_2 | 13.15 | 7.9 | 1.21E+06 | 180.67 | 607.07 | 426.40 |
| 7 | BSB_1 | 6.25 | 8.22 | 6.19E+05 | 56.28 | 200.7 | 144.42 |
| 8 | BSB_2 | 6.23 | 7.9 | 8.90E+05 | 72.11 | 197.26 | 125.15 |

**Table 1: Effective stiffness and energy dissipated by shear band**

Significant differences were observed in the seismic performance behavior of shear bands with different materials and configurations. These performances are to be balanced with materials and skills availabilities and their sensitivities to the quality of execution, which was not assessed yet.

## 6 CONCLUSIONS AND ACKNOLEDGEMENT

After Erzorum earthquake (1983, 2004, Turkey), Kocaeli earthquake (1999, Turkey) and Kashmir earthquake (2005, Pakistan), it was noticed that timber structures that had been properly maintained fared better than many concrete structures, and that the rather long distortion phase preceding collapse allowed for inhabitants to evacuate [7], [8], [13].

Horizontal insertions are one of these aseismic techniques that suffered more from the lack of recognition, of scientific knowledge and from political and economic contexts than from a lack of efficiency [6], but this trend seems to evolve as reconstructions in Pakistan after 2005 earthquake and in Nepal after 2015 earthquakes shows [12], [14]. But these techniques and their variations are still misunderstood.

The experimental campaign that was carried out by LMDC showed important results regarding the ladder-like timber insertions. As expected, a diagonal cracks pattern appeared in the unreinforced wall submitted to shear loads. The reinforced wall behaved similarly at the beginning of the test, but then a horizontal failure plane appeared and sliding occurred along this plane, and very few cracks appeared above the reinforcement. Moreover, the stiffness of the reinforced shear wall degraded more progressively, which fosters the hypothesis of a more ductile behavior of reinforced masonry. Finally, 12% more energy was dissipated in the case of the timber reinforced masonry wall.

This dissipation of energy due to the ladder-like timber insertions was the subject of the second experimental campaign, with a comparison between different materials and insertions designs used during the reconstruction in Nepal. Though concrete seismic band seems efficient regarding the energy dissipation, its cost is usually much higher than that of timber and local workers often lack basic skills to build it. Besides, low quality nails do not allow for satisfying connections when using hard timber and the research further argued for the use of embedded connections. However, these conclusions regarding the energy dissipation should be put in perspective with the lack of knowledge on the other functions of the shear bands, and more specifically on the impact of their rigidity.

In order to allow for a dissipative movement and increase the friction when using bamboo, it would be interesting to improve the roughness of the bamboo and increase its contact area by testing crushed and tangled bamboo bands. Moreover, it would be very interesting to study the sensitivity of the different kinds of insertions to improper execution. Observations following earthquakes in Italy, Pakistan and Turkey showed that timber structures with masonry infills had fared well, even though some of them were of low quality, which is hardly ever the case with reinforced concrete structures [6], [13]. The current development of an affordable shaking table at 3SR will allow for testing real-scale technical details and conducting more academic research.

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# AN OVERVIEW OF THE STRUCTURAL DETAILS AND NUMERICAL ANALYSIS OF THE POST-AND-PLANK TIMBER WALLS IN THE KOTEL REGION IN BULGARIA

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**Keywords:** Post-and-plank wall, Carpentry joints, Kotel, Non-linear static analysis

*Abstract*

*The post-and-plank wall is a typical timber structure in Bulgaria during the National Revival period between the XVIII-XIX centuries. Many buildings with this load-bearing structure are listed as immovable cultural heritage. Little information is available on the performance of these buildings under vertical and horizontal loads. Expeditions in the Kotel region were carried out by the authors together with students of civil engineering and architecture to study the main characteristics of this type of timber walls. The focus was also on the connections between all the elements of the timber structure and the damages which are facing them. This paper presents the main characteristics and structural details of the post-and-plank walls in the Kotel region. Finite element models are developed by the authors to examine the in-plane behavior of the wall structure under horizontal actions. The results are used as a preliminary performance evaluation related to upcoming experimental tests.*

# 1 INTRODUCTION

Timber is a widespread building material during the National Revival period in Bulgaria between the XVIII-XIX centuries. It was used for walls, floors, and roof structures. The structures of the timber walls can be divided into two main groups, namely half-timbered and post-and-plank. The half-timbered structure is the most widely spread type of wall structure with many types of infills, for example, wattle and daub, adobe, laths and plaster, stone, bricks, etc. The post-and-plank wall structure consists of timber frame and planks infill. One of the main reasons for its differentiation from the half-timbered structure is that the planks are inserted into grooves in the posts thus combining finishing with load-bearing functions. There are many buildings with such load-bearing structure in Bulgaria which are still present. Most of them are houses, others are monasteries or service buildings related to the customs of the residents. Some of the settlements, encompassing many buildings of this type, are architectural reserves. Others include fewer examples, some of them declared as immovable cultural heritage.

Many architects and ethnographers have studied the vernacular architecture and the building traditions in Bulgaria. Little attention has been paid by the structural engineers concerning the building techniques and the behavior of these structures. While the half-timbered structure is spread in many countries in the world, the post-and-plank structure is more rarely observed. In Bulgaria, there are four regions in which the post-and-plank structure still exists. These regions are mostly in the mountains where forests of hardwood species are present. One of those regions is the Kotel Municipality, located in the East Stara Planina mountain. The scope of this article includes six settlements which represent the biggest part of the typical vernacular houses in this area. Three of the settlements are declared as architectural reserves, viz. The Old Town of Kotel, the villages of Zheravna and Katunishte. The other three villages are Medven, Gradets, and Ichera. Expeditions were organized together with students of architecture and civil engineering to document structural details and test timber elements by non-destructive methods. The focus was also on the defects and damages which are facing those timber structures. A thorough description of the post-and-plank wall structure was made in [1], discussing the type of elements and joints between them. The defects and damages which were observed during the expeditions were also pointed out. This article concentrates on the structural behavior of these walls and discusses in depth the factors which influence their load-bearing capacity. Experiments with walls under horizontal loads are planned to be carried out. Finite-element models are developed by the authors to receive preliminary results before the experiments. The results are discussed here.

# 2 STRUCTURAL DETAILS OF THE POST-AND-PLANK WALL STRUCTURE IN THE KOTEL REGION

During the expeditions in the Kotel region, structural details of the timber walls were documented with sketches, measurements, and photos. The aim was to gather information about the different configurations of the structural systems and joints. Given this data, a specification of the post-and-plank wall in this region and discussion of the problems was made [1]. In this article, only the factors which influence the load-bearing behavior of the wall structure are presented.

## 2.1 Main elements and joints

The residential buildings from the Revival period in the Kotel region are constructed by stone masonry and timber structure. The stone masonry is present in the facade walls of the ground floor; however, the southern wall is usually from timber. The second floor is entirely timber. Oak and beech wood is mostly used in this region. Figure 1 shows typical houses from the villages of Zheravna and Katunishte. The three main parts of the timber walls can be clearly distinguished. They are horizontal beams, vertical posts, and horizontal planks. The horizontal beams and the vertical posts form a frame filled with planks. The main elements are connected through carpentry joints without the use of metal connectors.

**Figure 1:** General view of houses with post-and-plank walls in the Kotel region

The posts have tenons on both ends which are connected to the beam mortises. There are grooves along the length of the vertical elements for the planks (Figure 2). The planks are driven into the grooves one above another without any specific joint in the contact zone in the longitudinal direction. Considering the hand tools used during this period, the contacting faces of the planks are not perfectly smooth and plane, thus in some cases a gap is formed between them. Sometimes the gap is covered by nailed laths (Figure 1, left and right).

In many cases, secondary studs are added, fixed to the horizontal beams with nails and notched joints. Although some authors suggest that the secondary studs act as supporting elements for the beams and the planks [2], further investigation is necessary to determine their function. Different configurations are observed, i.e. studs which are not in contact with the planks at all; planks which are nailed to the studs; and studs which are supporting the planks.

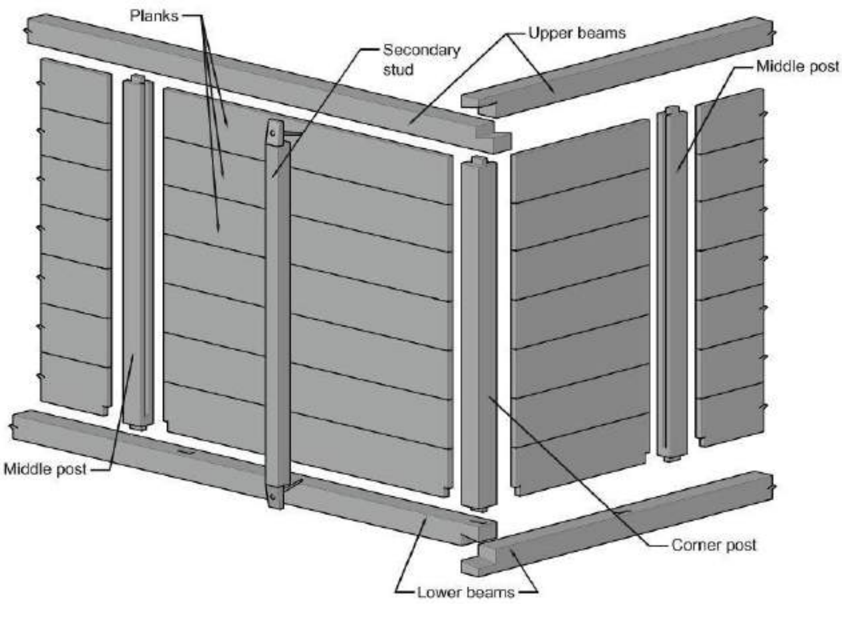



**Figure 2:** Main and secondary elements of the post-and-plank walls

The joints used for connections of beams in longitudinal or perpendicular direction are shown in Figure 3.

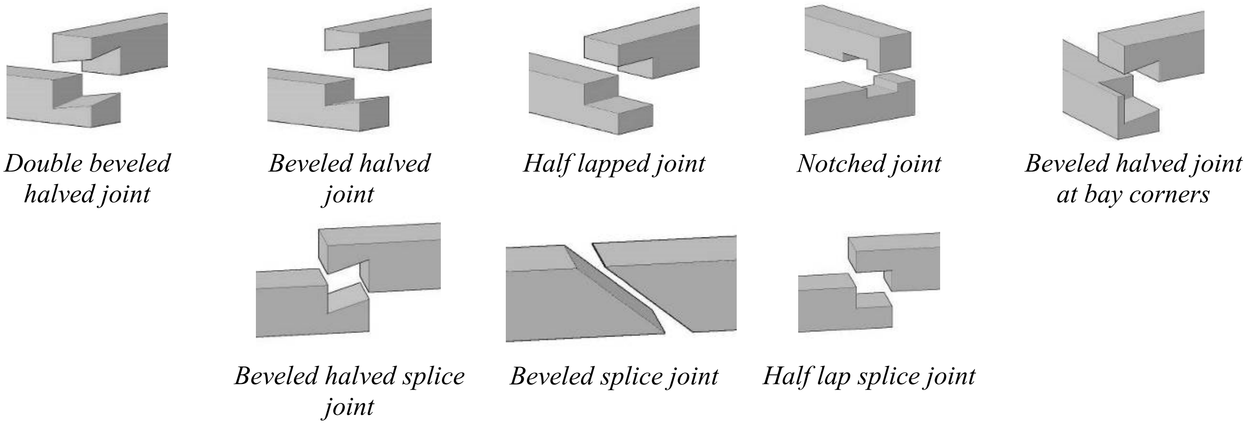



**Figure 3:** Joints used at intersections of beams in perpendicular and longitudinal directions

The thickness of the planks is between 3-5 cm, decreasing down to 2-3 cm in the ends to fit the width of the grooves. The width of the planks varies between 15-35 cm. Along the height of the wall, their width is different, and the adjacent planks are also different in size (Figure 8).

## 2.2 Connections with other structural elements

The post-and-plank walls are connected with the floor/ceiling joists that are crossing the upper and lower beams. The connections are realized through notched joints, wooden pegs, or iron nails. Figure 4 shows wooden pegs between floor joists and lower beam.

Since the eaves of these houses are very wide, in many cases the upper beams overhang the walls and act as a support of the external purlins. Sometimes secondary horizontal elements are added under the upper beams to distribute the concentrated loads (Figure 5).

**Figure 4:** Wooden pegs connecting the floor joists with the lower beam of the post-and-plank wall

**Figure 5:** Overhanging upper beam supporting the external purlin. A wooden peg is added to fix the two elements

## 2.3 Non-structural elements

Some elements that influence the structural behavior of the post-and-plank walls are observed in different cases. For example, there are wooden pegs connecting the planks in the vertical direction, thus ensuring a joint action along the height of the wall (Figure 6). The pegs are located in the middle along the lengths of the planks in holes about 3 cm in diameter and 5 cm in depth. As the planks are not connected in another way one above another, these pegs contribute to the shear capacity of the wall.

The wooden laths nailed to the planks on the inner side of the walls also have an impact on the overall behavior of the wall structures. One of the functions of the laths is to provide a rough surface for the clay plaster. Nailed in a diagonal direction, they restrain the planks against displacements in different directions (Figure 7). Sometimes there are even inclined planks nailed to the planks also contributing to the overall behavior of the walls.

**Figure 6:** Additional pegs connecting the planks in a longitudinal direction

**Figure 7:** Laths (left and right) and diagonal boards (right) nailed on the inner side of the planks when the walls are plastered

## 3 CURRENT STATE AND DAMAGES

The structural damages observed during the expeditions to the region were mostly due to bad maintenance. Mechanical problems were after-effects of decay problems. Since the timber structure is exposed to various weather conditions, more effect is added when the house is left without maintenance and leakages appear. Then the most vulnerable parts of the structure are the joints. Global mechanical damages are very rarely present. Global decay can be rarely seen because the wood material was finished with hand tools ensuring the intact cells of the surface. Also, the big eaves are protecting the facades from rainwater. Sometimes holes from wood-boring insects are present but they are either concentrated in small zones or very scattered.

One problem that decreases the horizontal load-bearing capacity of the walls is the out-of-plane deformation of the planks. Cracks are sometimes present in the middle line along the length of the planks where the deflection is the greatest (Figure 8). In those cases, shear due to lateral loading can cause the planks to split into two parts.

**Figure 8: Deformations of the planks causing cracks and splits**

## 4 NUMERICAL MODELLING OF THE POST-AND-PLANK WALL

Laboratory tests on post-and-plank walls are planned to be carried out this year in the UACEG. Three test specimens will be loaded with distributed vertical load and a horizontal force acting on the top until failure. Numerical finite-element modeling is developed by the authors to simulate the behavior of the structure under vertical and horizontal loads. The dimensions of the model and the types of joints are determined from the measurements during the expeditions in the region (Figure 9). The test specimen will be produced with the same size as the model.

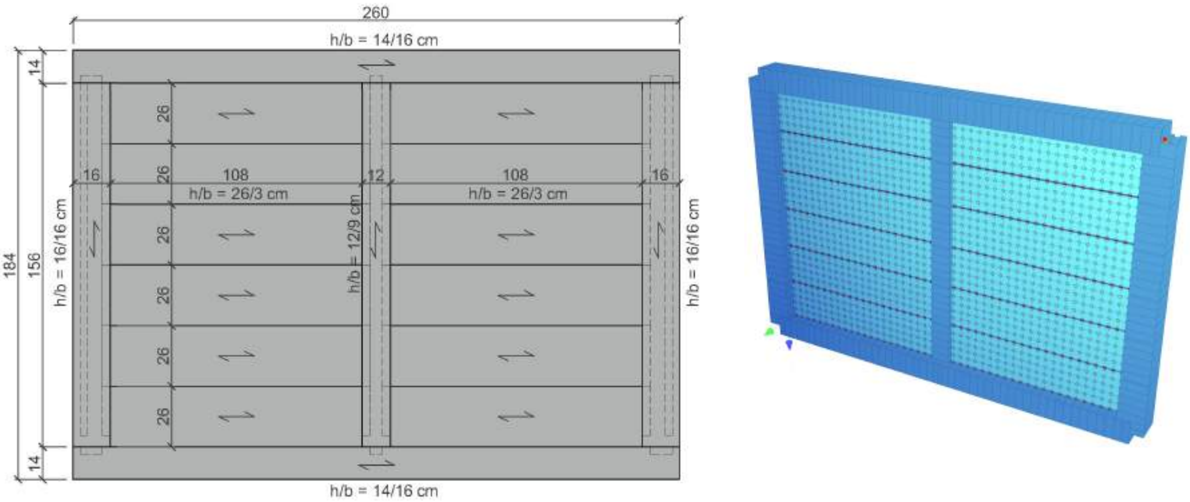
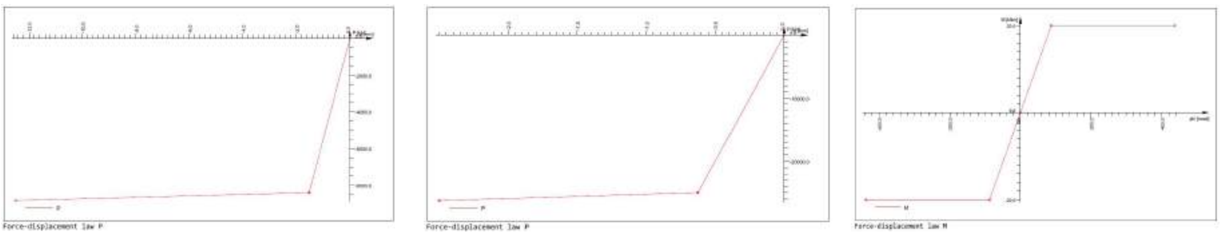



**Figure 9: Dimensions of the wall and 3D view of the FEM model**

The modeling of the structure was developed with the software SOFiSTiK. Shell elements were used for the planks and frame elements for the posts and the beams. Timber was assumed orthotropic elastic material with the characteristics of hardwood class D35 [3]. Concerning the connections between the elements, non-linear springs were introduced. Only compression work was assumed in the contact zones between the different elements. Bilinear elastic-plastic diagrams were accepted for compression perpendicular and parallel to the grain, and rotational stiffness. The limit deformation for compression perpendicular to the grain was presumed to be 10%, although plasticity is reached at about 1% strain. Failure from compression perpendicular to the grain may occur when the strain is more than 30% [4], so the authors decided that 10% is admissible. Regarding the stress-strain relationship for compression parallel to the grain, the limit deformation was accepted to be 0.01% in the plastic stage. Hardening by 5% in the plastic zone was also assumed. The spring constants for compression and rotation were calculated according to [5]. The ultimate rotation of the mortise and tenon joint was considered from the limit plastic deformation of the area where the post embeds the beam under compression perpendicular to the grain. The work laws of the different springs in the model are shown in Figure 10.



*Compression perpendicular to the grain* | *Compression parallel to the grain* | *Rotational spring*

**Figure 10:** Work laws for nonlinear springs

Friction between the planks was not taken into consideration because of the gap in the longitudinal direction. In fact, some parts along their length may be in full contact, but the model assumed the most unfavorable scenario. At the first stage of the loading, the top plank was not in contact with the upper beam. After the application of the vertical loads, springs were added at this contact zone. Non-structural elements that can contribute to the horizontal load-bearing capacity were not assumed in the numerical modeling. The vertical loads were calculated for a typical facade wall. Since the experiments will be focused on the behavior of the wall under seismic loads, a quasi-static combination was used for the vertical loads. The final value is 5.34 kN/m.

Limit load analysis was performed to find the ultimate capacity of the wall structure under horizontal loads. A standard procedure ULTI in the SOFiSTiK software was used to find the limit state at which the model loses its stability. The timber planks were supported out-of-plane. The non-linear behavior of the entire system was governed only by the non-linear springs. The main results are presented in the next pictures (Figure 11, Figure 12, Figure 13, Figure 14). The calculated horizontal limit force is 92.4 kN.

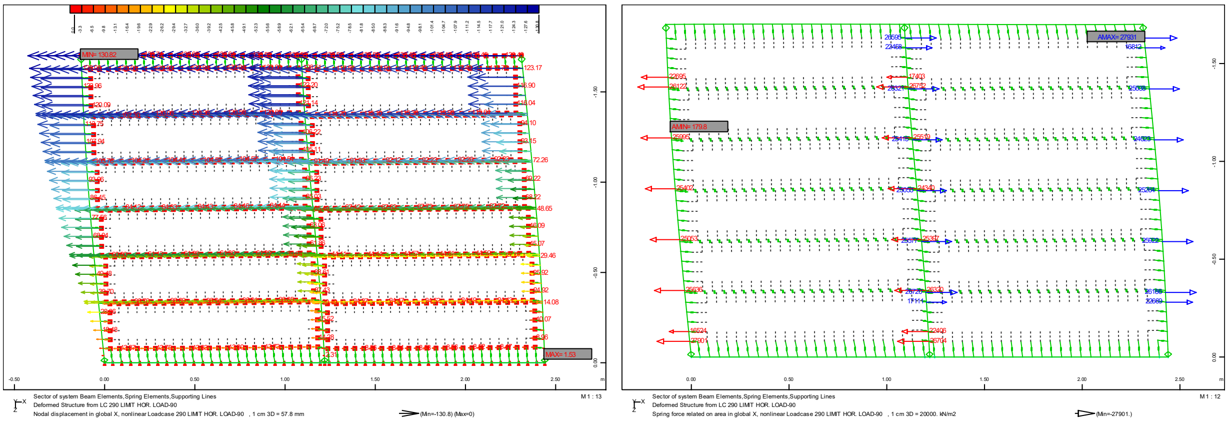


**Figure 11:** Displacement in the global X direction (left) and spring forces for the ultimate limit load (right)

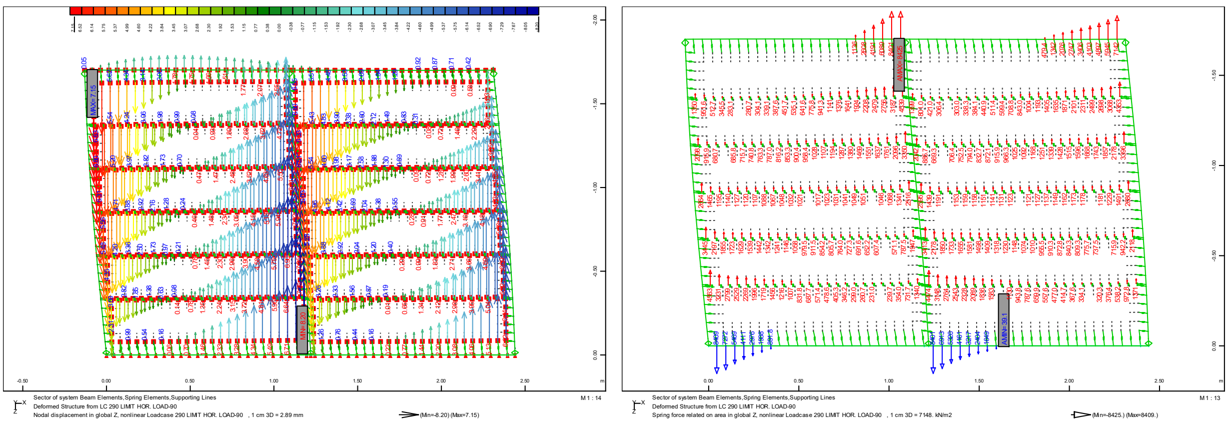


**Figure 12:** Displacements in the global Z-direction (left) and spring forces for the ultimate limit load (right)

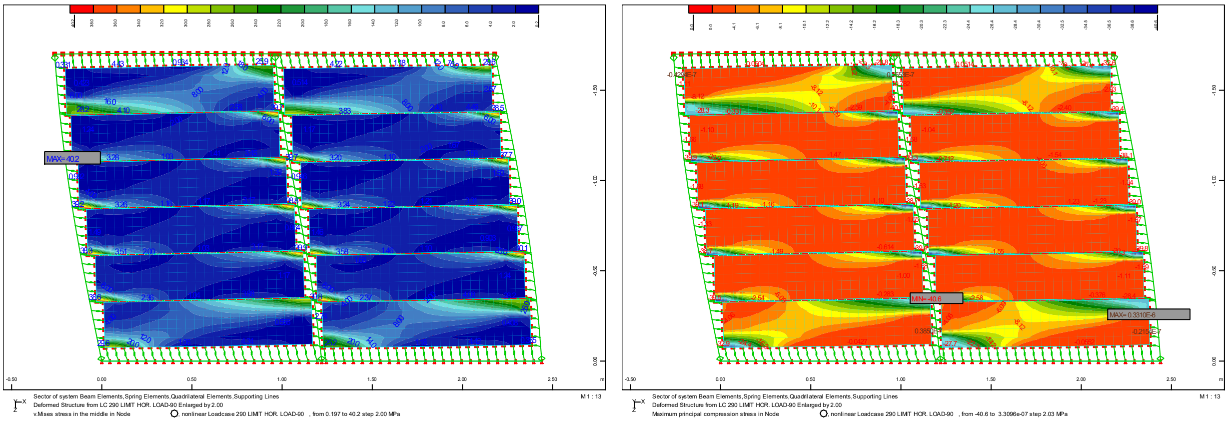


**Figure 13:** Von Mises stresses (left) and maximum principal compression (right) in quad elements

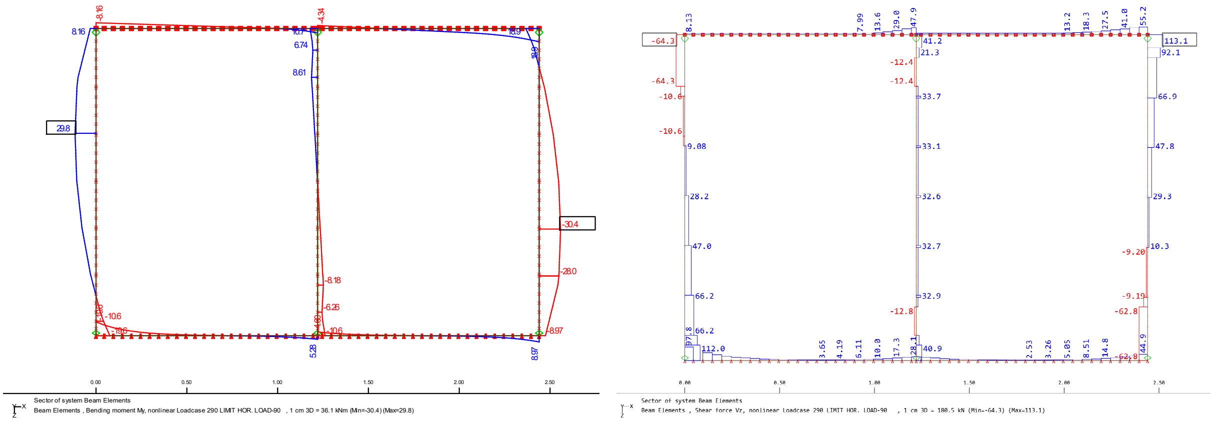


**Figure 14:** Ultimate bending moments My (left) and shear forces Vz (right) in the frame elements

As seen in Figure 12 (left), rotation is predominant for the planks, because friction between them is not considered. As a result, only parts of their lengths are in contact.

In the limit state, the compression stresses in the shell elements reach their maximum values in the lower and the upper planks (Figure 13, right).

Concerning the joints between the posts and the beams, large bending moments and shear forces are reached in this zone. On the other hand, the maximum bending moments are reached along the length of the posts at about one third from the top level. However, they are not combined with shear forces (Figure 14).

## 5 CONCLUSION

Timber structures have proven their durability, sustainability, and good load-bearing behavior characteristics for many centuries. The post-and-plank wall is an old construction technique from which the structural engineer can gain valuable knowledge. Moreover, it is essential to preserve this knowledge for the next generations. In the current practice, the architects are mostly responsible for the restoration of the historic buildings in Bulgaria from the National Revival period. In some cases, the post-and-plank wall is mistaken for a half-timbered structure with boarding. Therefore, if there is any problem with the timber elements of the wall, its structural integrity might be lost after restoration because of the lack of knowledge about its behavior. Usually, the structural engineer would not want to keep the old timber structure because it is easier to replace it with contemporary materials. If the building is immovable cultural heritage and the original structure must not be replaced, it would be duplicated by steel or reinforced concrete structure and brick masonry. This way the original timber structure will no longer act as main load-bearing structure.

Assuming the abovementioned facts, the authors decided to study this type of wall structure more thoroughly. The expeditions to the Kotel region were funded by the Research, Consultancy and Design Centre (RCDC) in the UACEG, Sofia. This year is the second stage of the funding project and the planned experiments are to be carried out.

This article focuses on the main characteristics and the numerical modeling of these walls and serves as a preliminary discussion of the failure mechanism of the structure.

According to the results from the FEM analysis, the following can be concluded:

- The maximum bending moments along the length of the posts exceed the elastic limit of the material, so failure may occur. This factor should be studied additionally because in the real cases, the posts are braced laterally by the planks in the perpendicular direction.
- Significant shear forces are induced in the joints between the posts and the beams, combined with bending moments. Although the lateral bracing of the perpendicular wall can contribute to the lowering of these results, the mortise and tenon joint should be checked additionally.
- Shear stresses are also present in the planks. As mentioned before, if the planks are deformed or cracked along their length, these shear stresses may lead to splitting. Thus, the behavior of the system will change.

The results from the experimental campaign will contribute to the calibration of the model. After that, a calculation procedure will be proposed to the structural engineers who work in the field of preservation.

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# SEISMIC PERFORMANCE OF THE VERNACULAR HERITAGE OF SIKKIM, INDIA

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**Keywords:** Vernacular houses, Sikkim, Heritage, Sikkim, Seismic Performance

## Abstract

*This paper presents the result of a study of the seismic performance and behavior of vernacular heritage in the Himalayan state of Sikkim, India. This region is seismically active and was struck by the $M_w$ 6.9 Sikkim earthquake on September 19, 2011, resulting in 112 deaths and widespread damage to a broad range of building types, including heritage structures and infrastructure facilities. The region is being seriously affected by rapid growth of tourism, haphazard development, and loss of precious forest cover. The consequence of these recent phenomena is that it will not be long before the precious vernacular architecture of the villages in different regions of Sikkim is lost forever.*

*Some of the villages near Pellin in Sikkim were visited as part of a summer school on vernacular architecture at CEPT University, Ahmedabad, for the purpose of studying the building typologies representative of this Himalayan state. The vernacular typology of the village houses in Sikkim is typically not well documented. The details of the observed mixed constructions involving wood framing and masonry, traditional roof and floor framing systems, and foundation systems are presented.*

*The earthquake performance of representative vernacular village houses in this region during the 2011 Sikkim earthquake are discussed. Some unique features of the structural systems of these traditional houses that helped them survive the 2011 Sikkim earthquake are presented. An overview of the performance of the beautiful Buddhist monasteries built using massive masonry walls, wood framing, and pagoda shaped roofs during the 2011 Sikkim earthquake is presented.*

*A small effort is presented here to help bring attention to the beautiful sustainable vernacular architecture of the villages in Sikkim, including the local and traditional building practices that must be saved, to help preserve the vernacular heritage of Sikkim, the beautiful Himalayan state of India.*

## 1 INTRODUCTION

The Himalayan state of Sikkim in India is a beautiful state in the Eastern Himalayas, with a very rich cultural history and architectural heritage, geography and environment, as shown in Figure 1. The highest peak in Sikkim is Khangchendzonga (8585 m). Sikkim is home to a multitude of hill cultures, languages, and traditional architecture. It appears that the Lepcha were the original inhabitants of Sikkim. The earliest records of the name ‘Sikkim’ date back to 8$^{th}$ century AD during the time of the patron saint Guru Rinpoche, who introduced Buddhism in the country. The whole Himalayan region is a very active seismic zone (Figure 2) and poses serious hazard to all communities, traditional housing, heritage buildings e.g. monasteries, as well as newer buildings, schools, hospitals and infrastructure.

This Himalayan region is being seriously impacted by rapid growth of tourism, haphazard development and its consequences on the broad sectors of the country, including infrastructure and the environment. In view of the above mentioned challenges facing this Himalayan region, there is a need to bring greater awareness of the beautiful traditional and vernacular architecture of Sikkim, so that more focused attention can be paid to the preservation and restoration of this beautiful cultural and architectural heritage of Sikkim.


**Figure 1**: Map of Sikkim and its Districts – Source: https://commons.wikimedia.org/wiki/Category:Maps_of_Sikkim#/media/File:Districts_of_Sikkim.png


**Figure 2:** Map showing Felt Zones of 2011 Sikkim Earthquake and neighboring regions – Source: **https://sikkimquake.wordpress.com/about-sikkim/**

## 2 SESISMICITY OF THE SIKKIM REGION

### 2.1 Past seismicity

The seismicity of the Himalayan Sikkim region is very well documented [1, 4, 5, 8]. The Sikkim region is part of the 'Alpide – Himalayan seismic belt' where four great earthquakes (Richter Magnitude 8.0 and above) have occurred in the last century. Earthquakes in Sikkim region are caused by the tectonic activity along two main thrust faults e.g. the Main Boundary Thrust (MBT) and Main Central Thrust (MCT) crossing the state of Sikkim. The entire Himalayan belt region is a very active seismic region in the world. The great earthquakes that have struck this region are: 1897 Shillong earthquake ($M_w$ 8.0), 1905 Kangra earthquake ($M_w$ 7.8), 1935 Bihar-Nepal Border earthquake ($M_w$ 8.3), and the 1950 Assam earthquake ($M_w$ 8.5).

In later years the Sikkim region experienced moderate earthquakes e.g. 1980 Sikkim earthquake ($M_w$ 6.0), and 1988 Nepal - Bihar Border earthquake ($M_w$ 6.5) during which widespread damage was observed in the Sikkim region [5, 6, 7].

The past seismicity is best represented by the epicentral map showing seismic activity in the Sikkim region as presented in Figure 3.

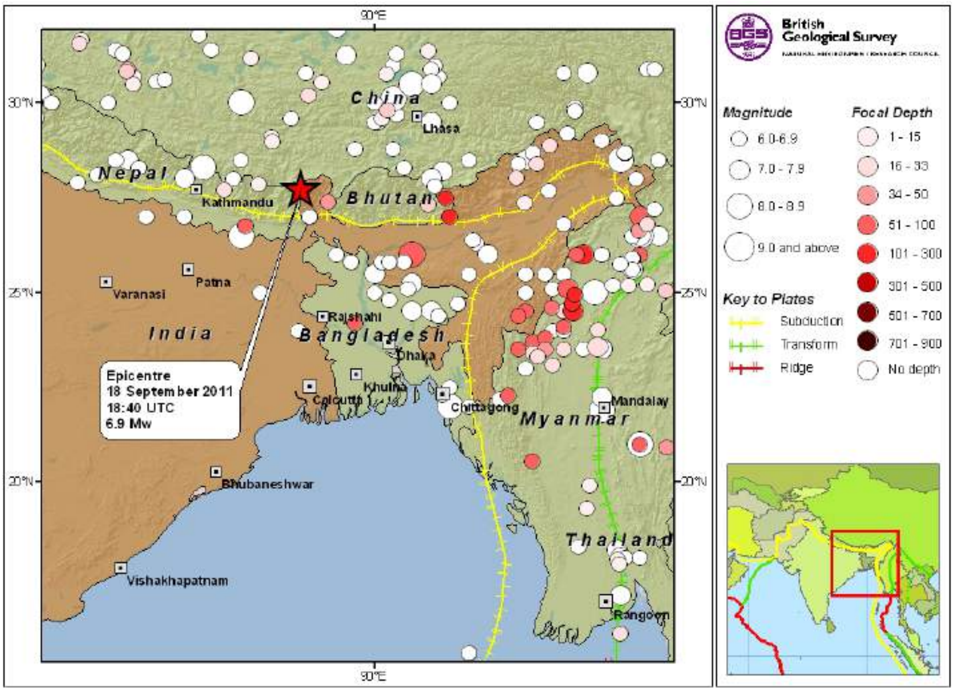


**Figure 3**: Seismicity of the Sikkim Region – Showing Epicenter of the 2011 Sikkim Earthquake

### 2.2 Recent Sikkim earthquakes

The Sikkim region has been struck by several earthquakes in recent years, the February 14, 2006 Sikkim earthquake ($M_w$ 5.3); and the September 2009 Bhutan earthquake ($M_w$ 6.1); and the September 18, 2011 Sikkim earthquake ($M_w$ 6.9).

#### 2.2.1 2006 Sikkim earthquake

The February 2006 Sikkim earthquake was a moderate earthquake ($M_w$ 5.3). The detailed reports about this moderate earthquake ($M_w$ 5.3), its characteristics and its impacts on the Sikkim region were reported by Kaushik, et. al, [1, 2]. The location of the epicenter and the shaking intensity felt in the Sikkim region is presented in the map shown in Figure 4 and Figure 5 [1]. These shaking intensity maps can help provide a rational basis of understanding the observed earthquake damage patterns in this region, and the performance and behavior of the architectural heritage of Sikkim


**Figure 4**: Seismic impact of 2006 Earthquake – Source: https://earthquake.usgs.gov/earthquakes/eventpage/usp000ea1q#map

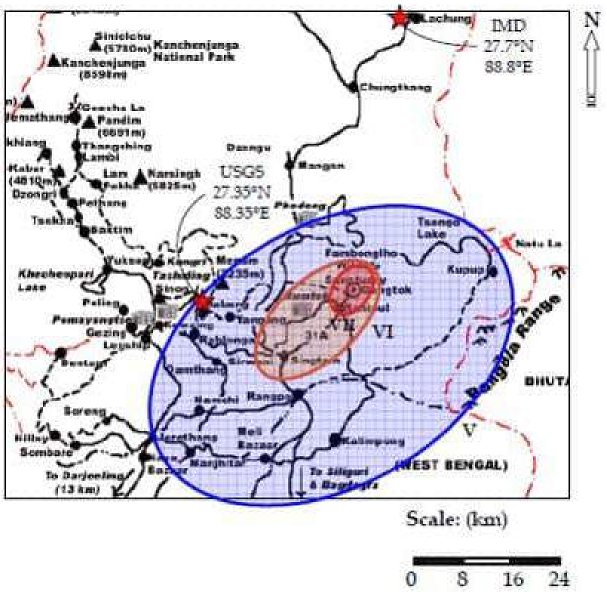


**Figure 5:** Epicentral locations and estimated shaking intensity map of 14 February 2006 Sikkim earthquake – Source: Kaushik, et. al., Ref. [1]

### 2.2.2 2011 Sikkim Earthquake

The September 18, 2011 Sikkim earthquake ($M_w$ 6.9) was a strong earthquake centered near the Nepal–Sikkim border, and was felt not only in Sikkim, but also in neighboring countries of Nepal, Bhutan Tibet and Bangladesh. The regions affected by this 2011 Sikkim earthquake are presented in Figure 6 below.

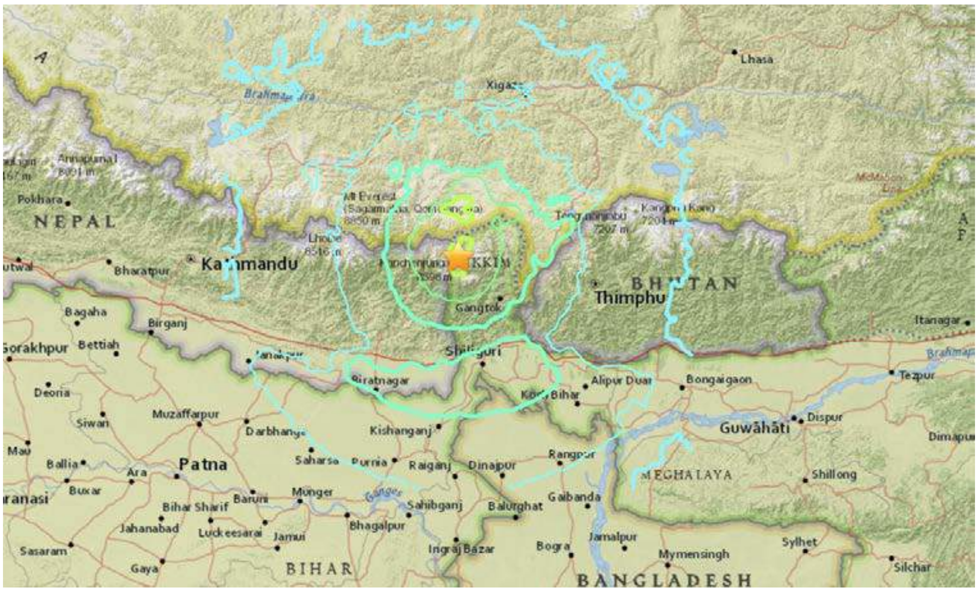


**Figure 6**: Seismic Regions Affected by the 2011 Sikkim Earthquake – Source: https://earthquake.usgs.gov/earthquakes/eventpage/usp000j88b#map

The details about this 2011 Sikkim earthquake and its impact on the Sikkim region have been reported by Murty et. al. [4], EERI [5], Sharma et. al [8] among others; based on findings by several reconnaissance teams from India that visited the affected areas of Sikkim after this earthquake. These findings include the discussion of tectonics of this earthquake; recorded ground motions and earthquake response spectra, estimated PGA's and their distribution in the affected areas, in addition to the broad impacts of this strong earthquake. It was reported that the PGA was reported to be 0.15 g at Gangtok, the capitol of Sikkim. The epicenter and the shaking intensities felt in the affected regions are presented in Figure 7.

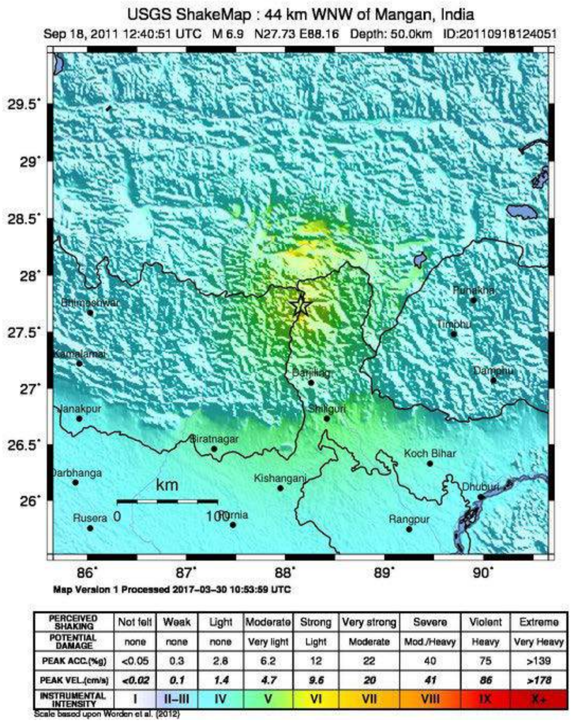


**Figure 7**: 2011 Sikkim Earthquake – Map of Shaking Intensities and Epicenter Location – Source: https://earthquake.usgs.gov/earthquakes/eventpage/usp000j88b#map

According to the reported findings the maximum shaking intensity was estimated to be approximately VI+ on the MKS scale. It was further reported that most of the loss of life in Sikkim was due to landslides, rock falls and mudslides caused by this strong earthquake. A comparison of the shaking intensity maps for the affected regions from the 2006 and the 2011 Sikkim earthquakes, can help us better understand the patterns of damage across the affected regions, observed during these Sikkim earthquakes.

## 2.3 Performance of traditional buildings

The observations and findings of the post-earthquake reconnaissance teams following the 2006 Sikkim earthquake and the 2011 Sikkim earthquake are presented elsewhere [1, 2, 3, 4, 5, 6, 7, 8]. The findings of the reconnaissance teams include the effects of landslides, observed damages of a broad class of housing, heritage structures (e.g. monasteries), schools, hospitals and infrastructure.

It was reported [1, 2, 4, 5] that by and large the traditional building typologies used in Sikkim showed very good performance compared to the recently built non-engineered RC frame buildings with URM infills that have been pushed aggressively in recent years in this region.

Rural housing in Sikkim have been found to consist mainly of Ekra or Assam-type construction. In urban areas the main housing typologies are (1) Unreinforced masonry URM, and (2) Non-engineered RC frame structures with URM infill walls.

The general details of the Ekra houses in Sikkim has been presented by Murty, et. al., [4]. The Ekra houses generally consist of wood-framed walls with an infill of cross-woven bamboo matting or wooden plank construction, which is called 'Shee Khim'; plastered on both sides typically with mud, or cement mortar in recent times. For a flat site, the wood-framed walls rest on a short masonry plinth consisting of stone masonry with mud mortar, around the building perimeter. An Ekra type of construction for a house annex, observed in Sikkim is presented in Figure 8

According to the findings of the reconnaissance teams this type of vernacular housing typology was found to have performed extremely well, as compared to the URM constructions, and the more recent building typologies e.g. non-engineered RC frame buildings with URM infills, under the varying levels of shaking intensities they experienced across the Sikkim region. The observed performance of traditional Ekra houses is presented in Figures 9-11 below, [4, 6]. The observed seismic performance of heritage buildings e.g. the Enchey Monastery in Gangtok is presented in Figure 12 [3].

**Figure 8**: Ekra House Annex – Woven Bamboo Matting – Exterior Walls – Photo Credit: S. Rihal

**Figure 9**: Performance of Traditional Ekra Houses – Photo Credit: Murty, et. al., Ref. [4]

**Figure 10:** Ekra House - Partial Collapse of RR Support Wall – Source: Ref. [6]

**Figure 11:** Unreinforced Masonry House – Photo Credit: Murty, et. al., Ref. [4]

**Figure 12**: Enchey Monastery in Gangtok – Heritage Landmark, Shear Cracks in URM Walls – Source: Ref. [3]

A global overview of the state of the art of learning from vernacular architecture and seismic retrofitting has been presented by Correia et.al. [9]. A valuable perspective on preservation of vernacular architecture of Kashmir has been presented by Langenbach [10].

## 3 VERNACULAR ARCHITECTURE OF SIKKIM

An excellent overview of vernacular houses of Sikkim has been presented by Mistry [11]. The architecture of the vernacular houses of Sikkim has evolved over a long time based on the cultural traditions of the people of Sikkim, their knowledge and wisdom, appropriate local materials and innovations passed on through generations. There is clear evidence that sustainability has been a fundamental basis of the evolution of the architecture of the vernacular houses of Sikkim. The three predominant communities in Sikkim are as follows:

i. Lepcha – the original inhabitants of Sikkim
ii. Bhutia – migrants from Tibet
iii. Nepali – migrants came from Nepal

Two case studies each of the vernacular houses of Lepcha, Limbu and Bhutia communities were carried out and reported by Mistry [11]. These case studies included site analysis, structural framing system, fastening details, construction process, and their structural behavior.

### 3.1 Lepcha houses

Based on a study of the architecture of the vernacular houses of the Lepcha [11], it can be stated that Lepcha houses have a rectangular box type of construction, and are raised about 1.83 – 2.13 m above ground level. The space under the house is used as a shelter for domestic animals and storage of firewood. The house is built of wood, bamboo, mud and thatch. The north–south side of the Lepcha house is longer than the east-west side. The Lepcha house consists of three rooms, a living room and kitchen, a prayer room and a store room and an attic. The north and south side of the house covers the whole space below but the east-west roof steps back before reaching the ridgeline, to provide ventilation of kitchen smoke. The kitchen space actually warms up the whole house, complimented by the large animals sheltered underneath. It is further observed that the Lepcha house is always located in the center of their land where they grow their own food, raise chickens, and even a fish – pond to raise their own fish for food. The roof is built of bamboo reeds, hung over bamboo and supported on the wood-framing.

A representative ground floor plan and a section of a typical Lepcha vernacular house is shown in Figures 13-14.

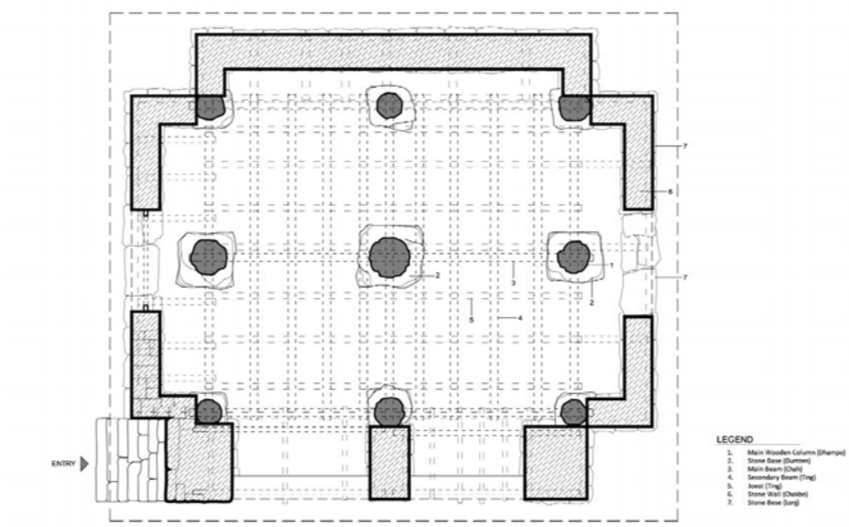


**Figure 13:** Ground Floor Plan of Lepcha House – Source: Ref. [11]

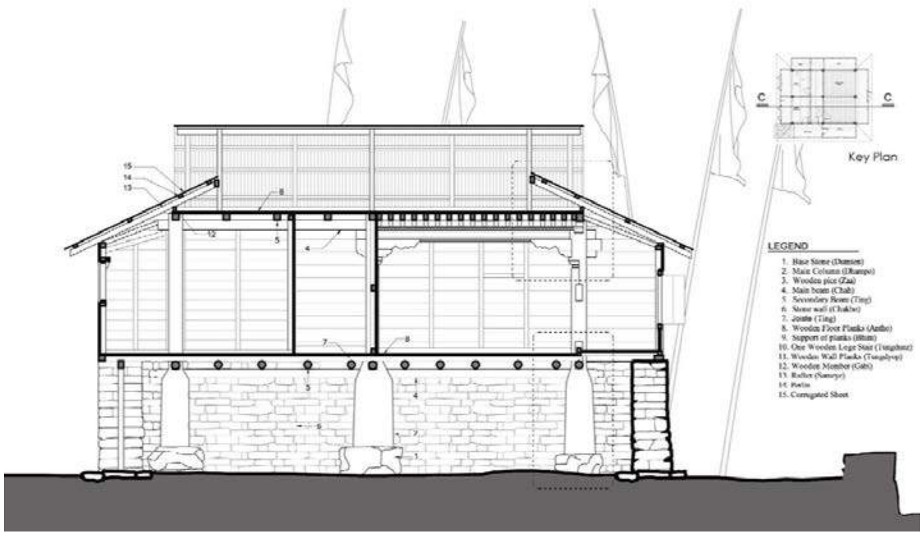


**Figure 14:** Section 2 of Lepcha House – Source: Ref. [11]

An exterior view of a representative Lepcha house is presented in Figure 15.
The view of the ground floor in the Lepcha house is presented in Figure 16.
An interior view of the kitchen area is presented in Figure 17.

**Figure 15:** Lepcha House View – Source: Ref. [11]

**Figure 16:** Ground Floor of House – Source: Ref. [11]

**Figure 17:** Kitchen area of inside House – Source: Ref. [11]

Another example of a Lepcha house is presented in Figure 18.

The view of the timber posts seated on a stone pedestal, underneath the Lepcha house, is presented in Figure 19. A closer view of joinery connecting the posts and floor framing is presented in Figure 20.

**Figure 18:** Lepcha House Exterior View – Photo Credit: S. Rihal

**Figure 19:** Timber Posts seated on a stone base: Ground Floor – Photo Credit: S. Rihal

**Figure 20:** Connection details – Wood posts and floor framing – Photo Credit: S. Rihal

## 4 CONCLUSIONS

An analysis of the findings of the several post-earthquake reconnaissance teams, for study of the observed performance of vernacular houses in Sikkim, provides a consensus and clear evidence that the traditional vernacular houses performed extremely well compared to the recently built non-engineered RC frame buildings with URM infills, that have been aggressively pushed due in part to the fast-paced development for expansion of the tourism sector of the Sikkim economy.

During our field study trip to Sikkim, it was suggested that one of the possible reasons for survival of the Lepcha houses was the innovative detail at the base of the round timber posts under the house, as shown in Figure 21 [9]. It appears that the nine round wooden posts, seated under the house on a slightly rounded stone bases, worked like an isolation system to help the Lepcha houses ride out the earthquake without damage and collapse of the overall structure during the 2006 and 2011 Sikkim earthquakes.

Therefore, the cultural heritage of traditional vernacular houses in Sikkim, that has evolved over centuries of cultural development and wisdom, should be improved upon and actively preserved for future generations. There is a lot that can be learned from the wisdom of the traditional materials and methods of construction of the vernacular houses in Sikkim for ensuring safety of vernacular houses, during future earthquakes in the region. During our field study trip to Sikkim in 2014, a proposed new demonstration earthquake resistant house structure was observed as presented in Figure 22.

**Figure 21:** Wood Post seated on a Stone Base – Source: Ref. [11]

**Figure 22:** New Demo Structure using Vernacular Techniques – Photo Credit: S. Rihal

## 5 ACKNOWLEDGEMENTS

The author gratefully acknowledges the help of co-authors Prof. Vinod Shah, CEPT University, Ahmedabad, Architect Ankit Mistry, Ahmedabad; and Timothy Gobel, undergraduate student in landscape architecture at Cal Poly State University, San Luis Obispo, California during the preparation of this paper

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# SEISMIC RESPONSE OF VERNACULAR BUILDINGS

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**Keywords:** Durability, jerk, immolation, safety, shaping, stability, three-lobed church

## Abstract

*The paper deals with traditional nonhomogeneous structures, like the three-lobed churches, located in areas prone to strong EQs between the Danube River and the Carpathian Mountains. The three-lobed architectonic and ecclesiastic pattern is typical for the extra-Carpathian region. The first ancient three-lobed churches made by wood were frequently destroyed by fires. After no long they were replaced by stone and brick masonry structures. Much larger and heavier than the former ones these churches became targeted by earthquakes. The typical quakes for this region are of tectonic origin with focuses of about 200 km deep and an average occurrence of 40 to 60 years. In these conditions the paper is focusing on two structural issues, one regarding the church body, and the second to the church steeples. The first structural intervention refers to reshaping the original three-lobed pattern of the church in order to support in safety conditions the seismic actions. According to the Legend of Master Manole that objective, by using the myth of immolation, was fulfilled in the year 1512. It was an effective measure of seismic protection. All subsequent three-lobed churches such shaped successfully passed by the strong EQs that occurred during those five centuries since then. The second structural intervention refers to the steeples of the three-lobed churches. Generally, they have a decorative function, but also important for illumination, ventilation and sometimes for hosting the church bells. Architecturally the steeples are appreciated after their slenderness, but the earthquakes are cutting them ruthlessly. This is why nowadays, in many cases, the original masonry steeples, broken during earthquakes, were replaced by wooden steeples. As a study case the paper presents the Antim Monastery founded in 1715 in Bucharest, and since the anniversary year 2015 the authors are directly involved in its rehabilitation works.*

# 1 INTRODUCTION

The Southern and Eastern regions of Romania are periodically haunted by strong earthquakes. They are much different by the EQs occurring in other countries like Greece, Italy and Turkey because are deep, with focuses at about 200km, last long, often more than 60 seconds and occur rather periodically, at intervals of 40-60 years. For long time these EQs are famous by a popular dictum that they are damaging without killing. The three-lobed churches are the oldest and most representative constructions ever built up in the two regions [1]. This is why they are country's the main vernacular heritage [2]. Unfortunately, the churches three-lobed shaped are extremely vulnerarable to earthquahes. The first reason of vulnerability is due the shape of church body. The circular walls of the two lateral absides, those that are closing the altar, are easily losing their stability by shearing. This is why the reshaping of church body was necessary. According to the Legend of Manole Master the church pronaus was enlarged. The additional space such created was devoted to apply the immolation concept [3]. Practically, the positions of the two intrinsic centers CG and CR were changed and the two circular walls of the altar became protected against seismic actions [4]. The second reason of vulnerabilty is due to the slenderness of the steeples. Having masses much smaller than those of church bodies they are easily cut during earthques by seismic jerks [5]. The phenomenon of dynamic amplification is practically controlled with the aid of the first law of conservation [6]. Three years ago, in 2015, the Antim Monastery in Bucharest celebrated its 300 years of existence. For that occasion the authors were involved into an extensive program of rehabilitation. The results of field investigations and proposed solutions of seismic protection were presented to the Monastery owner [7]. Traditionally, the masonry used for the three-lobed churches is based on pure lime without cement. It is a dry masonry. For after-quake interventions a method of reinforcing masonry with polymer grids was patented by the authors since 1995 [8]. The final solution of intervention in the case of Antim Monastery in Bucharest will be decided on the basis of plausibility principle provided by the ISO 13822:2010

## 1.1 Brief history

All the Saints Church, founded by Antim Ivireanu Metropolitan, was sanctified in 1715, according to the stone writing. An earthquaqe distroyed the steeples of the church, in 1738. The steeples were replaced with wooden ones.

First restauration work was made between 1746-1747, with funds from donations. On this occasion, the iconostasis of the stone is painted and covered with gold. In 1812, the steeples were repaired.

Between 1854-1859, Bishop Clement made a series of inquiries to the Council of the Valachia, bringing to knowledge the advanced state of degradation of the church, the cells and the belfy. Funds are allocated and an important work campaign begins in 1863. On this occasion several restoration interventions were carried out, performed by important personalities from the artistic world. The options are courageous and sometimes quite atypical to the Orthodox cult. There is a strong Western influence. So:

- Schlatter Architect orders the lowering of the porch and the construction of a Neo-Gothic Rosette, the same shape as the one from the main facade from the Notre Dame Catedral from Chartres. This one was made from wood and sheet. The western wall of the pronaos (narthex) was reshaped, making a semicircular fronton.
- Carol Stork and Constantin Mihail Babic made wooden furniture, the pulpit and the cafas, as well as as a new wooden iconostasis, that replaced the original stone.

- The mural painitng is completely replaced and the execution was made by Henry Trenk and Petre Alexandrescu. The latter places a copy of the famous „The descending from the cross" scene, made by Daniele da Volterra in Trinita dei Monti chapel from Rome, in 1541, on the western wall, right under the rosette.

**Fig.01 –** Current photography – original stone iconostasis refitted in initial positions

**Fig.02** – Vintage photography – wooden iconostasis made by Carol Storck and Constantin Mihail Babic in 1863

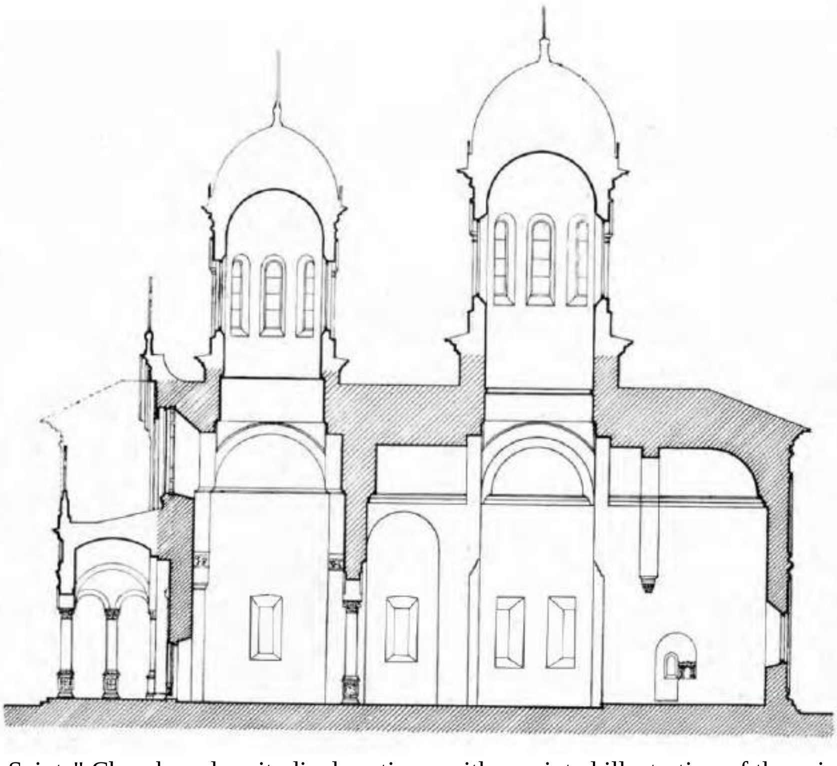


**Fig.03** – "All Saints" Church - a longitudinal section - with a pointed illustration of the original porch gauge and the architectural modifications of the 19th century.

The Historical Monuments Commission Bulletin from 1908 notes the need for urgent work on the church’s roof, which was affected during storms. In 1912 funds are required for the restoration of the All Saints Church, but because of the heavy economic situation, demand is rejected.

Only after historian Nicolae Iorga’s speech from 1937, for salvation the Antim ensemble, a new campaign of restauration works took place beetween 1938 - 1946. On this occasion, the current brick steelpes are executed. In 1950, the new steeples are painted inside by Costin Petrescu in an unusual style. He also painted the porch. The beautification of the porch is completed with the monumental mosaic made by Olga Greceanu.

The next restoration campaign took place between 1964-1966. On this occasion:

- The original stone icon is recovered and restored, the oak being sent to the Roman Orthodox parish in London.
- The original wooden rosette and the highly degraded metal sheet are replaced by one of the same type.
- The zinc coated plate is replaced with one of the copper sheets
- The last campaign of notable works took place between 1984-1986, after the damage caused by the earthquake of 1977. The painting is recovered in particullary.

**Fig.04** – "All Saints" Church from Antim Monastery – archive photo (1939)

**Fig.05** - Antim's "All Saints" Church - current photo

## 2 THE STRUCTURE OF CHURCH BUILDING

### 2.1 The state of preservation of the all saints church

The construction had many restoration and conservation interventions. From the beginning of the 20th century all interventions on the monument were carried out under the supervision and approval of the Commission responsible at national level for the protection of the built heritage, Commission for Historical Monuments / National Commission of Historical Monuments, etc.

Since brick masonry was apparently exposed to the outside in the middle of the 20th century, certain areas - repeatedly exposed to weathering - were affected by humidity, affecting both brick and mortar.
At the base of the steeples and above the nave windows and above the decorative stone paths in the upper register of the facades there are concrete belts, introduced in the second half of the twentieth century.
Small cracks, filled with cement-based mortar, are found in the parapet of the altar window and adjacent to the dividing wall between the porch and the enlarged pronaos.
The travertine steps of the church are damaged and require restoration.
The artistic components of wood and stone, metal grids and painted surfaces are in an average preservation state.
The building installations, water supply system, heating system, ventilation system, sound system and lighting, paratrasnet etc. are currently over-site.
The general state of preservation of the church with the All Saints patronage of the Antim Monastery is medium to good.

## 2.2 The constructive system of all Saints Church

The church was built in the style of three-lobed plan with enlarged pronaos in 1715 by Antim Ivireanul. The first church with this plan was erected in 1512 by Prince Neagoe Basarab in Curtea de Argesh. Since then other three similar churches were built, two in Bucharest, to Radu Voda and the actual Patriarchy, and he third to Hurez. [6]
In the case of the Antim Monastery "All Saints" Church the pronaos was unfortunately only partially enlarged (Fig 8). This is why the church proved to be sensibly to seismic actions. Indeed, in 1738, after only 23 years from completion, under a strong earthquake both steeples collapsed and later were rebuilt. In 1865 the church was flooded by the waters of the Dambovita River. Lately, by the strong earthquake in 1940 both steeples collapsed again and were rebuilt until 1948. [6]
The model of the Episcopal Church at Curtea de Arges was adopted faithfully with some changes throughout Vallachia, but also in Moldavia, Dobrudja and even Transylvania

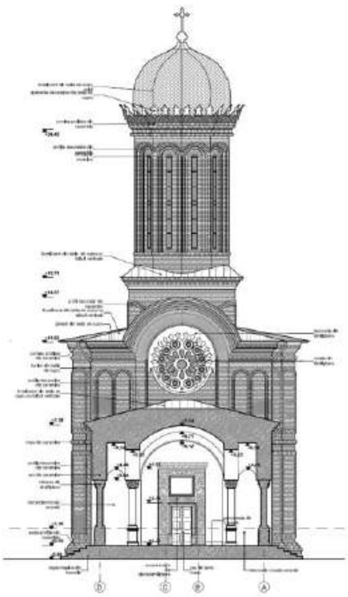


**Fig.06** Cross-section through the church porch

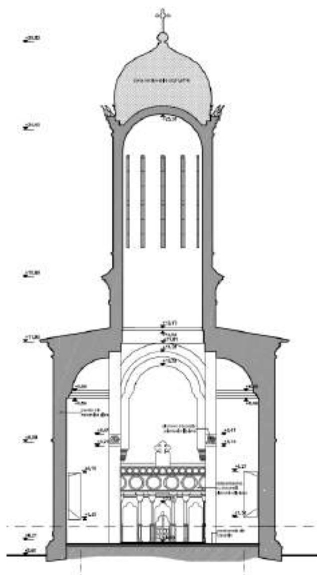


**Fig.07** Cross-section through the church steeple

After the earthquaqe occured in 1940, the chruch's steeples were damaged again, so they were rebuilt with atypical proportions so:

- Steeple's diameter/ steeple's height = 0.49
- steeple's height / body's height = 0.88

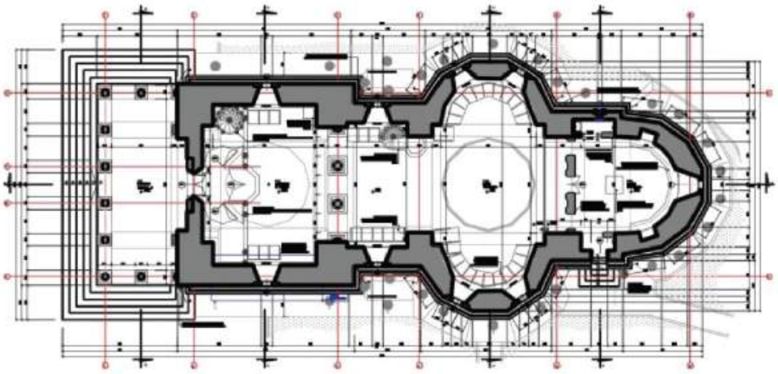


**Fig.08 –** The three-lobed plan of the Church

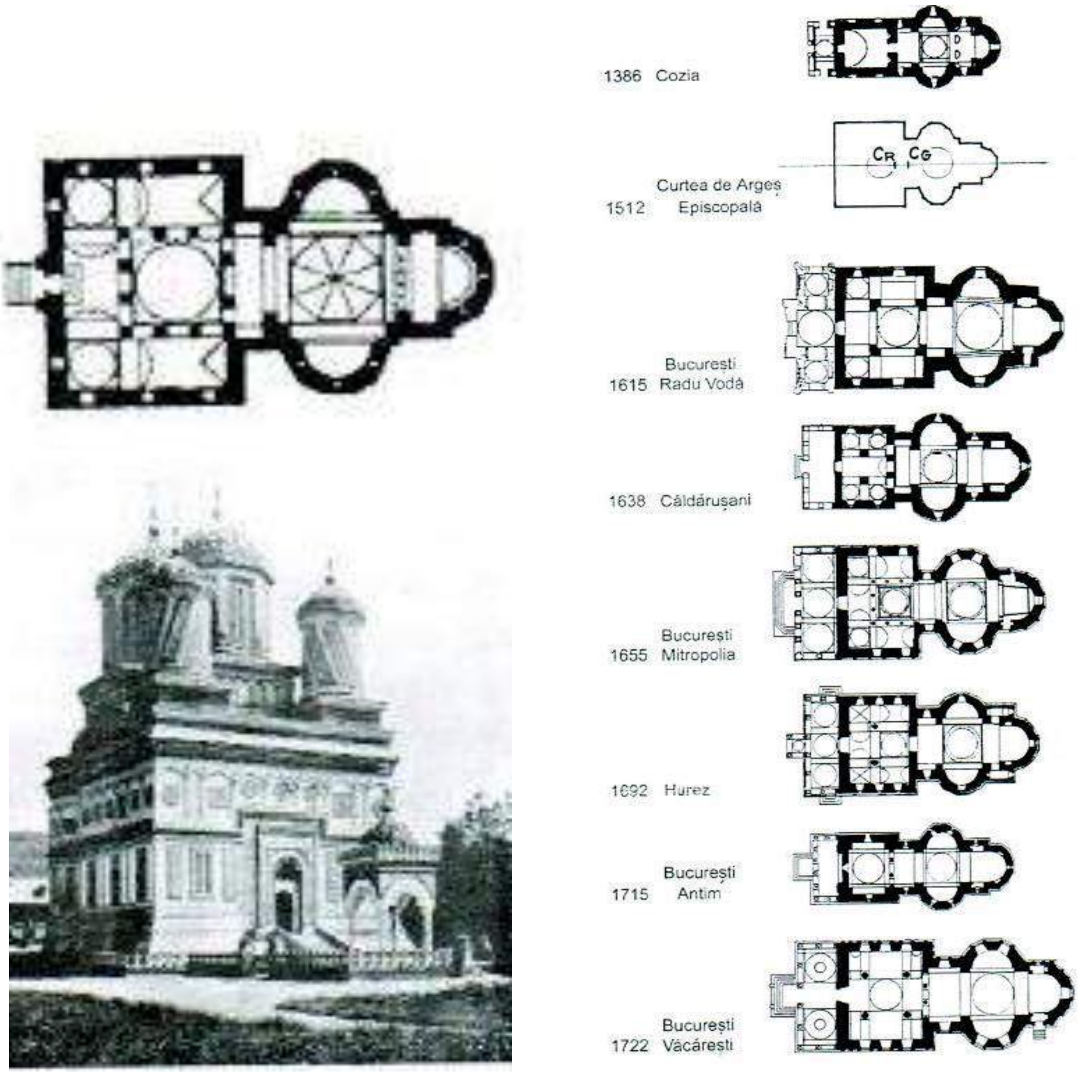



**Fig.09**: The information comes from the articles published in Lisbon 1997, Madrid 1999 and Paris 2001

### 2.3 Behavior of the three-lobed style over time

Although Grigore Ionescu and Gheorghe Curinsschi Vorona described the three-lobed churches in Romania, no reference in any architectural study was made to the changes that took place in the three -lobed system [7].

The earthquake occurred in 1977 showed that most of the three-lobed churches behaved well in the sense that they were not damaged, while others suffered damages [7].

If one compares the configuration of the Metropolitan Church built in 1655 and the all saints Church, you can find the following differences, shown in the following tables [7]:

Table 1: Comparative Table of Geometric Features

| Comparative Table of Geometric Features | | |
|---|---|---|
| | Metropolitan Church | All Saints Church |
| Width B | 17.30 m | 13.03 m |
| Length L | 31.80 m | 27.40 m |
| Height H | 22 m | 30 m |
| Depth of foundation $D_{foundation}$ | 1.5 m estimate | 2.3 m |

Table 2: Comparative table of dimensional ratios

| Comparative table of dimensional ratios | | | |
|---|---|---|---|
| Metropolitan Church | | "All Saints" Church | |
| plan ratios B/L | 0.54 | plan ratios B/L | 0.47 |
| areas ratios pronaos/naos | 1.55 | areas ratios pronaos/naos | 0.85 |
| vertical ratios B / H | 0.78 | vertical ratios B / H | 0.43 |
| foundation ratios $D_{foundation}$ / H | 0.068 1/14 | foundation ratios $D_{foundation}$ / H | 0.076 1/13 |

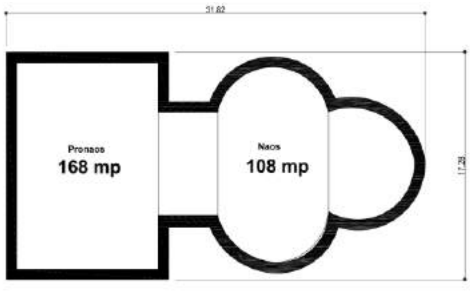



**Fig. 10**: Footprint Metropolitan Church in 1655

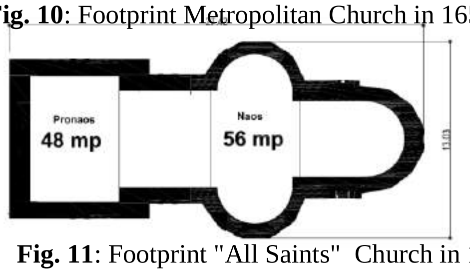



**Fig. 11**: Footprint "All Saints" Church in 1715

### 2.3 Geometric irregularities with the two intrinsec centers CG and CR.

The church has a structural regularity because the following criteria are met:
- the building is symmetrical in relation with the longitudinal axis;
- it is compact, with a regular contour;
- the distribution of the structural walls in the plan does not lead to significant disimmetry of the rigidity of the building, of the resistance or of the permanent loads in relation to the main directions of the building;
- the distance between the center of gravity (CG) and the center of stiffness (CR) is just for the longitudinal direction, and it does not exceed 10% of the longitudinal lenght of the building (e= 2.13m < 0.1 x 27.42 = 2.74m). [7]

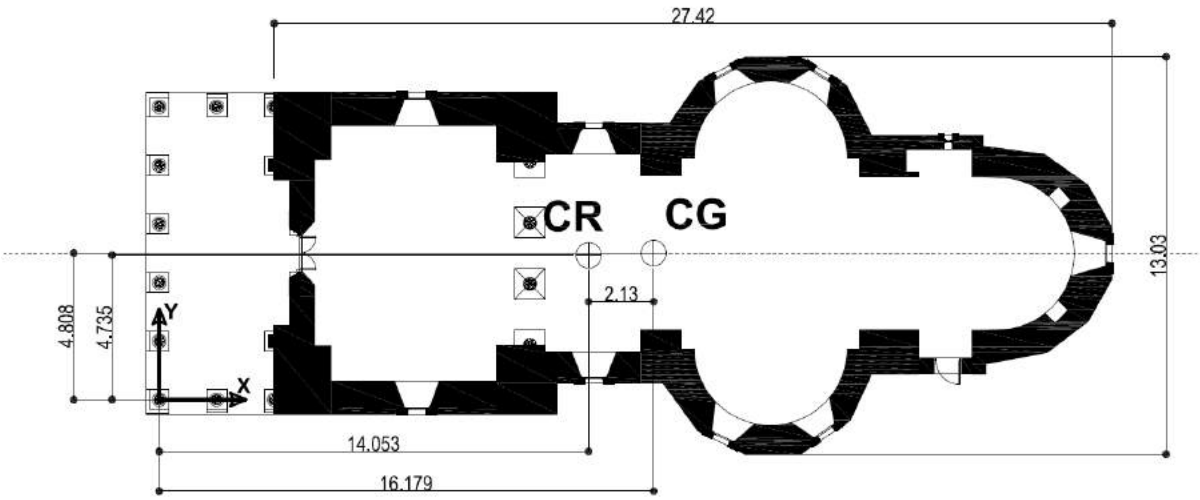



**Fig. 12**: The "All Saints" church's overall plan highlighting the position of the rigidity center and mass center

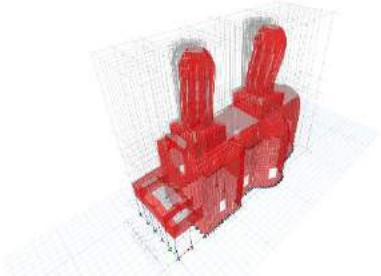
The construction has no structural regularity in elevation due to the following considerations:
- Church steeples are a irregularity in the elevation of the structure, because the structural system does not develop monotonically vertical, with no significant variation from the foundation to the top of the building.
- The structure shows lateral stiffness reductions of more than 30% of the rigidity of the upper or lower level of stiffness (the structure has flexible levels - the steeples which by their slenderness increase the amplitude of the building's oscillations by leading to the effect of the “snap of the whip” effect;
- the so called “the snap of the whip”, which occurs in the upper part of the building. [7]

### 2.4 Modeling and numerical analysis

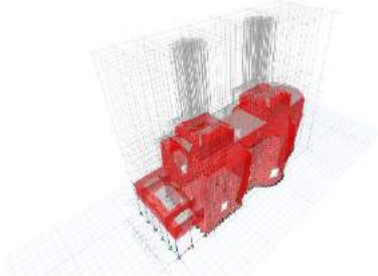
We used the 3D structural computing program ETABS, and we made dynamic calculations for the entire structure, in two versions:

- Entire building – with steeples;
- The main part of the building – without steeples, but considerring the loads and masses generated by them. [7]

Table 3: Comparison Table of Own Vibration Periods

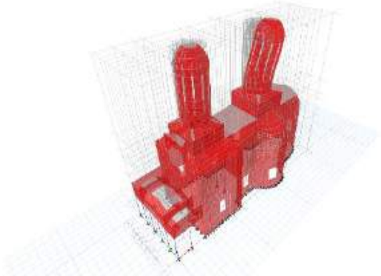


$T_1$=0.32s

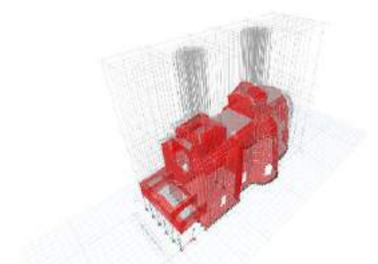


$T_1$=0.255s

1[st] vibration mode

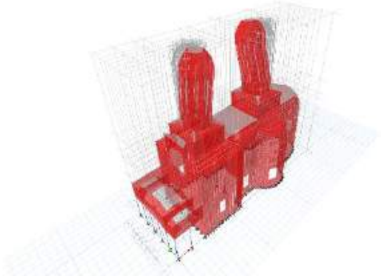


$T_2$=0.285s

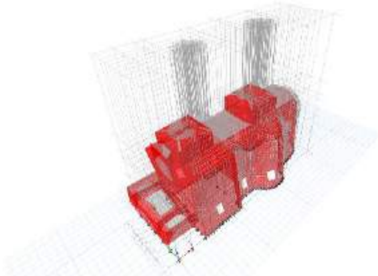


$T_2$=0.3151s

2[nd] vibration mode

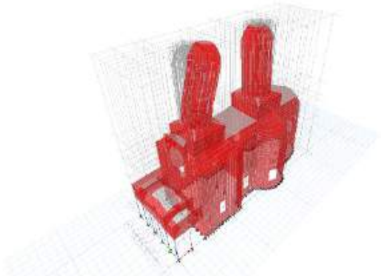


$T_3$=0.270s

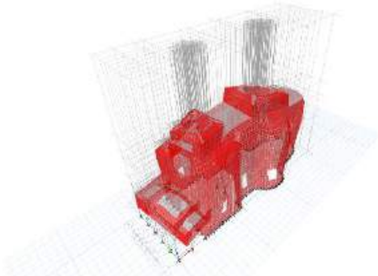


$T_3$=0.141s

3[th] vibration mode

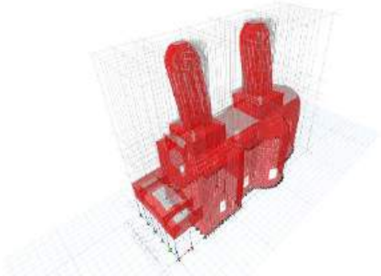


$T_4$=0.255s

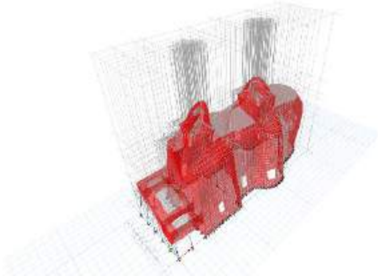


$T_4$=0.116s

4[th] vibration mode

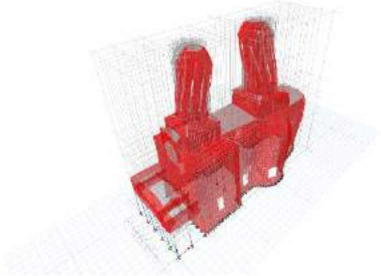


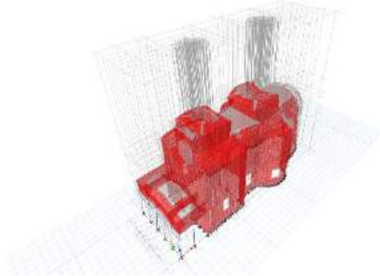
$T_5$=0.21s



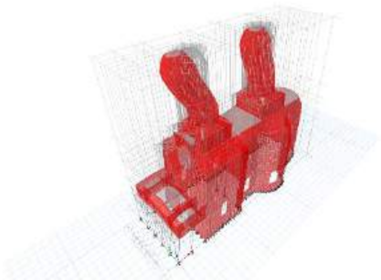
$T_5$=0.080s

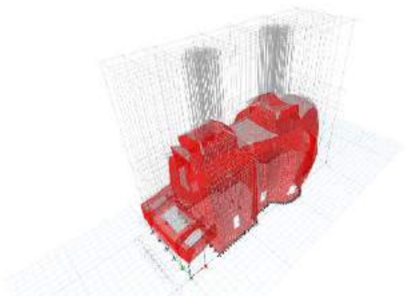
5[th] vibration mode


$T_6$=0.15s

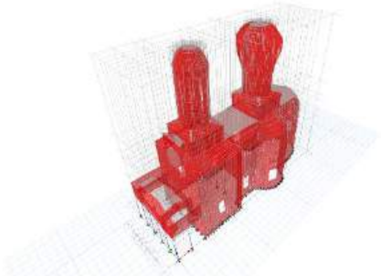

$T_6$=0.076s

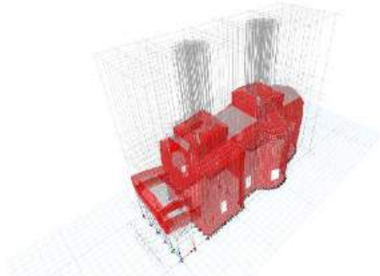
6th vibration mode


$T_7$=0.138s

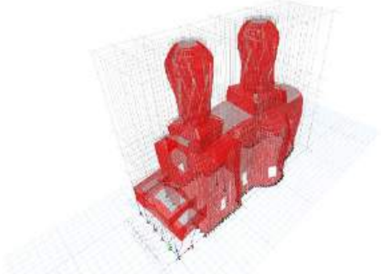

$T_7$=0.066s

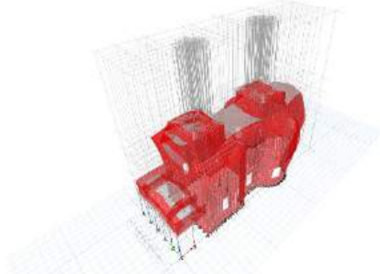
7th vibration mode


$T_8$=0.128s

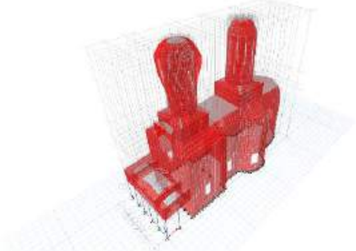

$T_8$=0.066s

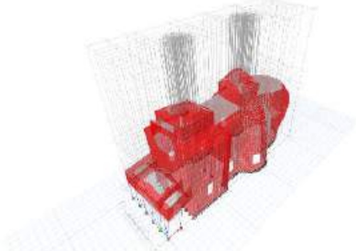
8th vibration mode


$T_9$=0.116s


$T_9$=0.061s

9th vibration mode


$T_{10}$=0.100s


$T_{10}$=0.060s

10th vibration mode

The above table highlights the major influence of the presence of the steeples, which, by their shape and position within the structure, makes the structure more flexible (the first 3 modes are due to the steeples) and increases the risk of the occurrence of “the snap of the whip” phenomenon. [7]

### 2.6 Structural assessment

Tabel 4: The evaluation of the overall assurance of the structure, according the Romanian Code P100-3/2008

| Characteristic | Direction | Building |
|---|---|---|
| Wall area in plan ($m^2$) | Longitudinal | 40.00 |
| | Transversal | 30.00 |
| Weight (kN) | Total | 32474 |
| $\sigma_o$ | Total | 463.91 |
| $\tau_o$ | Total | 231.96 |
| Maximum Base Shear force V (kN) | Longitudinal | 9278.29 |
| | Transversal | 6958.71 |
| V,adjusted KL (kN) | Longitudinal | 7731.90 |
| | Transversal | 5798.93 |
| V (kN) | | 9510.00 |
| $R_{3,initial}$ | Longitudinal | 0.98 |
| | Transversal | 0.73 |
| $R_3$ | Longitudinal | 0.81 |
| | Transversal | 0.61 |
| **$R_{med}$** | | **0.67** |
| **$R_{min}$** | | **0.61** |

$R_3$ is the seismic structural assurance degree, which is the ratio between capacity and structural seismic requirement, according to Romanian Code P100-3/2008 and P100-1/2013.

The structural calculations result in an $R_3$ seismic insurance level as follows:

2.6.1 On the transverse direction:

$R_{min}$=0.61

$R_{med}$=0.67

2.6.2 On the longitudinal direction::

$R_{min}$=0.81

$R_{med}$=0.90

So from the point of view of design capacity resistences, considering average values, $R_3$ = 0.67 = 67%

## 3 CONCLUSION

The paper presented the seismic response of vernacular heritage regarded from the present perspective of the existing advanced technologies and the available computing concepts of analysis. Obviously, both criteria are different by the specific technologies and analyses concepts used in the past. Two facts however, as basic parameters, remained unchanged, namely the building shapes and the seismic actions. This is why the lessons learned from the vernacular heritage are of great value. Particularly, in the case of the three-lobed churches, by appropriate shaping of church bodies and by proportionate the size of church steeples the expected safety and durability of three-lobed churches can be reached.

**ACKNOWLEDGMENT**

The confidence and unconditional support of Arhim. Dr. Policarp Chitulescu, from Romanian Patriarchy of the Orthodox Church in Bucharest, for carrying out the design of rehabilitation works and the technical assistance provided by designers on the construction site is gratefully acknowledged.

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# TIMBER-FRAMED STRUCTURES IN GREECE AND THEIR EARTHQUAKE PERFORMANCE.

# TIMBER FRAMES REINFORCED BY MASONRY? OR TIMBER REINFORCEMENTS OF MASONRY

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**Keywords:** Timber-framed wall, Greek traditional anti-seismic system, timber earthquake-resistant structures, timber ties/lacings, timber reinforcements of masonry, Minoan timber frames

**Abstract**

*Many traditional anti-seismic building techniques and systems have been developed all around the world in different periods as a defense against earthquake destruction. In almost all cases that different civilizations tried to deal with earthquakes, timber is present.*

*The paper aims at describing briefly the construction typologies of the timber-framed masonry structures in Greece from prehistory till the 20$^{th}$ century and their main characteristic, pointing out similarities and differences from each other, trying to answer the question: Timber frames reinforced by masonry? or timber reinforcements of masonry.*

*Another goal is to arrive at a clearer understanding of their architectural and structural conception, the interpretation of their structural role, with emphasis on their earthquake resistant characteristics, differentiating the anti-seismic systems deliberately conceived to face earthquake (Casa Baraccata or Borbone system in Italy, "gaiola pombalina" in Portugal, Lefkas system in Greece), from the other ones that have earthquake-resistant features and they perform well in seismic events, but they were not born and evolved specifically to face them.*

## 1. INTRODUCTION

Earthquakes arguably pose the most important risk among natural hazards worldwide. It affects people and societies mainly through their buildings, causing many losses in human life and severe damage and destruction to the built environment. In Greece, many severe earthquakes occurred from prehistory till nowadays. In parallel, in Greece there is a long building tradition on the use of wood in collaboration with masonry, from prehistory till the last centuries [9], resulting in anti-seismic and earthquake-resistant buildings and systems.

The majority of timber-framed prehistoric and historic structures in the world constitute usually mixed (composite) structural systems based on the collaboration of wood, stone, brick and raw earth, the wood being the main load bearing element in the majority of cases. But this is not always so evident and clear. These systems, at first glance, appear to be the same. In reality, decoding their genesis and evolution and mainly their structural role, we realize that they present differences, which are essential for their response to seismic events.

During the last decades, much effort has been made to identify reliable criteria for the comprehensive study of historic timber based earthquake-resistant systems. Earthquake engineering through numerical analysis, static or dynamic testing in shaking tables, observations on site of the damages and the seismic behavior of existing buildings, can help us understand the behavior of a structure during a seismic event. It is important to be noted though, that even if all these scientific methods can give to scientists, engineering tools and new insights into the seismic behavior of buildings, the classification and comparative study of these timber systems through constructional analysis and typology, the qualitative assessment and recognition of the structural system and mainly its idiosyncratic features of the construction details, is the first and most important step before any numerical analysis or laboratory experiment.

## 2. STRUCTURAL TYPOLOGY OF TIMBER-FRAMED STRUCTURES

The following classification will be based on structural criteria and not chronological. Concerning the structural and mainly the seismic behavior, 5 main categories of composite masonry and timber-based load bearing systems will be discussed.

### 2.1 Thin timber-framed walls (2-dimensional systems)

The main load bearing system in these cases is clearly the timber skeleton, while the infill plays a fundamental but secondary structural role, mainly for the improvement of the lateral-resistance and in-plane stiffness of the wall. That is why these walls are thin and their width is small (about 14-20cm).

#### 2.1.1. Timber-framed walls of post-byzantine buildings in Greece (Ottoman period)[1]

Buildings of two or three-stories, with similar architectural and structural characteristics, were very common during the Ottoman period in several countries in Balkan and Minor Asia area. In Greece, structures of this type are found in many areas of the central and northern part, in Thessaly, Macedonia, Thrace. The majority of them have been built before 19$^{th}$ century and although there is substantial variation in size, configuration and regional techniques, the main construction principles are similar. The ground and mezzanine floors are usually built using thick rubble walls reinforced with timber lacings (see below, 2.5), while the last floor consist of both rubble masonry and timber-framed walls (Figure 1).

[1] In Greek this system is called "*xylopikto or tsatmas*", *"hımış"* in Turkish, and *''dhajji-dewari'* in Kashmir (Pakistan and India) which means patch quilt wall.

**Figure 1:** Post-byzantine buildings in Greece, in a) Macedonia, b) Epirus, c) Thessaly.

#### 2.1.1.1. Load-bearing timber-framed walls

Timber-framed walls are composed by vertical, horizontal and diagonal elements, with different types of infill (stone, adobe or solid bricks, canes or small diameter flexible timber branches plastered with raw earth (Figure 2). The mortar is either lime based, or raw earth. In several cases the plaster is reinforced with straw or animal hair.

**Figure 2:** Different types of infill. a) stone, b) raw earth on timber branches and c) solid bricks. Round timber mortises and "*gypsy*" nails of rectangular section were used for the timber-to-timber connections.

The width of the wall depends mainly on the dimensions of the timber posts which is usually 10-16cm, without the plaster. In most cases the main load bearing system of the frame is composed by vertical timbers placed every 70-160 cm over and under horizontal beams (beddings), at the level of the floor and at the level of the roof (Figure 3). The connection of the vertical posts to these horizontal timbers was accomplished in several cases by round tenon and mortise joints (Figure 2 c)). The other vertical, horizontal and diagonal timbers have usually smaller dimensions and their connection to each other and to the vertical posts, was made either with 1 or 2 mild steel "*gypsy*" nails, or by shallow grooves and a nail (Figure 2, c)) [1].


**Figure 3:** Concerning architectural and structural characteristics, two types of timber-framed walls are met in Greece. a) The one with a lot of openings which has none or few diagonal elements, and b) the one without or few openings that has several diagonal bracing elements [1]. c) A 3-story house in *hımış* construction, with many openings in Safranbolu, Turkey [2].

The use in most cases of diagonal timbers that work as bracings improves a lot the rigidity of the frames. There are cases that diagonal timbers are few or do not exist (timber-framed walls with many openings) (Figure 3 a), c)). In these cases the capacity of the filling is even more important for their lateral resistance. In Greece, most of timber-framed walls are plastered.

Though this type of construction technique was probably not born as a result of a conscious design for an anti-seismic system[2], it was soon widely appreciated for its beneficial features against earthquakes[3] (Figure 4) [2,3,5]. Recent research on this topic through numerical analysis and laboratory testing has proven too their good performace in earthquake events. It was observed that the many in number nailed timber-to-timber connections, the slip along timber–masonry interfaces and the cracking of the infill during an earthquake, work as dissipative mechanisms, providing damping [3].

Another important observation, based mainly on full-scale testing of timber-framed walls, is that cladding, either with timber planks or *bagdadi* system (see 2.1.1.2), results in a higher load-bearing capacity and stiffness than infill, because the later results in significant increase of the weight of the wall [3].

**Figure 4:** Timber-framed structures that presented excellent ductile behavior. a) Earthquake in April 1881, Chios, Greece (after Fasoulakis, Bouras 1983), b) Earthquake in 1999, Turkey (photo by Nat. Geographic). The seismic fault is passing through the house. c) Earthquake in 2005, Kashmir. Half-timber structure severely damaged but still standing [2]. d) A house in Scandinavia, though deformed, is still in use (after Copani 2007).

[2] The origin of timber-framed walls with the evidence we have till now (archeological sites of Pompeii and Herculaneum), goes back to Roman period. It was considered a low cost, quick, and easy to build and repair construction, called *opus-craticium*. Timbered-framed walls were also widely spread during Middle Ages throughout Europe, in countries that do not have earthquake problems, Germany (*fachwerk*), France (*colombages* or *pan de bois*), United Kingdom (*half-timbered*), Poland etc. A theory for their genesis and evolution in England is that they were used because wood was expensive. Most people couldn't afford to build the entire building out of timber. It was cheaper and quicker to build a frame of wood with different infill and plaster. But soon they realized that you could make attractive patterns and an architectural, aesthetic and decorative aspect of half-timbered motifs (St. Andrew's crosses, the Swabian wife, the Husband and the Half etc.), started to define their use and their construction details [4]. The abundance of timber in these forested countries as an easy to find and work with raw material, played a significant role for the use of timber-based structural systems (log houses, or timber-framed). It must be noted that in the above cases, the rigidity of the frames (inclined timber members-bracing, infill etc.) is necessary too, due to another force that can impose horizontal loads, the wind.

[3] After the 1509 great Istanbul earthquake which resulted in about 13000 casualties, the Ottoman authorities prohibited masonry and enforced the construction of timber-framed houses, claiming that masonry was responsible for most of the casualties. By the end of the century, the city was almost entirely built of wood [3]. Again, after the Istanbul earthquake of 1894, both experts and ordinary citizens were impressed by how well wooden buildings performed [5]. Similar observations have been recorded for the earthquake in Turkey in 1999 by Golhun et.al. (see also Figure 4 b)), and after the 2005 Kashmir earthquake in Pakistan [2]. In Papazachos B. and C. published catalogue (1989, 2003) of historical earthquakes in Greece, there are several references about the good seismic behavior of timber-framed structures. In 1856 earthquake, in Heraklion in Crete, the timber mansion of Mustafa Pasha had no damages, while 3620 houses were destroyed. Because of this, the mansion was used as a hospital. As reported also by Leake, a ascholar and a traveller of the beginning of the 19$^{th}$ century, in Patras in Greece, the residence of the English Consul was timber due to the severe earthquakes.

#### 2.1.1.2. Non load-bearing timber-framed walls

In several cases timber-framed walls are non-load bearing, since they are used as partition elements in order to form the interior spaces of the building. They are composed by a timber skeleton built of vertical and horizontal timbers, without usually diagonals and without infill (less weight). The sections of the timbers are small, 6-10cm. They are either cladded with timber planks or, more often, they are plastered using a common technique called in English '*lath and plaster*' or in Turkish *bağdadi* [4]. Small laths of timber (about 10 mm thick and 20–100 mm wide) (Figure 5 c), d)), canes or small flexible branches (Figure 5 a), b)), are nailed or stabilized geometrically on the timber skeleton (Figure 5 b)), leaving at least 1cm gap in between, creating this way a mechanical anchorage of the lime or earth-based plaster (Figure 5 d)) on the timber skeleton. Since they are not structural elements, usually there are no underlying walls, and for this they are placed on timber floor beams.

In few cases these systems have been used for load-bearing walls too (Figure 2 b)).

**Figure 5:** Non-load bearing partition walls: a), b) with curved branches and c), d) with *bağdadi* system.

Concerning earthquake behavior it is worth to be noted that historical research (photographs, documents etc.) and post-disaster observations on-site after strong seismic events, have revealed the valuable structural role of these non-structural elements, which become active during and immediately after the earthquake, preventing in several cases total collapses, saving partially the buildings and the inhabitants (Figure 6).

**Figure 6**: Partition non-load bearing timber walls supporting the roofs after the collapse of the external walls, in Korinthos earthquake (1928, web photo), in Cephalonia (1953) and in Vrisa in Lesvos island (2017).

### 2.1.2. Timber-framed walls of *Lefkas anti-seismic system*

An example of a structural system developed to resist earthquakes is that of Lefkas island [6]. In that Ionian island (belonging to the most earthquake prone area of Greece and Europe), a peculiar structural system based on timber was developed. In 1810 the English rule was established and in 1825 a strong earthquake occurred proving the adequacy of an existing system to sustain seismic actions. Two years later, the British Authorities imposed rules, a seismic code, for the construction of new houses following the main characteristics of the lo-

[4] *Bağdadi* is a term used to describe these kind of structures in many countries in Balkan area. In Greece too.

cal structural system[5]. The system which was used till the 20th century for both residential and public buildings, proved its satisfactory seismic behavior during several extremely strong earthquakes (the last important one in 2003). It is considered one of the anti-seismic systems of the world, since it presents unique traditional earthquake-resistant construction practices that even though they look similar, they differ significantly from construction methods of relevant buildings in Greece of the same era (Ottoman period timber-framed walls, 2.1.1). Briefly, some of the main anti-seismic characteristics that diffentiate this system are:

- As most timber-framed walls (2.1.1), the timber-framed walls of the upper floors, are reinforced by the usual diagonal elements. But in Lefkas system they are placed in a quite regular pattern, in most cases in conjunction with one-piece L-shaped elements from olive trees, an innovative technique which improves even more the rigidity of the frames and secure the connection of the vertical and horizontal members especially at the corners (Figure 7) [6].

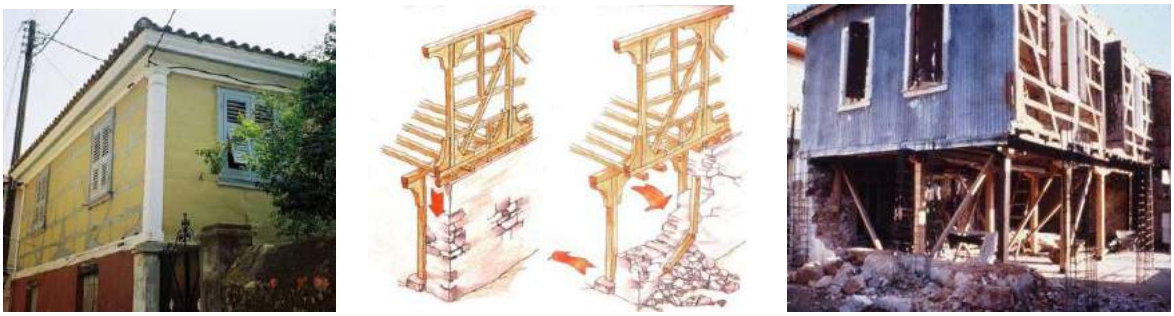

**Figure 7:** The Lefkas anti-seismic system [6].

- Concerning the overall behavior of the whole structure, the main anti-seismic characteristic is the timber double load-bearing system, used inside the building, in parallel (at a distance of ~5-10cm) to the masonry walls of the ground floor, acting as a 2nd line of defense against earthquakes. This secondary auxiliary load bearing system, structurally, is a moment-resisting timber frame, consisted by free-standing wooden columns, horizontal beams placed just under the floor joists, and L-shaped timbers that provide the necessary rigid connection of the columns and the beams (Figure 7 b)). When the masonry is severely damaged or collapses, these timber frames are activated, carrying the loads of the floor, the roof and the timber-framed walls of the upper floors, preventing the total collapse of the building during the seismic event and moreover, keeping it in place till the damages are repaired (Figure 7 b), c))[6]. It is interesting to be noted that the same principle is used for historic churches too (Figure 8).

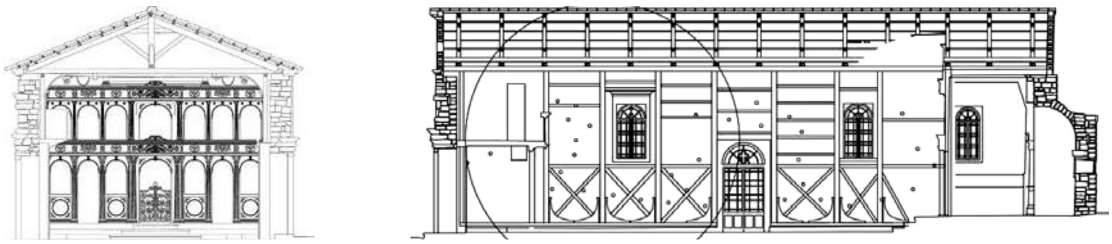

**Figure 8:** Church of Virgin Maria of the Strangers in Lefkas (Venetian period) [7]. In the interior of the church along its longitudinal sides, at a distance from the internal face of the masonry walls, a timber frame without

[5] Further historical research is needed to identify the origin of the system and if and how English, after 1810, have enriched it. The double system and its structural role is reported by Leake in 1806, in Cephalonia island too. Nowadays the system has been documented in few buildings in Cephalonia but its use is limited and rare.
[6] It is characteristic that in Lefkas the occupants (oral information from older people), never leave their houses during an earthquake, since they feel safer inside, avoiding this way injuries and deaths that in many cases are caused either due to collapses of walls on the streets, or detachments of tiles and other decorative elements.

infill, covered with wooden paneling, is supporting the roof if the masonry is damaged or collapses [7]. It is noteworthy also the use of a different layout for the double timber system compared to the double system used for the other buildings of Lefkas (the L-shaped stiffening timbers placed at the lower part of the frame, and the use of double diagonal elements).

### 2.1.3. Timber-framed walls of the anti-seismic "*gaiola or pombalino*" system in Lisbon [8]

The reconstruction of Downtown Lisbon after the 1755 earthquake that destroyed partially the city was based on a novel construction system with an internal 3-dimensional timber-framed structure[7]. In the Pombalino buildings, the ground floor is comprised of stone masonry supporting up to 4 upper floors constructed by timber-framed walls, timber floors and roof, (Figure 9). The thin timber-framed wall system, consisted of vertical, horizontal and double diagonal bracing elements, is hidden, placed inside the building. The masonry facades are anchored on it with metal elements. If the heavy and brittle masonry walls fall down, the timber skeleton can keep the building standing. Metal elements were used too for the connection between the floors, the roof and the timber-framed '*gaiola*' walls in order to provide a box-type behavior for the whole building. The use of double diagonal elements (*St. Andrew's crosses*) and the regularity that the frame layout and the connection present, are not met at the non-engineered examples of the Balkan and Minor Asia areas. The same regularity in design and construction can be seen at the *Borbone* systems (see 2.2.3, 2.4.2), probably because they were constructed with regulation, codes and guidelines from official military engineers[8] [10].

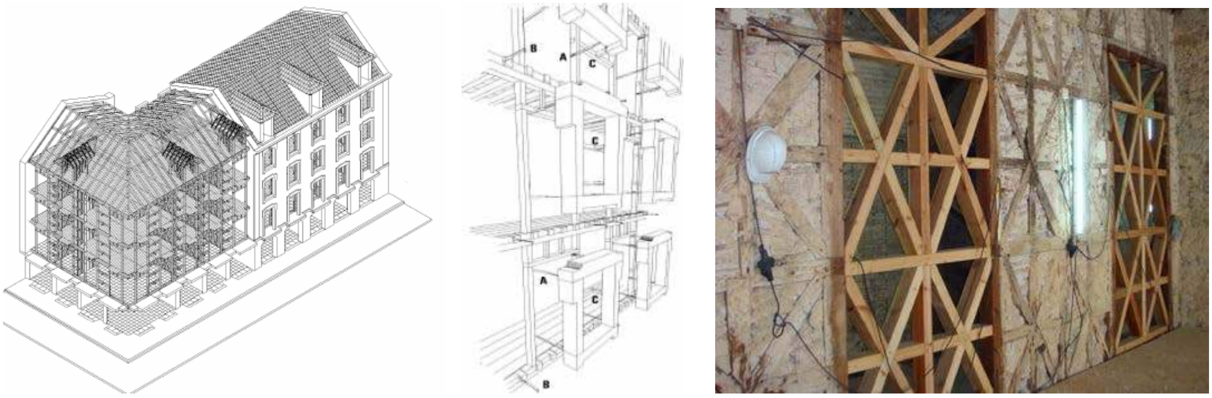

**Figure 9:** a) A Pombalino building. b) Details of the timber frame and the anchoring system of the masonry facade (after Mascarenhas et. al, 2005). c) A typical timber-framed wall of *gaiola* system.

## 2.2 Thick timber-framed walls (3-dimensional systems)

### 2.2.1 Minoan palatial buildings. Neopalatial period ($17^{th}$-$16^{th}$ B.C.) [9]

The Minoans suffered the effects of frequent earthquakes since they lived on an island regularly struck by extremely severe seismic events. A major catastrophic earthquake is believed to have been responsible for the destruction of the $1^{st}$ Minoan palaces in Crete. The erection of the $2^{nd}$ palaces (about1700 B.C.) during Neopalatial period (the '*Golden Age'* of the Minoan era), was a turning point in Minoan architecture, marked by the crystallization of a new and unique architectural and structural concept. The sophisticated design that characterizes most

[7] Portuguese experience in naval constructions, probably played an important role for the invention of this anti-seismic system since both buildings and boats, are subjected to dynamic loads. It is interesting to be noted that the L-shaped timber pieces of Lefkas system were, and still are extensively used for the construction of timber boats and ships. Concerning Minoan cases (2.2.1, 2.3.1), ship-building technology must have influenced building techniques too since Minoans were considered the rulers of Aegean Sea (Minoan Thalassocracy).

[8] The *gaiola* system was designed too by military engineers of Pombal period [10].

of the important buildings of this era is supported, metaphorically and literally, by several innovative composite structural systems, based on the collaboration of wood and stone, the wood being the main load-bearing element in the majority of cases. In this paper, only two of them will be presented briefly (2.2.1, 2.3.1). During Neopalatial period in Crete, a double timber framing system incorporated into thick masonry walls (60-120 cm) was introduced for the construction of palatial buildings. A *massive timber framework* according to Evans, the excavator of Knossos palace[9]. The vertical timbers, always in pairs on both faces of the masonry were placed on a stone base, transversally set through the thickness of the wall. Two other pairs of horizontal longitudinal timbers connected to the vertical ones existed in 2 levels over the lintels (Figure 10 a)), forming a 3-d timber frame embedded in both faces of the thick masonry walls. The space between the two vertical timbers, transversally to the wall was filled with small stones and mud. The material used for this filling was quite loose compared to the well-built masonry between the timber frames along the walls (Figure 10, a)).

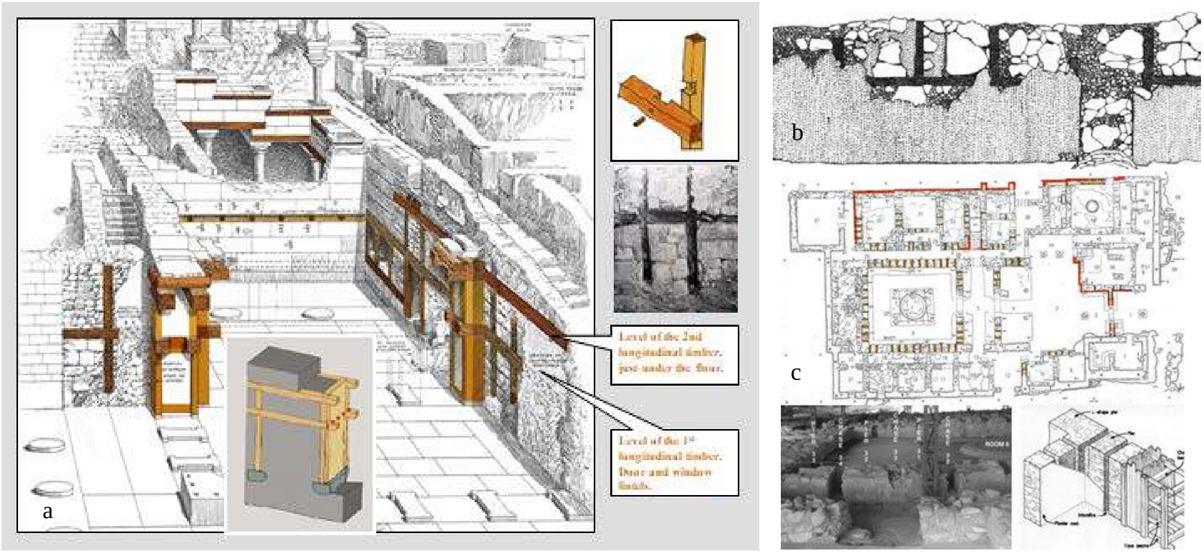


**Figure 10:** a) Domestic Quarters at Knossos, Hall of Double Axes, documented as found during excavations, by the excellent axonometric drawing of Evan's architect, T. Fyfe. Reconstruction proposal of the timber frame incorporated in the walls by Tsakanika (2006) [9]. b) Citadel House in Mycenae (Wace, BSA25). Rubble masonry wall reinforced with timber frame. c) Pylos. The palace of Nestor. Plan, photo and reconstruction proposal by Nelson (2001), showing the gaps (colored in plan) that the timber frame left in masonry walls.

From a constructional point of view, it is reasonable to assume that the timber frame was built first. The rubble wall was likewise built in a later phase, between and around the timber framework. Masonry in this case, does not seem to have the prime structural role, and we cannot consider it as masonry reinforced with a double timber frame but as timber-framed wall reinforced by masonry. So masonry walls in this case provide the necessary stiffness for the timber frames in which they are embedded, and the necessary rigidity for the overall structural system, constituting, in modern engineering terms, the shear walls of the Minoan prehistoric buildings. The use of vertical timber frames embedded in stone walls is an effective earthquake-resistant measure. They limit the development of cracks thanks to the compartmentalization of masonry and moreover, timber frames can act as support for the floors and upper story walls preventing fatal building collapses during strong earthquakes. This structural concept appears similar to the one that dictated the use of timber frames on the ground floor

[9] In Knossos palace the dimensions of the timber framing elements were more than 20-25 cm.

of traditional buildings of Lefkas. The difference is that the Lefkas timber frames are not embedded in the masonry as the Minoan.

### 2.2.2 Mycenaean buildings. ($16^{th}$-$11^{th}$ B.C )

During Mycenaean period in Greece, different types of timber reinforcements of masonry walls existed too in buildings in Mycenae (Figure 10 b)), in palaces of Thebes, Tiryns and Pylos from where the most prominent example comes from (Figure 10 c)). These systems are considered by several scholars and researchers similar to the Minoan one, but in reality they present many differences. In many cases this argument drove them to the wrong conclusion that Mycenaean architecture is similar to Minoan. In reality, they are completely different.

### 2.2.3 "*Casa Baraccata* or *Borbone*" anti-seismic system in Calabria, Italy (*double frame*)

A lot of similarities can be observed between the Minoan palatial structural system of the walls (2.2.1), and one of the versions of the famous *Borbone or casa Baraccata* anti-seismic system, conceived and used in Calabria 4000 thousand years later, after the catastrophic earthquake of 1783. In this case too, all load-bearing walls were made of thick masonry, about 60 cm, incorporated, as in Minoan rubble walls, into strong double timber frames placed on both wall faces, extensively reinforced in this case with diagonal elements (Figure 11), [10].

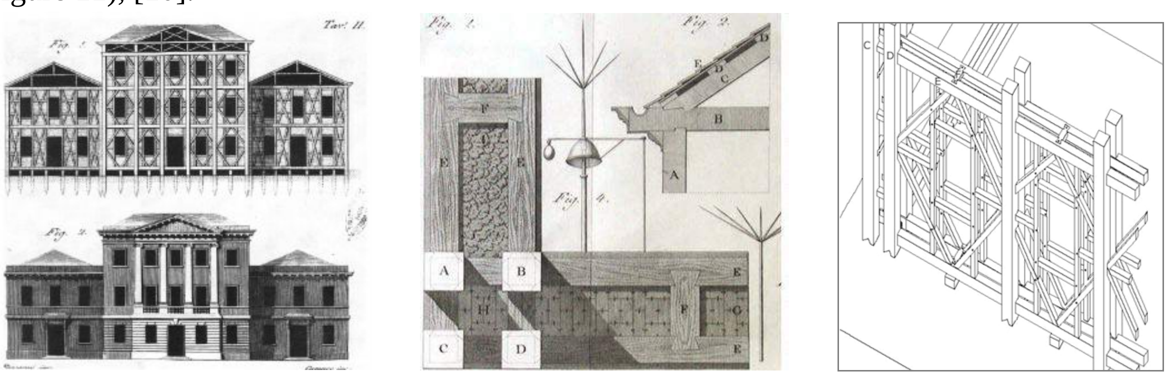


**Figure 11:** Illustrations of Giovanni Vivenzio's Italian "anti-seismic house" (1783), showing one version of "*casa Baraccata*" system with double timber frame incorporated in the thick masonry walls. Axonometric drawing of the double timber frame by Ruggieri [10].

## 2.3 Timber moment-resisting frames

In terms of resistance to lateral loads, we must distinguish the moment-resisting frames from the stiffer timber braced 2-d wall systems (thin timber-framed walls, see 2.1).

### 2.3.1 The Minoan timber frames (*pier-and-door partitions*) [9]

The most important architectural and structural innovation of Minoan Neopalatial architecture is the *pier-and-door partition*, (see also 2.2.1). It appears in the form of a series of doors (*polythyron*), and it consists from a structural point of view a unique, innovative moment-resisting timber load bearing frame that substitutes entire walls, even at the ground floor of multi-story buildings. It is based again on the collaboration of wood and stone (composite system), the wood being the main load-bearing element. The vertical elements of the frames were composed of timber posts set over transversal horizontal timbers which were resting on visible stone foundations ([- or I-shaped), which worked as door jambs too. As in the timber frame incorporated in masonry walls (the structural concept is the same, see 2.2.1), horizontal timbers longitudinal and transversal existed at 2 levels. The $1^{st}$ horizontal timbers were composing the lintels of the doors, while the $2^{nd}$ row over them was necessary not only for architectural reasons (creation of clerestories for light and air (Figure 12 a)), but also for the improvement of the frames' lateral stability. The rigidity in all directions was based mainly on the moment-resisting connections at the upper part of these timber frames which were accomplished by the continuation of the vertical timbers until the 2nd level of horizontal timbers, and by the use of stone or mud brick infill between the vertical and horizontal timbers (Figure 12).

The structural concept of this composite 3-dimensional timber frame, is much closer to the reinforced concrete or steel frames of the last centuries and much more advanced than the 2-dimensional timber-framed walls used as described above in Greece and in several other countries around the world during historical periods (2.1).

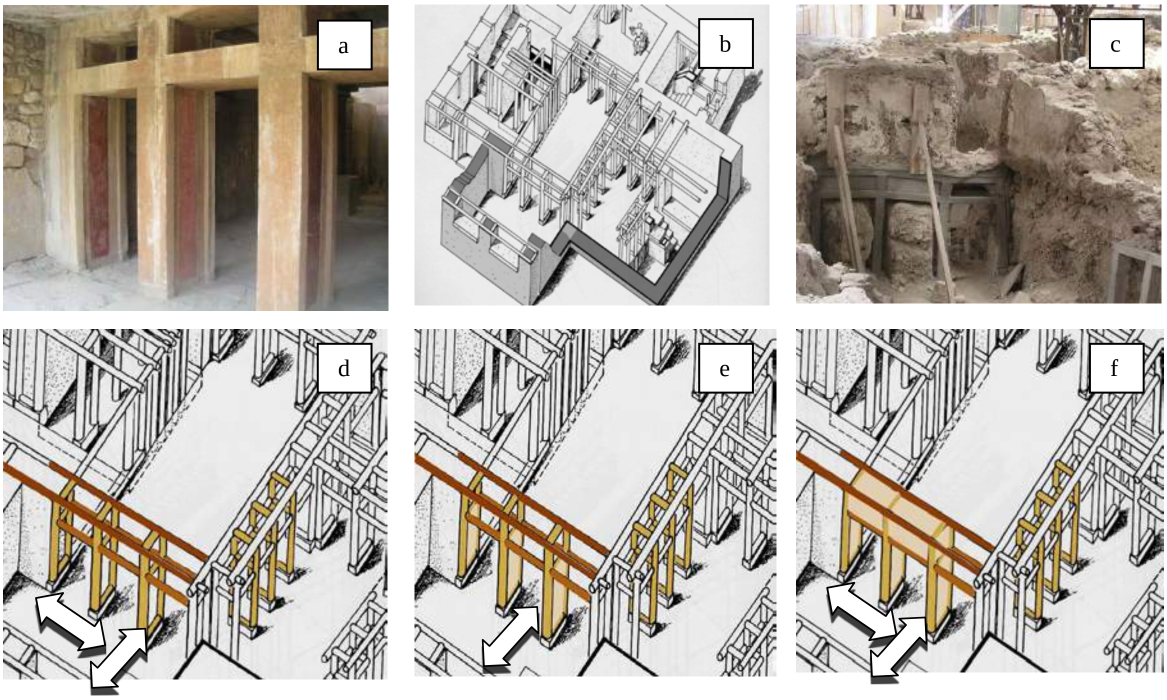


**Figure 12:** a) Royal Villa. Knossos. Reconstruction of a *pier-and-door partition* by Evans. The timbers are colored in yellow and the masonry infill in red. In this case the upper part over the lintels is open. b-f) Xeste 3, Akrotiri, Thera (axonometric drawing after Palyvou, 2005). Most of the internal "pierced walls" of the ground floor are composed by *pier-and-door partitio*n timber frames. c) In Xeste 3, a *pier-and-door partition* frame is supporting a masonry wall over it. d) The rigidity of the timber frames in all directions was accomplished by the continuation of the vertical timbers until the second level of horizontal timbers, e) by the use of stone or mud brick infill between the vertical timbers and f) between the horizontal elements too [9].

From an engineering point of view, it is remarkable that the Minoans, almost 3700 years ago, in a high risk seismic area, dared to remove compact massive masonry walls not at the upper floors as in all historic cases (Figures 1,7,9), but at the ground floor of 3 or 4-story buildings, substituting them with timber frames full of openings (Figure 12). It is noteworthy that in a 3 story building (Xeste 3) at the Minoan settlement of Akrotiri in Thera, they dared something even more extreme and provocative from an earthquake engineering perspective. Their trust in these timber frames was such that they decided to use a *pier-and-door partition* frame at the ground floor to support a heavy two-story masonry wall constructed over it! This timber frame and the masonry wall over it survived the Theran eruption and all the associated earthquakes (Figure 12, c)) [9].

Probably during Minoan era the first moment-resisting timber frame of the world was invented.

### 2.4 Masonry reinforced with timber frames

For all the above discussed systems, timber is considered as the main load bearing element while masonry the secondary. On the contrary, the following systems cannot be considered as timber-framed walls but as masonry structures reinforced by a timber frame incorporated only at the internal face of the wall. This feature differentiates a lot the structural behavior of the wall for vertical and horizontal loads too.

#### 2.4.1 The *Eressos system* in Lesvos island, Greece [11]

Eressos system was first located and studied at traditional buildings of the settlements of Eressos, in the island of Lesvos, in Greece (Figure 13). The timber-frames were used only at the upper floor of 2-story buildings. Their absence at the ground floor is a weakness of the system. The same system was found in Bergama too, in the western coast of Turkey [11], and recently it was located in two other settlements of Lesvos (Plomari and Vrisa (Figure 13 c), 15 a)) and in few buildings in the island of Chios (Figure 15 b) [12].

**Figure 13:** a), b) The Eressos system [11]. c) An external part of the masonry collapsed. The embedded timber frame, at the inner face of the wall is supporting the roof of this building of Vrisa in Lesvos. A big part of this village was destroyed during the recent earthquake in 2017. The Eressos system was used only in few buildings.

#### 2.4.2 The "*Casa Baraccata / Borbone*" anti-seismic system in Calabria, Italy (*single frame*)

In this version of *Casa Baraccata* system, a timber frame is incorporated only at the internal face of the thick masonry wall [10].

**Figure 14:** Bishop's Palace of Mileto, Italy a) Axonometric drawing by Stellacci and b) photo, showing the timber frame at the inner face of the external thick masonry wall. c) Messina, Italy. A baraccato building. The external masonry leaf fall outside after the 1908 earthquake. The embedded timber frame at the inner face of the wall prevented the collapse of the building [10].

The above systems, are considered anti-seismic and have a lot of structural similarities. However differences exist. The Eressos system is reinforced by diagonal elements too, and in some cases by the presence of timber lacings that connect more effectively the outer face of masonry with the internal timber frame. Especially for Eressos, further research is needed in order to discover what dictated its use, why, when and how it evolved.

**Figure 15:** a) Plomari, Lesvos island. An industrial building. b) Chios island. The building of Ephorate of Antiquities [12]. It is noteworthy that after the restoration projects, in both cases, the timber frames was decided to remain visible, an excellent choice for didactic reasons too.

## 2.5 Masonry reinforced with a horizontal timber system (*timber ties, timber lacings).*

This timber reinforcing system is actually a horizontal grid of longitudinal and transversal timbers embedded in masonry in several levels along its height (Figures 1,16). It is considered the oldest timber reinforcement system of masonry (stone or adobe), used continuously for probably thousand of years in Minor Asia and Greece, in Minoan and Mycenaean buildings, in Troy (Figure 16 a, right), during Byzantine and Ottoman period, even till the beginning of the 20th century (Figure 16 b, c) [1,6,9]. In several studies this system is considered wrongly as timber-framed masonry or half-timbering. It is important to be noted though that it is completely different, both typologically (no vertical elements exist) and structurally[10].

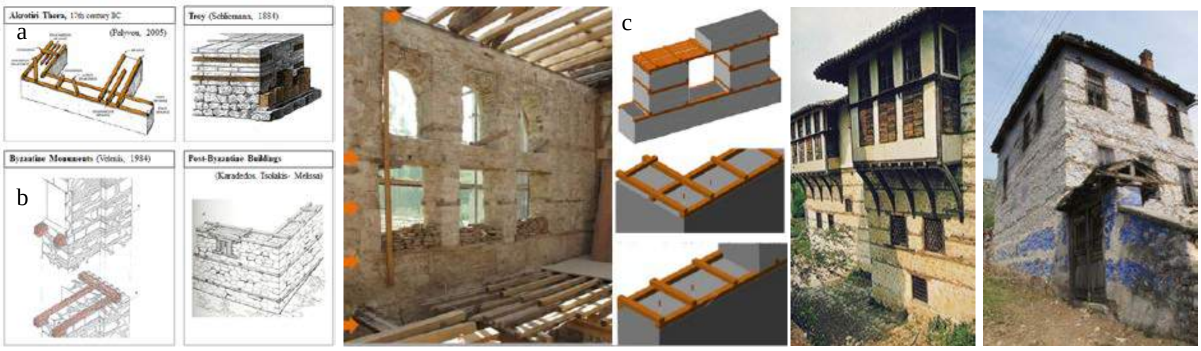


**Figure 16:** The horizontal timber reinforcement system is continuously used in countries around Eastern Mediterranean for thousand years, helping masonry buildings withstand earthquakes [1,6,9].

[10] In modern Greek this system is called *xylodesia,* which means the tying of a building with wood. During the Byzantine and earlier periods, it was designated as *imantosis* meaning belt [9]. This word accurately describes its main structural role: the tying of the walls like a belt preventing their outward collapse [6]. Moreover this system improves the seismic performance of buildings thanks to its multiple structural roles: the connection of the outer and inner leaf of the masonry walls, the improvement of ductility and the tensile and bending strength of the brittle (by nature) masonry working as reinforcement for in plane and out of plane induced seismic forces [1, 9].

## 3. CONCLUSIONS

This paper intended to provide information on the typology and earthquake performance of the composite timber-framed masonry structures in Greece from prehistory till the 20th century, comparing them with similar systems in Europe and Anatolia, and thus contribute to the state of the art on this issue. The different systems were classified into 5 categories concerning their structural and seismic behavior: *1) Thin timber-framed walls (2-d systems), 2) Thick timber-framed walls (3-d systems), 3)Timber moment-resisting frames, 4) Masonry reinforced with timber frames* and *5)Masonry reinforced with horizontal timber system (timber lacings).*

The following question is discussed too: *Were all these systems born as anti-seismic*? The answer is not easy. Probably no. Not from the beginning. In most cases other factors dictated their use and evolution. Traditional architecture is the product of many years of experience expressed with many adjustments and variations. The builders of prehistoric and historic periods were for sure not aware of the characteristics of the earthquake motion as we are today. But they were observing the 'good' or 'bad' behavior of their structures, the damages and failures after a small or severe earthquake, valuable observations that were made on a natural 'seismic table', on full scale 'specimens': their buildings. As a result, they either promoted and used more extensively structural systems that they presented earthquake-resistant behavior, or they produced anti-seismic systems as Pombalino, Borbone, or Lefkas, improving the existing timber-framed structures. Most of these anti-seismic systems were based mainly on the use of timber with various innovative ways reinforcing or being reinforced by masonry.

A better understanding of this kind of structures based also on experimental and analytical investigations (*quantitative approach*) is very important. Research on this topic is rather recent and limited, but thankfully of increasing interest [1,3,7,8,10]. Quite valuable is also the historical research and the data that describe the real behavior of real buildings hit by real earthquakes along with the nowadays observations of the seismic behavior of the existing structures, since they can calibrate both analytical and experimental investigations [1,2,5,6,9,11].

Further work needs to be done concerning their typological, architectural and mainly their constructional and structural features (*qualitative approach*). The details make the difference, especially if one takes into account the variety of the structural systems. It is very important to recognize, assess and exploit the hidden in several cases effort of the traditional builder to safeguard his building, and benefit from it. These systems, important or humble ones gained our respect not only as a part of our tradition and culture, but in strictly engineering terms, as constructions that survived and worked properly for many years or centuries. Studying them we can discover innovative earthquake-resistant solutions of the past that can inspire us to use them in the future, either for historic buildings that need to be reinforced, or why not, for modern structures too.

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# EARTHQUAKE EFFECTS ON VERNACULAR BUILDINGS: AN EXAMPLARY STUDY IN ÇERKEŞ/ÇANKIRI

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**Keywords:** Vernacular Architecture, Architectural Documentation, Earthquake Effects, Restoration

## Abstract

*Çerkeş, located on the border between Central Anatolia and Western Black Sea regions, is a district of Çankırı. The settlement which has been an important commercial center due to its location was ruled by the Ottomans beginning from the fifteenth century. In the seventeenth century, Çerkeş gained significance with the result of that it was among the most important military destinations during the Baghdad and Revan campaigns. The building complex including a mosque, and a public bath constructed in this period, and has been indicated the old center of the town. Moreover, the urban fabric surrounding the center has been reflecting the local architectural characteristics of the region. However, Gerede Earthquake in 1944, which caused big damages and losses at the Western Black Sea Region, also resulted in big devastations on the monumental and vernacular buildings in Çerkeş.*

*In this research, the House of Uyanık Family, which is among the survived examples of vernacular architecture in Çerkeş, has been studied. The first construction date of the house isn't known. Yet, the building is probably dated to the end of the nineteenth century considering the information given by the family. The house constructed in timber frame is rectangular in plan (approximately 12,80 m x 10,50 m) and surrounded with a garden on the north. The building was affected by the earthquake in 1944, and some parts were damaged severely. Consequently, Uyanık Family built a small house in the garden for temporary use. After some repairs and changes, the family continued to live in the house. Within this study, the house has been documented in detail and identified its original materials and construction techniques. The earthquake effects on the vernacular buildings in this region has been examined considering the structural damages in the House of Uyanık Family with the result of the earthquake.*

# 1 INTRODUCTION

Çerkeş, situated on a plain crossing from Middle Anatolia to Western Black Sea region, one of the significant settlements in the Ottoman period due to its position on the commercial roads. The geographical location has affected the architectural and urban characteristics of the town. The vernacular buildings in Çerkeş and its surroundings have many similarities with the civil architecture in the Black Sea Region. However, the settlement located on the North Anatolian Fault, was affected severely by the earthquake in 1944. The epicenter of earthquake with the magnitude of 7.2 was Gerede situated 68 km on the west of Çerkeş [1]. Strong tremors caused severe damages on the buildings and even their collapse[1]. Consequently, few vernacular buildings are intact in Çerkeş today. In this study, the architectural features of the House of Uyanık Family which is one of the traditional houses in Çerkeş dated to the end of the 19th century has been evaluated and the effects of the Gerede Earthquake on the house has been examined. (Fig. 1)

**Figure 3:** Aerial view of Çerkeş (General Command of Mapping, 2011), and the position of the house in Çerkeş

## 1.1 Urban development of Çerkeş

The environs of Çerkeş have been area of settlement since the Late Bronze Age. After the Roman and Byzantine rules, Çerkeş and its surroundings came under Turkish domination and became the settlement of Turkish tribes beginning from the second half of the 11th century. In the 12th century, Çerkeş was under the rule of the Seljuks, and then entered into the Ottoman domination completely in the second half of the 15th century. The settlement gained importance with its selection as a military destination of Baghdad campaign in the 17th century and incurred to construction activities. In this period, a mosque which indicates the center of the town today, a bath and a caravanserai were built. The mosque collapsed with the result of

[1] 20865 buildings were heavily damaged due to Gerede Earthquake which affected a large area from Bolu Plain to Kurşunlu district in the province of Çankırı [1].

Gerede Earthquake in 1944, the bath has lost its function and was abandoned, the caravanserai was placed with shops which has constituted a bazaar in the center after its collapse. [2]

Evliya Çelebi visited Çerkeş in the second half of the 17th century and gives information about the town. In that period, it was a township of Kangırı/Çankırı which had significance militarily. The town located on the bottom of a hill had three hundred houses with a mosque, a bath and a bazaar of 40-50 shops. He also adds that Silahtar Mustafa Pasha who was the grand vizier of Sultan Murad IV constructed a grand city-inn with 150 rooms and 100 shops. [3]

According to two sources dated to the end of the 19th century gives more information and indicates the urban development of Çerkeş in two centuries [4] [5]. The number of the houses in Çerkeş was 635 in that time, and also had a government office and a post office. Additionally, the settlement included 9 mosques, 1 high school, 7 primary schools, 2 madrasahs, 5 city-inns, 197 shops and 3 baths. It also had a weekly bazaar as a consequence of that the town had commercial importance with the result of its position on the road from Istanbul to Baghdad. On the other hand, agriculture was not at the forefront due to hard climatic conditions. Yet, livestock raising has had significance.

The town has been developed on the northern and southern sides of Hükümet Street which points to the old road to Baghdad. Muradiye Mosque and the market place constitutes the center of the town, and old town which indicates the settlement dated to Pre-Republic time is located on the north of the center. In the Republic Period, the town was developed northwards. Then, with the result of the construction of the railroad between Ankara and Zonguldak and also the train station on the southern of the center caused the development of the town towards to the south. [6]

The big fire in 1939 and Gerede Earthquake in 1944 affected the old urban character of the town [7]. Consequently, some of the historic buildings survived today. In the territory of Çerkeş, there are 7 listed archaeological sites. In addition, 1 monumental building, 13 civil buildings, 11 mosques, 6 tombs, 4 fountains and 4 bridges are registered with the decision of the Conservation Board of Ankara. [8]

### 1.2 Vernacular architecture in Çerkeş

Surviving vernacular buildings in Çerkeş have common architectural characteristics similar to Turkish Houses[2]. They are two or three-storey. The entrances of the houses open to the street directly. Entering the house, a hall called as "taşlık" is located. All of the rooms of the ground floor open to the entrance hall on either sides. This hall has connection to the garden at the back of the house. Kitchen, storage room are situated on the ground floor. There can be also a sheep fold or atelier according to the need of the residents. A staircase located in the hall leads to second floor of the house. The staircase can be I, L or U-shaped. The staircase usually has a wall on side and a wooden screen on the other side. There can be also a door at the bottom, middle or top level for reasons of insulation or security.

The first floor consists of a centered hall called as "sofa", the rooms on the corners. A toilette is also located on the first floor. However, some houses have one more toilette on the ground floor. The toilette is constructed within the building or as a projection on the façade. Some houses have also second floor.

The rooms are living units of the traditional Turkish Houses which serve for many functions like sitting, sleeping, eating and even cooking. Each room has a separate unit, called as "daraba", at the corner entrance which provides privacy. A wooden screen facing the door is

[2] B. Ayhan gives information about the characteristics of civil architecture in Çankırı and Çerkeş [7]. As a part of this study, a research on the typology of surviving vernacular buildings in Çerkeş has also examined [9].

hiding the interior of the room at first glance, and a second door provides access to the room. In each room there is usually a fireplace. They also include wooden built-in cupboards which were used for bedding and also bathing.

Vernacular buildings in Çerkeş have also common façade orders. The façade characteristics indicate the social and economic status of the owner. So they have differences in details. The façades are in two types; with projection or without projection on the first floor level. The façades with projection are also divided into three types. The first has projection on the middle of the façade, the second has projection on the corner and the last one has projection all along the façade. The projections are not only on the main façade which has the entrance, but also on the other façades of the house.

The entrance is usually in the middle of the façade, and a small window is located on one side or either sides of it. The windows on the upper floors are sash windows in general. The number of the windows on the garden facing façades are more than on the main façade with regards to the privacy.

## 2 HISTORICAL AND ENVIRONMENTAL FEATURES OF THE HOUSE

The construction date of the House of Uyanik Family (Fig. 2) is not known exactly, yet the information obtained from the family members indicates the second half of the 19$^{th}$ century. The house was damaged by Gerede Earthquake in 1944. So, some repairs were done and some parts of the building were changed. Moreover, the change is not limited at building scale. The vicinity of the house has undergone some changes socially and physically.

**Figure 2:** The house of Uyanık Family (2015)

### 2.1 Historical background

It is thought that the house was constructed by Ömer Uyanık in the second half of the 19$^{th}$ century[3]. Little information is known about Ömer Uyanık. However, his son Ali Uyanık's place of registery is Yeni Mahalle (New Quarter) where the house is located in. Although Ali Uyanık was moved to another quarter after his marriage, he moved back old house with his wife and three children, after their house was damaged due to the fire in Çerkeş in 1939.

With the result of Gerede Earthquake in 1944, the house was damaged. So, a small house, which was one-storey and had two rooms and a toilette, was built on the eastern side of the

[3] The information about the first construction and later changes of the house is based on the personal interviews with Metin Uyanık and Kadir Uyanık in 2017.

garden. This small house was constructed with traditional construction techniques. The basement was stone masonry and the ground floor was made of timber framework. Today, only the traces of basement walls are visible. The family moved back to the old house probably after that its maintenance and repair was done.

Then, İsmail Uyanık who is the middle child of Ali Uyanık continued to live in the house with his wife and four children. After the loss of İsmail Uyanık in 1975, his wife Şevale Uyanık lived in the house until her death in 2013. The house has not been used henceforward.

With the contribution of her grandson Kadir Uyanık, the house has been subject of this study and listed with the decision of Cultural Heritage Conservation Board in Ankara with the number 5538 on the date of 11$^{th}$ November 2010.

## 2.2 Environmental features

The House of Uyanık Family, located on Doğdu Street in Yeni Mahalle, is close to the historic center of Çerkeş. Doğdu Street, which is parallel to the center, has old urban character with traditional houses with garden on either sides despite some changes. The Stream of Boya which was running from north to south direction within the town, limited Doğdu Street on the west. In the 1990s, the stream was closed and Atatürk Boulevard was constructed on its direction.

Little is known about the development of Yeni Mahalle. It is thought that it has been existed since the second half of the 19$^{th}$ century[4]. However, as it is understood from its name, it is a new quarter comparing the northern side of the town-center. The northern side of the center has a radial road network. On the other hand, Yeni Mahalle is in grid plan. Doğdu Street is the northernmost street of the quarter parallel to the center, and still maintains its old urban character (Fig. 3). The traditional houses with gardens are lined up on the both sides of the street. However most of the old houses have been abandoned, and new apartment buildings have been constructed at some parts of the street.

**Figure 3:** View of Doğdu Street and the house (2018)

[4] The place of registry of Ali Uyanık, who was born in the late 19th century, is Yeni Mahalle.

## 3 ARCHITECTURAL CHARACTERISTICS OF THE HOUSE

### 3.1 Architectural Features

The House of Uyanık Family is located on the southern side of a plot which is 28,45 m x 29,50 m in plan (Fig. 4). The house is two-storey and has rectangular plan with the dimensions of 12,80 m x 10,50 m. On the west, there is a hayloft adjacent to the house. It is 5,80 m x 7,00 m in plan. The garden is surrounding the house on the east and north and enclosed by the masonry walls in original. The entrance of the house is located on Doğdu Street on the south. There is another entrance to the garden on the east of the entrance of the house.

The small building, built just after the earthquake in 1944, was on the east side of the garden. It is visible on the aerial photos dated to 1983 and 1998. The building, which was approximately 5,80 m x 5,80 m in plan, was demolished, and today only its remains are visible.

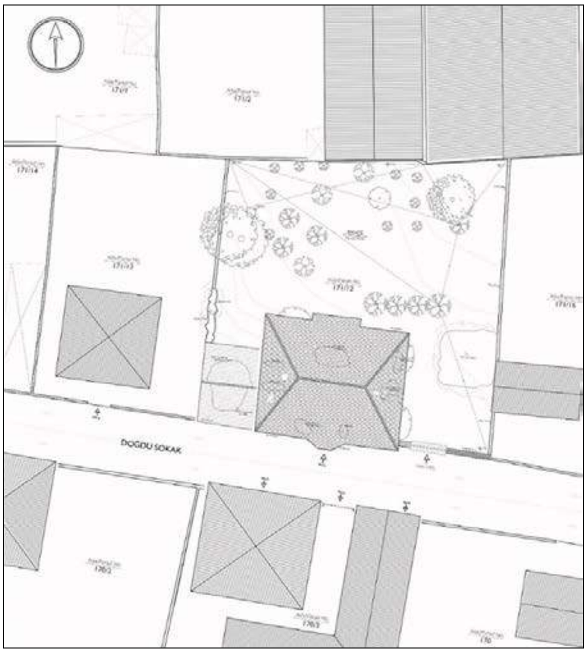


**Figure 4:** Site plan (B. Arslan, 2017)

#### 3.1.1 Plan features

The plans of the ground and first floors have the plan layout of traditional Turkish House. There is also a mezzanine floor. Entering the house from Doğdu Street, there is an entrance hall, called as “taşlık”. The *taşlık* is located in the middle of the ground floor (Fig. 5). There is a door on its north end which is opened to the garden. On the west side, there are two rooms, which have been exposed to many changes, probably due to the effects of the earthquake in 1944. The original floor of the room on the southwest corner is lost, the walls have damaged and repaired with concrete bricks at some parts. Other room on the north was enlarged to the east, occupying the *taşlık*. The access to this room is from the garden on the north. At first, it was used as sheep fold, then it has been used as storage room.

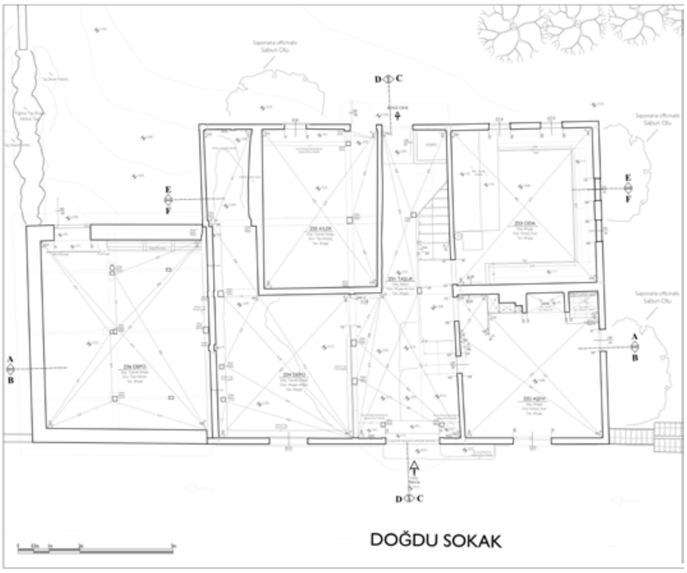


**Figure 5:** Ground floor plan (B. Arslan, 2017)

First three stairs on the east of the *taşlık* leads to a platform in front of the entrances to the rooms on the east. The room with a fireplace has the characteristics of a room for daily use. Yet, the other on the northeast corner has no fireplace, and a large storage chest or granary is located in front of the west wall. So, probably, this room was used as a storeroom.

The staircase leading to the first floor is located on the north-south direction on the east side of the *taşlık*. It is closed with a wooden screen on the west and the south side and there is a door for the reasons of insulation probably. On the west wooden screen, there is another small opening to access to the mezzanine floor (Fig. 6). This floor is covering on the northern part of the entrance hall and old sheep fold on the north.

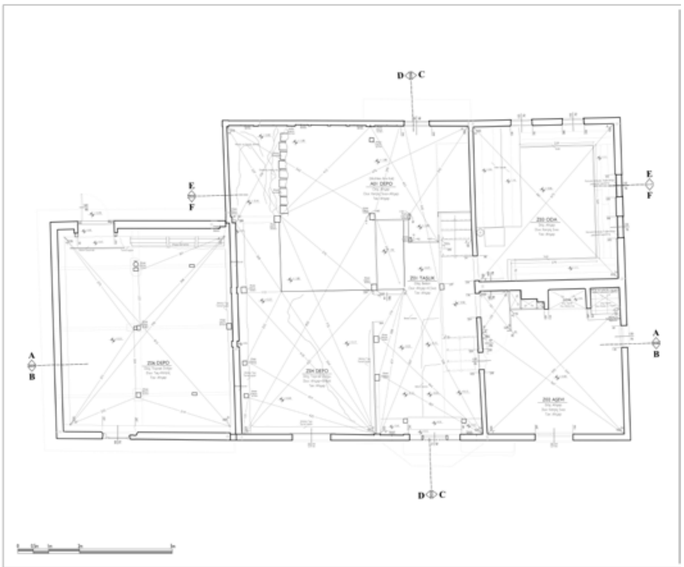

**Figure 6:** Mezzanine floor plan (B. Arslan, 2017)

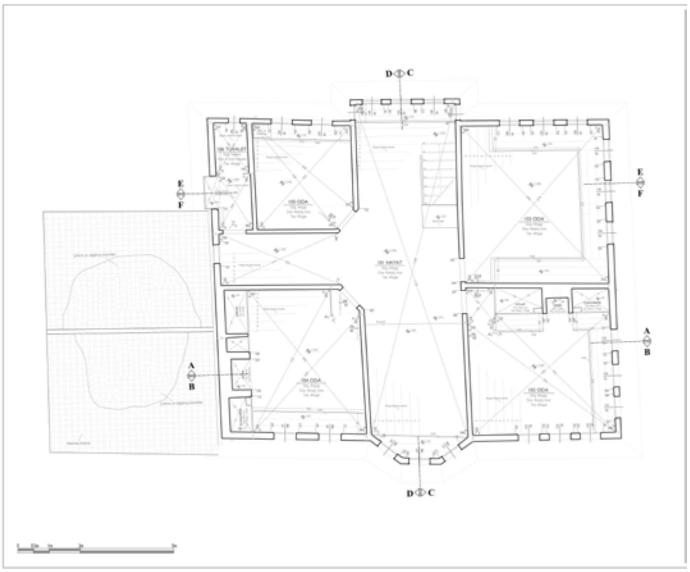

**Figure 7:** First floor plan (B. Arslan, 2017)

At the first floor (Fig. 7), there is a hall which is called as “sofa” in the middle and four rooms on the corners. There is also a toilette on the northwestern corner. The *sofa* is T shape in plan. The south part of the *sofa*, elevated with one stair, has the character of a room. The rooms and *sofa* are served as multifunctional spaces where one can sit, eat, work and even sleep. Special sitting platforms which is called as “divan” in front of the windows have been preserved in the rooms and also in sofa, mostly.

3.1.2 Façade features

Each façade layout take shape according to the interior organization. The southern façade, facing Doğdu Street, has the entrance in the middle and one window on its either sides at the ground floor level (Fig. 8). There is a chamfered bay over the entrance. Due to privacy, two windows at the ground level are smaller and in different proportion comparing the sash windows at the upper level. As a consequence of that the eastern and northern façades are facing the garden, the lower windows are also sash windows at the ground level. Yet, some them has been changed or closed. Moreover, there are more windows at the upper level. On the northern façade, another projection is located in the middle of the upper level. The western façade which is mostly covered with hayloft adjacent to the house on this side has only one window at the first floor level (Fig 9). There is also a wooden projection which represents the washbasin of the toilette.

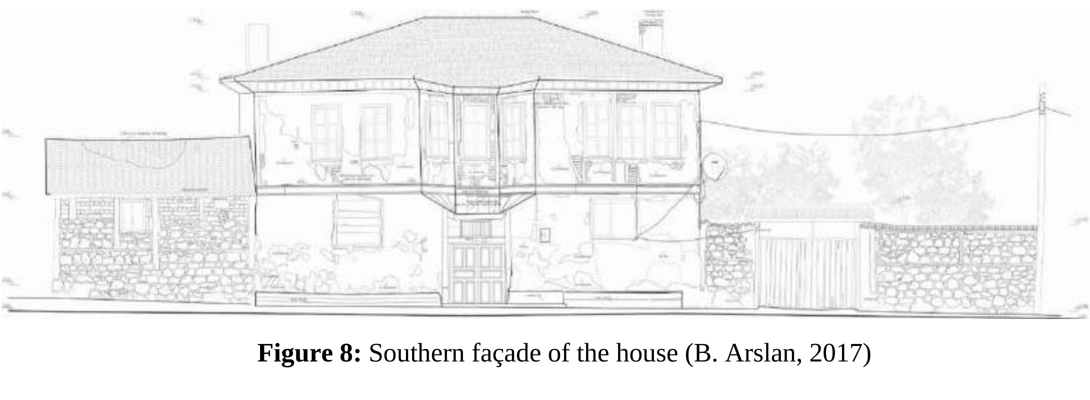

**Figure 8:** Southern façade of the house (B. Arslan, 2017)

All the façades were plastered in original, except main vertical and horizontal wooden bearing elements, and timber doors and windows. The eaves are covered with timber. However, the plasters have been detached, and wooden materials are deteriorated due to the lack of maintenance. Moreover, the deformations at some parts of the façades indicate structural problems on the house.

**Figure 10:** Western façade of the house (2015)

## 3.2 Materials and construction techniques

Different materials and construction techniques are used at the building. Yet, the basic construction technique is timber framework. Timber framed house is erecting on the masonry basement which is approximately 1 m in height. The basement is made of rough-hewn stone and mortar. The stone type is a kind of travertine which is obtained from the quarries close to Çerkeş. The timber framework of the building is infilled with adobe blocks at the ground floor and with fire bricks at the first floor. On the other hand, it is observed that “bağdadi” which is a timber-work made of lath and plaster is also used at the ceilings of the rooms.

All the surfaces inside and outside of the building are lime plastered. Yet, the main horizontal and vertical bearing elements are visible as a part of decoration. Moreover, the eaves and the lower part of the projection on the entrance are cladded with wood. The roof system is also made of timber. Cylindrical clay tiles were used for roof cladding, then they changed with the Marseilles tiles. All the building elements, like doors, windows, staircase, cupboards, etc. are also timber.

The walls surrounding the garden are made of rough-hewn stone and mortar, similar to basement walls of the house. However, they were rebuilt with concrete bricks at some parts. In addition, the small house built after the earthquake on the east side of the garden was also constructed with traditional techniques. The house which was one-storey and consisted of two rooms and a toilette was also built in wooden carcass system with adobe infill on a masonry basement.

# 4 EARTHQUAKE EFFECTS ON THE BUILDING

A large part of Turkey is under earthquake risk due to the fault zones covering all of the country [10]. R. Günay points out that widely use of the timber frame construction system in Turkish Houses as a consequence of that all the geographic areas where the Turkish House has spread are within the seismic zones, and he added that this construction system is resistant to horizontal forces and is also safer due to its lightness [11]. The traditional timber framed houses are ductile buildings, so their behaviour against the earthquake is favourable.

On the other hand, the researches claims that this is due to the quality of construction rather than the use of timber in the structures [12]. According the research of R. Kafesçioğlu on the traditional timber houses in the Black Sea Region, the unworked foundation walls and the lack of diagonal braces and weak joints caused the injuries on the buildings, which were heavily damaged due to Gerede Earthquake. [13]

The House of Uyanık Family is among few buildings which survived from Gerede Earthquake with moderate damage and has been used since then. The construction of a small house, called as "earthquake house", on the eastern side of the garden indicates that the house was damaged with the effects of strong tremors in 1944. The deterioration on the materials should been taken into consideration as a reason of structural problems. However, the owners of the house have remarked that the house has been in this situation in general after the earthquake. Within this study, the house was surveyed, using time-honoured practice and advanced methods, like the measurement with total-station. The deflections and deformations on the building are presented on the survey drawings in detail.

**Figure 11:** Loss of adobe infill on the western wall (right), and detachment of the plaster and deformation on the wall between the rooms on the southeast and northeast corners (left) at the ground floor (2018).

Especially, the ground floor of the house was affected by the earthquake. Consequently, the plan layout of the western part of the ground floor has been exposed to some changes. Two rooms used as storerooms today were probably ateliers, or one located on the southwest corner was possibly served as a room and the other was a sheep fold (Fig. 5). The floor of the room on the southwest corner was destroyed. The adobe infills of the timber framed walls on the western side of the ground floor have also been changed with fire bricks and cement bricks. There are also detachments of plaster caused by the deformation and deflection on the structural system at some points (Fig. 11). On the first floor, the floor of the *sofa* has deflection towards to the south and the north. In the rooms, the deflection of the timber frame has been resulted in cracks on the walls and deformations even at the built-in cupboards. The deflections on the vertical bearing elements are also visible on the façades (Fig. 12).

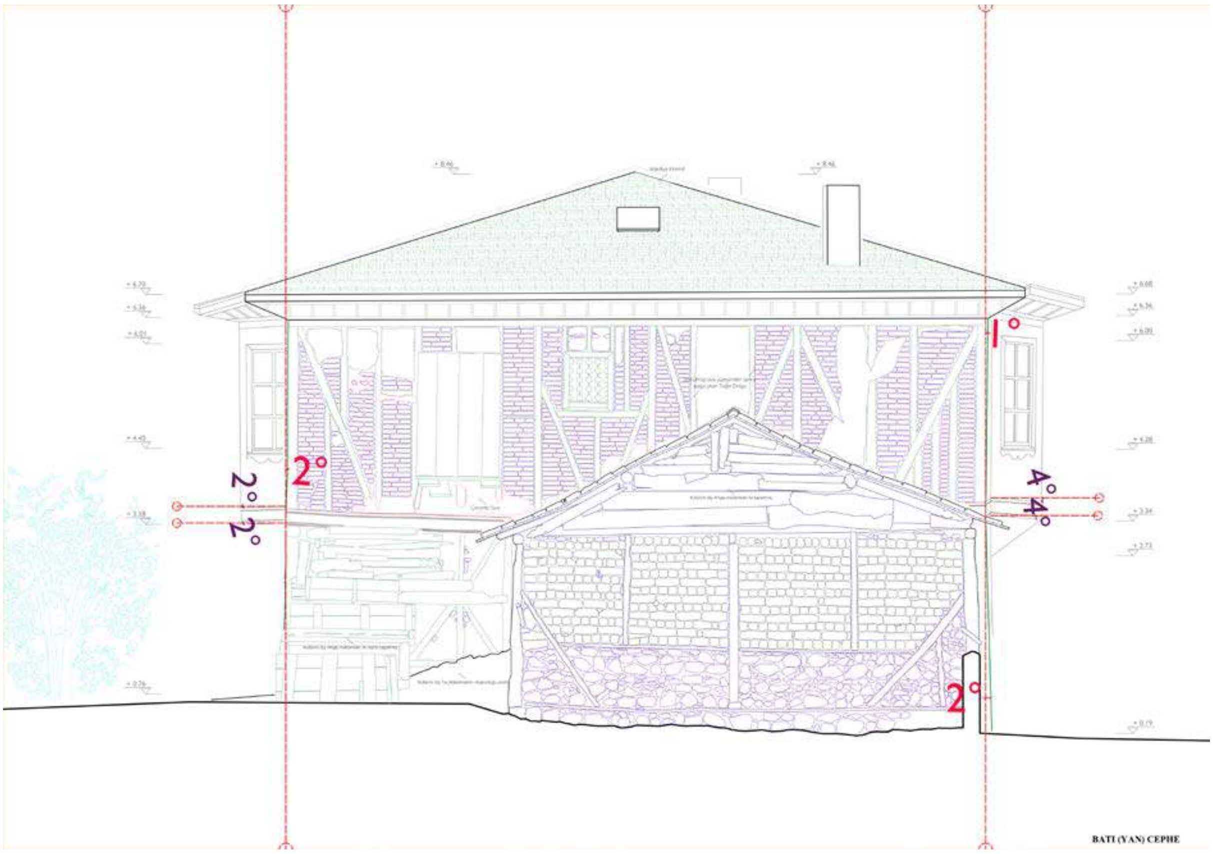


**Figure 12:** Vertical deflections on the western façade and horizontal deflections at the southern and northern projections.

## 5 CONCLUSIONS

- The vernacular architecture in Çerkeş represents the characteristics of the traditional houses in Black Sea Region made of timber framework.
- Gerede Earthquake in 1944 affected a large area at the northwestern Black Sea Region and also caused heavy damages on the buildings in Çerkeş where is located on the North Anatolian Fault.
- Although there are some general researches on the effects of the earthquakes on the traditional buildings in Turkey, it is needed more comprehensive investigations and analyses on surviving buildings.
- The house of Uyanık Family which is among the surviving traditional houses in Çerkeş gives the opportunity to investigate the behaviour of timber structures against the earthquake. The result of this study shows that the lightness, flexibility and ductility of traditional timber framed structures are advantageous against destructive effects of the earthquakes.
- Large part of Turkey is under seismic risk. The researches indicate that traditional timber structures are safer against earthquakes compared to the other structures. But this is resulted from the quality of construction rather than the use of timber in the structures.
- Comprehensive researches on surviving traditional timber houses in seismic zones in Turkey enables to understand the ways of adapting their potentialities to modern structures.

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# REHABILITATION AND SEISMIC STRENGTHENING OF THE TSETO GOENPA IN BHUTAN

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**Keywords:** Rammed Earth, Seismic Retrofit, Seismic Bands, Sustainability, Wood Framing

**Abstract**

*The authors were the design team for the rehabilitation of the Tseto Goenpa in Paro Dzongkhag, Bhutan. The project was funded through the World Monuments Fund in New York USA. Tseto Goenpa is a Buddhist Monastery complex located on the western upper Paro Valley of Bhutan and was reportedly constructed in the fifteenth century by Lama Lotey Gyemtsho. Tseto literally means 'Top or Pinnacle' and the Temple's name was derived based on its location. It is culturally tied to the well-known "Tiger's Nest" Monastery located on the opposite slope of the Valley.*

*The Tseto Goenpa can be described as a traditional and vernacular structure composed of rammed earth, wood framing, clay plastering and wood framed roofing finished with corrugated sheet metal panels. It is a u-spaced complex around a stone paved courtyard - the Lhakhang and lhakhang ante room to the north; and residences, kitchens and storage on the east and west wings. A high rammed earth wall closes the courtyard on the south.*

*The rehabilitation, completed in 2018, has included restoration and seismic strengthening of the Lhakhang and ante room; expansion of the facility to accommodate a greater monk population and addition of contemporary kitchen and bathrooms. All construction techniques utilize, rammed earth, locally harvested timber and locally quarried stone. The seismic strengthening system uses traditional and contemporary building materials that are compatible with rammed earth construction.*

## 1 INTRODUCTION

To the north of Paro valley, facing the cliff that supports the internationally recognized Paro Taktshang (Tiger Nest) stands an equally significant a monument, Tseto Goenpa (Figures 1 and 2). It is positioned on a hilltop that appears like a tip of a vajra, a ritual three-bladed knife that contains spiritual power. About two hours walk from Lango village, the temple is at a vantage point that serves spectacular view of Paro valley.

Figure 1: Exterior view of the Tseto Goenpa. The Lhakhang is the large structure in the foreground (June 2014).

## 2 HISTORY AND SIGNIFICANCE

Records show that a Buddhist master Lam Loday Jamtsho founded Tseto Goenpa in the 14th century. He was believed to have spent twelve years in solitary retreat at Pelphu, a spiritual site above the Tiger's Nest, where he discovered a treasure, a statue of Phurba. While at Pelphu, it is said that the Lam saw a burning lamp at the present location of Tseto Goenpa at night. Upon reaching the location, he found the treasure he discovered at Pelphu floating in a pond, and this pond can still be witnessed today under the ground floor of the Tseto Goenpa Lhakhang.

While meditating there, the deity of the place requested that the Lam establish a seat at the location. Following the request, the Lam planted his walking stick and prayed that he would consent to the deity's request should the walking stick grow. The next morning, the Lam saw flowers budding from the walking stick. Taking it as an auspicious sign, he constructed a three-story Lhakhang (temple). The Phurba statue was installed as the main relic. An adjoining caretaker's residence, and two structures flanking the Lhakhang are also said to have been built around the same time forming the Goenpa (monastery). The one on the east served as Lam's residence.

The Goenpa was renovated around the turn of the last century, and the structure was reduced from three-stories to two while retaining the original wall and layout. Later, in 1993, after another earthquake damaged the structure, former Dorji Lopon Ngawang Tenzin initiated the renovation of the ground floor.

Figure 2: View looking northward in the courtyard. The Lhakhang is in the center of photograph. Note the large vertical cracks on the corner of the Lhakhang (June 2014).

Until recently, the ownership of the Tseto Goenpa rested with the local community, and they were responsible for care and maintenance while facilitating routine offerings, rituals and festivals. However, unable to effectively carry out these duties, the community surrendered the ownership of the Goenpa to the central monk body.

The Tseto Goenpa is considered an important historic and religious site. It was founded by an important Buddhist master and is home to numerous sacred objects. To the east of the Goenpa are the stupas built to retain the body of the founder after he passed away. To the southeast is the flower bearing tree believed to have sprouted out of the lam’s walking stick. These and other factors make Tseto Goenpa an important pilgrimage site for not just the people of Paro but from across the country. Despite having undergone renovation at least three times, the Lhakhang retains some of its original fabric, the most significant of which is rammed earth wall structure. The timber columns (kachen) are also said to be hundred of years old.

In view of its year of establishment, the Goenpa also holds immense historic value for the country as compared with the recent ones. In the early days, realized Buddhist masters, following an auspicious dream, vision, or other signs, founded monasteries and temples. Even the design of the structures and wall paintings were envisaged by the master. Such historic religious buildings are generally considered more sacred and a national heritage.

The historic value, complemented by its strategic location on the hilltop with picturesque view of Paro valley, is also a tourist attraction today. It draws a good number of foreign visitors every year. Meanwhile, the Goenpa continues to serve its traditional function as the centre for annual religious festival and rituals for the community of about hundred households. For instance, every year, on the 10th day of the first month, the community comes together to conduct Tshechu at the Goenpa.

## 3 TECHNICAL DESCRIPTION

The Tseto Goenpa is located at approximately 2,878 meters above sea level. Its location is Latitude N 27 27’ 13” and Longitude E 89 20’ 25”. It is about a 2-hour trek from the trailhead near Paro. On a clear day one can have views across the valley of the Tiger’s Nest Monastery, Paro Dzong, Ta Dzong and the Paro Valley.

Tseto Goenpa comprises a Lhakhang (temple) - a two story structure - facing south. In 2014, the periphery structures were homes and kitchen for monks, and another kitchen for the community. Except for the Lhakhang and the adjoining structure forming its vestibule, all other ancillary structures have very low ceiling height. The boundary wall on the front enclosed the courtyard, which is stone paved. A traditional doorway (gorago) at the south-east corner forms the main entrance (Figure 3). The Goenpa can be described as a traditional and vernacular structure composed of rammed earth, wood framing, clay plastering and wood framed roofing finished with corrugated sheet metal panels.


Figure 3: The plan on the left is the goenpa prior to work and on the right, after work is completed. The Lhakhang is shown in red. Areas shown in yellow have been rehabilitated, and those shown in green are new construction.

### 3.1 Rammed earth walls and floor framing

Rammed earth construction in Paro Valley and in the western part of Bhutan is fairly ubiquitous due to the lack of suitable building stones. The rammed earth walls vary in thickness between 0.5 and 0.8 meters and form the exterior walls of the complex. They do not have many window penetrations. The technique of rammed earth wall construction is being quickly supplanted by reinforced concrete construction in the larger villages. The following procedure is used in construction of the rammed earth walls:

3.2.1 On top of the uncut stone foundations cross beams are laid to support wooden formwork of approximate 2.5 meters horizontal lengths. The formwork is attached to the cross beams and shimmed into place.

3.2.2 The opening is filled in layers with clay and sand rich mud and rammed into place with wooden mallets (Figure 4).

3.2.3 When the height reaches about 60 cm and the rammed earth is set the formwork and cross beams are removed and reset on top of the new wall.

3.2.4 As the walls rise the construction technique leaves a horizontal and vertical pattern of joints from the formwork size and holes through the wall from the cross beams. These are then finished with plaster to obscure these construction features.

Figure 4: Workers ramming dampened clay into the formwork. On the left is a rammed earth wall where the formwork was recently stripped away.

The upper floor structure is composed of round or rectangular wood joists that span between the rammed earth walls. Caning is laid across the joists and then a clay layer which acts as a fire barrier is laid across the caning. On top of the clay layer is typically a wood plank finished floor.

### 3.2 Framed wood walls

Framed wood walls are found facing into the courtyard are more prevalent on the first floor and are also used for small post supported rooms that extend beyond the rammed earth walls. These frames are constructed of rectangular cut timber members that are mortised into place in a grid (Figure 5). The openings are either filled with *horzhing* windows (trefoil shaped) or *eckra* panels (woven bamboo panels that are plastered on both sides with clay plaster).

Figure 5: Eckra walls being installed.

### 3.3 Roofing

The standard roof framing is a simple shallow-sloped gable that typically drains inward to the courtyard and outward to the exterior of the goenpa. The overhangs are quite large so that the rammed earth walls are protected from the rainfall. The wood framework is a trussing system that is mortised together. The roof framework is not mechanically attached to the rammed earth walls and stays in place due to its own weight alone and metallic wires that extend from the eave corners and are anchored into the soil. The roofs are finished with corrugated sheet metal panels that are fastened into place.

### 3.4 Interior finishes

The whole of the interior of the Lhakhang is a mass of rich colors as is typical of Bhutanese lhakhangs. The rectangular ceiling joists are laid out across wooden girders to architectural effect. The joists, joist ends, beams and wooden interior columns are decoratively carved and polychromed. The floor boards are stained and finished. The east, west and south walls have wall paintings on cotton cloth that are covered with representations of deities, saints and lamas. The paintings depict the following: Phub Tshering, are the following: Gongdu and his manifestations (tutelary deity); Tsepadme (Amitayus), Buddha of longevity; Drukpa Kuenley (Divine Mad Man); Chenrezi (Avolokitesvara) God of compassion; Lord Buddha and sixteen Arhats (elders); Guru Rinpoche with eight manifestations; and three Buddhas (Past, present and future Buddha). There is also a wall painting on canvas on the east Lhakhang antechamber.

Ground floors are typically unfinished earth. The exterior walls are finished with whitewash. The wood framing is also decoratively painted on the exterior.

Interior walls at living spaces are typically coated with paint applied to paper adhered to the clay plaster. Utilitarian spaces, mostly on the ground level are unpainted clay plaster.

Ceilings are typically painted in living spaces but sometimes obscured above colorful fabric that is suspended from the ceiling.

# 4 CONDITION

## 4.1 Earthquake Damage

The Tseto Goenpa was heavily damaged by the 2011 Himalayan Earthquake. The earthquake occurred with a moment magnitude of 6.9 and was centered within the Kanchenjunga Conservation Area in the country of Sikkim on September 18. The earthquake was felt across northeastern India, Nepal, Bhutan, Bangladesh and southern Tibet. Structural damage occurred in Bangladesh, Bhutan, and Tibet.

The earthquake opened vertical formwork joints within rammed earth walls, particularly at corners, and caused diagonal cracking damage to rammed earth walls over windows at the second level. Corner cracks were through the walll thickness ranging and ranged from 25mm to 50mm wide. The presence of structural cracks in rammed earth walls decreases their bearing capacity and stiffness, and disrupts the monolithic behavior of the structure. Furthermore, cracks constituted paths for movement of water and other weathering agents, and the walls were generally suffering from long term erosion.

Much of the cracking damage was translated onto the wall paintings of the Lhakhang, most noticeably at the corners. Furthermore the shaming may have shifted the roof framing above the Lhakhang.

## 4.2 Functional and Technical Issues

The monk population had outgrown the goenpa which provided one toilet and no showers for the monk population of 13. The present Lama planned to increase the monk population to 30.

There was significant woodworm damage to some of the wood joists and sublooring - a chronic and long-term problem. The clay plaster walls suffered from normal wear and tear, and the plaster was becoming detached in some areas.

There are two kitchens within the complex. One is an outside communal facility used on ceremonial occasions. The day-to-day kitchen was on the first level of the east wing and posed a fire hazard and places the goenpa at risk.

# 5 DESIGN PARAMETERS

## 5.1 The project included the following activities:

5.1.1 Restore and install a seismic retrofit system on the Lhakhang structure.

5.1.2 Restore and consolidate the two-storied Lhakhang anteroom adjoining the Lhakhang.

5.1.3 Rehabilitate and renew the disused east and west wing two-storied structures to be used as monks’ quarters.

5.1.4 Construct a new two-story residential quarter at the location of the community kitchen. The new building consists of the Lama’s quarters with a kitchenette and toilet on the ground floor, and monks’ bedrooms on the first floor.

5.1.5 Construct a new one-story dining, kitchen and store block at the south end of the courtyard replacing the rammed earth perimeter wall.

5.1.6 Construct and new community kitchen at new location.

5.1.7 Construct a new toilet and shower facility for the monks.

5.1.8 Construct a new butter lamp house.

5.1.9 Relocate the prayer wheel at the new courtyard entrance.

5.1.10 Repave the courtyard with new drainage system.

**5.2 The following philosophies were used for the restoration, rehabilitation and renewal:**

5.2.1 All work would be based upon and sensitive to the history and development of a goenpa.

5.2.2 Important historical features and elements would be retained and preserved.

5.2.3 The historical form, design and elements of the goenpa would be retained and utilized in the new constructions.

5.2.4 The same local traditional materials and techniques; i.e. rammed earth construction, wood framing, clay plaster and stucco, and paint; would be utilized.

5.2.5 New technologies were introduced in the form of a seismic retrofit system on the Lhakhang such as increased electrical, sanitary and fire alarm systems.

5.2.6 Any seismic strengthening scheme would be designed to augment rather than replace existing load paths.

**5.3 Sustainable Construction and Traditional Crafts**

Due to the challenging location of the Tseto Goenpa, which is a two hour hike the nearest roadway, great care was taken in the planning for the project. Materials to be transported to the site were either carried by horse or man. The clay deposits in the immediate area around the goenpa were found to be an almost perfect mix of clay and sand with a minimum amount of organic residue. Such a sand-clay mix ratio is ideal for the construction of rammed earth walls as the sand mitigates the shrinkage of the rammed earth as it dries. In addition, existing rammed earth walls that had been compromised could be demolished, and the clay reused for new rammed earth construction.

The wood used for joists, the construction of eckra walls, window and door frames, flooring and trim were felled in the immediate vicinity and milled on the spot. Milled lumber was seasoned for about nine months and then carried to the site when needed for construction. Permission was sought and given by the Commission on Gross National Happiness (GNH) to fell the blue pine trees.

Zorig Chusun, the thirteen traditional crafts, were formalized during the reign of the fourth Druk Desi Gyalse Tenzin Rabgye (1680-1694). Masters of the art of carpentry, masonry, carving and painting were employed during the project (Figure 6). In addition, there was help from the local villages. The villages in the Paro Valley are agrarian and are centered on a huge collection of rice patties that stretch throughout the Valley. Local workers at the goenpa were also rice farmers, and work would need to be scheduled taking planting and harvesting seasons into consideration.

An important aspect of the project was the restoration of the wall paintings inside the locating. These water-based paintings were applied to paper that was adhered to the interior walls. The painted paper was dis-adhered from the walls and rolled up for storage while consolidation and retrofit work was taking place. Once this work was done wall paintings were re-adhered to the walls and then restored.

Figure 6: A carpenter's shop at the Wangduephodrang Dzong.

## 5.4 Seismic Retrofit

Seismic retrofit of rammed earth walls presents an interesting case study. The behavior of rammed earth is analogous to the behavior of unreinforced masonry or unreinforced concrete. Though UMC, unreinforced concrete, and rammed earth all lack ductility, there is a difference in the compressive strength and overall hardness, rammed earth having less capacity.

Of all the structures at the Tseto Goenpa, the Lhakhang was the oldest structure, the single element which would remain relatively untouched, and earmarked for restoration. All the other structures were either rehabilitated or renewed and continuous wood elements were introduced into the rammed earth walls to provide continuity and integrity. It was determined that the Lhakhang would require a seismic retrofit system to assure a level of safety. Excessive strengthening might result in loss of original fabric so the performance levels were not set high.

Prior to strengthening walls of the locating required consolidation in the form of stitching and pressure mud grouting of cracks. All the voids due to cracks and other defects were mud grouted. Larger cracks were cleaned out and manufactured adobe brick was laid in common bond across the crack. These measures were intended to aid in improving structural integrity and monolithic behavior of the structure.

The Lhakhang structure has some interesting features to consider when choosing the proper seismic retrofit system. It is relatively square and plan and lends itself to box-like strength with its center of gravity very close to its center of rigidity. Historical records indicate that it was once three stories in height but was shortened to two stories at the turn of the last century. Therefore, the exterior rammed earth walls have greater mass than what would have been required for gravity loads alone. Finally, the heavy timber frame roof is not mechanically attached to the walls, but simply sits atop them, and is tied to the ground at his corners. Therefore, the load transfer of the roof to the walls would be lessened during a seismic event.

Numerous seismic retrofit techniques were discussed at the beginning of the project. Any retrofit that would remove or modify historic or aesthetic features were not considered. At present a base isolation system is being installed beneath the utse of the Wangduephodrang Dzong. This is a very large reconstruction project following a devastating fire in 2013. However base isolation or other energy dissipation devices were out of scale for the Tseto Goenpa project. Two techniques were considered for implementation: seismic bands with corner keys; and jacketing. Both techniques are contingent upon the availability of appropriate materials in Bhutanese or Indian construction markets.

### 5.4.1 Seismic Bands with Corner Keys

Horizontal seismic bands wrapped around the exterior of the Lhakhang would hold the walls together and ensure integral box action (Figure 7). Bending stresses in the walls due to out-of-plane earthquake effects would be reduced and out-of-plane failure of the rammed earth walls would be mitigated. To be effective the seismic band would need to be continuous around the entire structure like a belt. During earthquake shaking, the band would undergo both bending and tension forces.

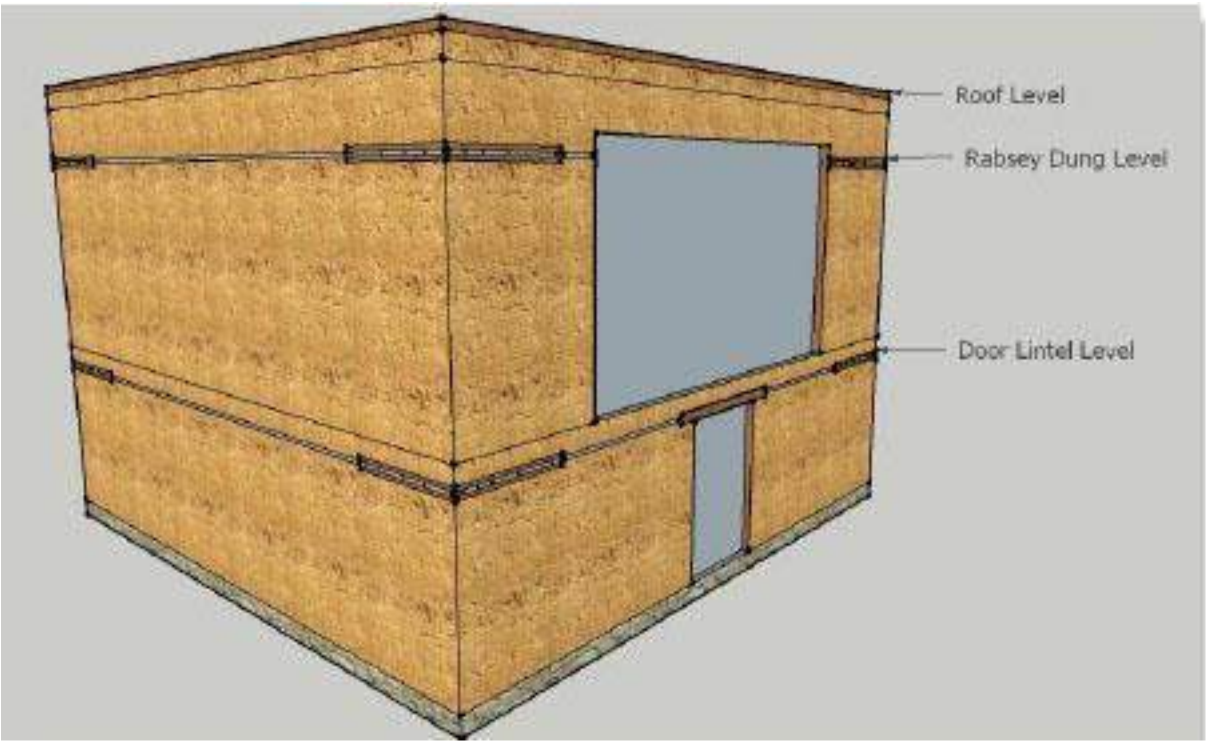


Figure 8: Schematic view of the horizontal seismic bands.

The seismic bands would be implemented in conjunction with corner keys that would be fitted in and made flush with the exterior and interior faces of the perimeter rammed earth walls of the Lhakhang (Figure 8). Proper placement of the bands and corner keys, proper materials and workmanship would need to be carefully studied to increase their effectiveness.

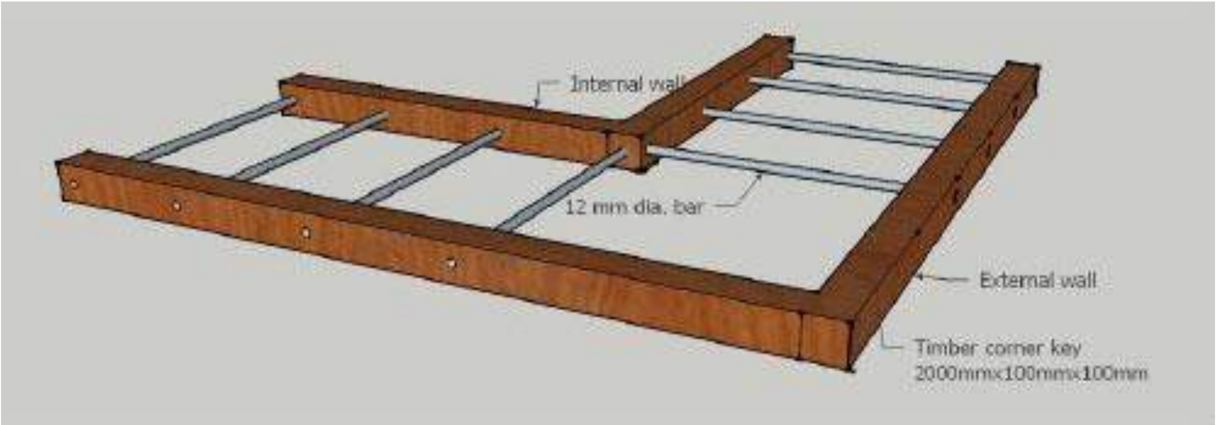


Figure 8: Schematic of the quarter key. The horizontal frames of the exterior and interior are connected by steel bars.

### 5.4.2 Jacketing

Jacketing consists of covering the wall surface with a thin overlay. In contemporary construction jacketing would be composed of reinforced mortar, micro-concrete, or shotcrete. However, none of these materials would be compatible with rammed earth walls. Therefore, the reinforced netting composed of either fiberglass or carbon fiber was considered. Such reinforcing would need to be applied to both the exterior and interior faces of the perimeter walls of the Lhakhang. The jacketed wall surfaces would then need to be interconnected by means of through-wall anchors. Jacketing causes an increase in the wall thickness, mass and stiffness. This in turn causes an increase in shear forces and overturning moments at the base of wall, which need to be transferred to foundations. Therefore, the foundations would need to be studied. If properly implemented, jacketing would provide confinement of the rammed earth and augment wall integrity for in-plane and out-of-plane seismic effects.

## 6 CONCLUSIONS

It was resolved after much debate to utilize the seismic bands and corner key option. The seismic bands and corner keys were less intrusive then the jacketing, it was difficult to find a source for the carbon fiber netting, and there was a concern about thickening the walls for the jacketing. Polypropylene straps were located in Calcutta which would be suitable to use as seismic bands.

After the rammed earth walls had been consolidated, wall corners of the rammed earth walls were strengthened with corner keys composed of timber of 100 cm x 100 cm profile. The timbers were inserted into channels created in the rammed earth walls so that the timbers were flush and could be coated with clay plaster (Figure 9). The internal and external timbers were interconnected with 6mm diameter steel bolts that were drilled into place after the timbers were set.

The entire envelope of the building was then wrapped with the structural strap. The strap was installed in three places: at the first-floor level; at the first-floor ceiling level; and just below the roof (Figures 10 and 11). The straps were tensioned after they were put in place around all four sides. Each strap was then mechanically fastened to the wooden corner keys that they overlapped. Finally, the clay plaster beneath each strap was cut away allowing the straps to rest inside the shallow channel created. The straps could then be plastered into place, so they could not be seen. On the wall between the Lhakhang and anteroom the straps were left exposed so that the intervention could be seen and understood.

Figure 9: the northeast corner of the Le Kang with the corner keys installed.

Figure 10: polypropylene seismic straps being installed at the top of the Lhakhang.

Figure 11: polypropylene seismic straps in place at the first floor level, second floor level, and below the roof.

The Tseto Goenpa was consecrated on 30 December 2017 with a one-day long ceremony that was attended by the villagers and some international guests. It was not until April that the seismic retrofit system was in place and functioning (Figure 12). The lama is now implementing this plan to expand the monk population.

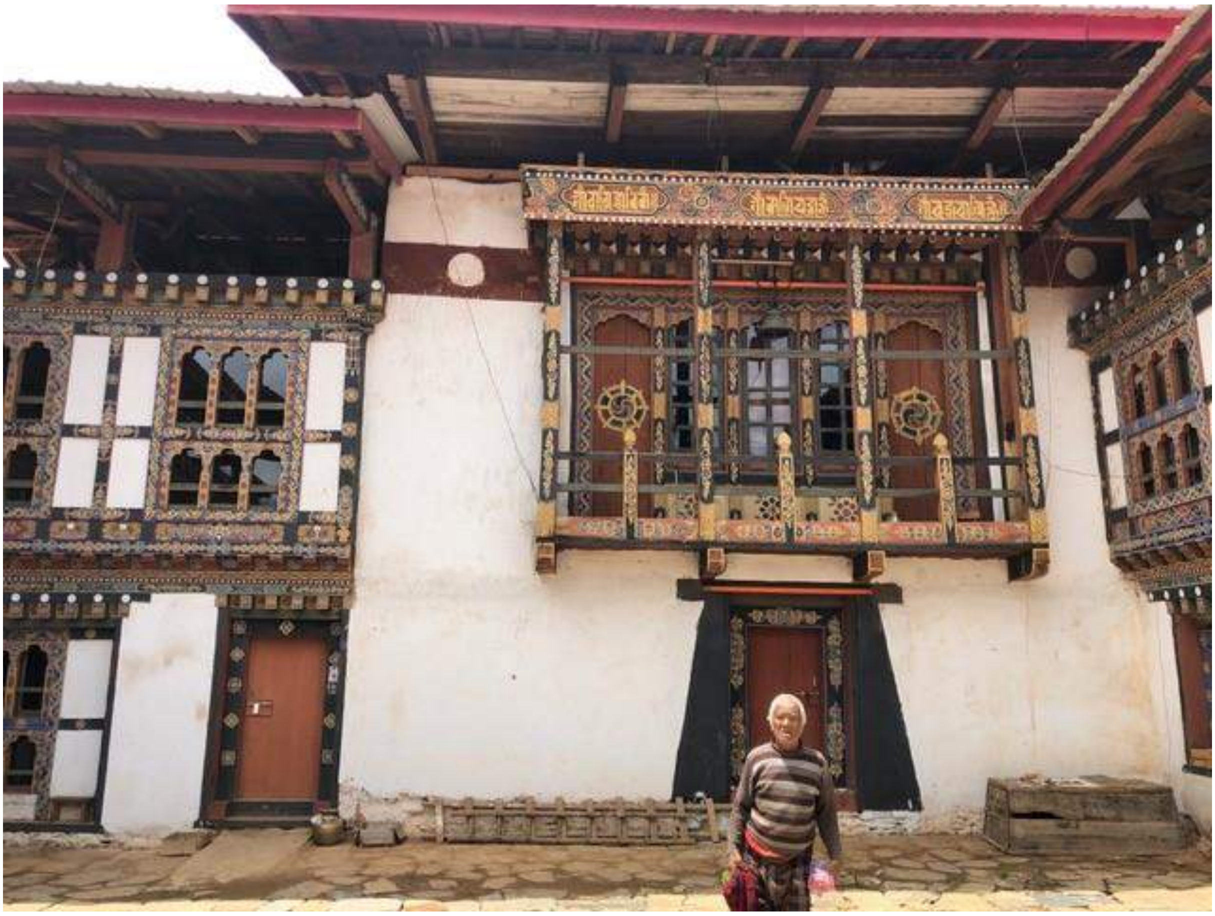

Figure 12: Completion of work.

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# THE USE OF INNOVATIVE STRATEGIES FOR THE PRESERVATION OF WOOD-FRAMED MASONRY VERNACULAR STRUCTURE: THE SEISMIC BASE ISOLATION

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**Keywords:** FPS, Vernacular Structures, Retrofitting

**Abstract**

*According to the Venice Charter principles, the preservation of the identity of the cultural heritage should consider, among other aspects, the preservation of materials and static behaviour of the construction, leading to a non-trivial problem in case of high seismic risk areas and poor engineered constructions.*

*In these cases, the use of passive seismic control strategies may give a smart solution in some circumstances. Within the passive control strategies, the base isolation technique appears particularly useful to protect high seismic vulnerable structures by creating a proper interface between the ground and the upper-structure. In particular, the base isolation can be realized interposing a rigid layer between the construction and the isolation devices that will reduce the earthquake excitation like a low pass frequency filter. In the case of vernacular architectures, the friction pendulum system (FPS) is the best solution since it controls the maximum seismic base shear as well as exhibiting a dynamic behaviour that does not depend on the mass of the overall structure.*

*The paper presents an overview of the base isolation techniques and discusses the main aspects regarding the protection of cultural heritage with attention to the vernacular architecture.*

## 1 INTRODUCTION

The Mediterranean Sea, the cradle of the oldest civilisations, finds its broader artistic expression in vernacular architecture. The constructive philosophy has evolved based on the presence of numerous popular cultures and the principles of freedom of style, the saving of natural resources, the intelligent use of the territory and the comfort of the interior living spaces.

The vernacular architecture uses inferior building materials, given the scarcity of resources in poor communities, sometimes associated with the lack of proper construction techniques, this makes the structures particularly vulnerable to seismic events. However, due to the prolonged exposure to the risk of earthquakes, local communities have been forced to adapt to this risk and learn how to protect their buildings.

The traditional seismic construction techniques derive from this need to repair damage to buildings caused by earthquakes. These efforts by local populations as a reaction to earthquakes have given rise to the development of a regional seismic culture, which is a crucial element for the preservation of cultural identity and vernacular construction practices [1]. Local seismic cultures and traditional anti-seismic techniques have been identified in many regions of the world frequently exposed to earthquakes, such as Italy [2], Greece [3], Turkey [4], Algeria [5], Iran [6], India [ 7], Nepal [8], Japan [9], Haiti [10] and Colombia [11].
Moreover, some studies have discussed the existence of local seismic cultures aimed at reducing the seismic vulnerability of traditional houses, based on the rediscovery and development of local knowledge [12,13].

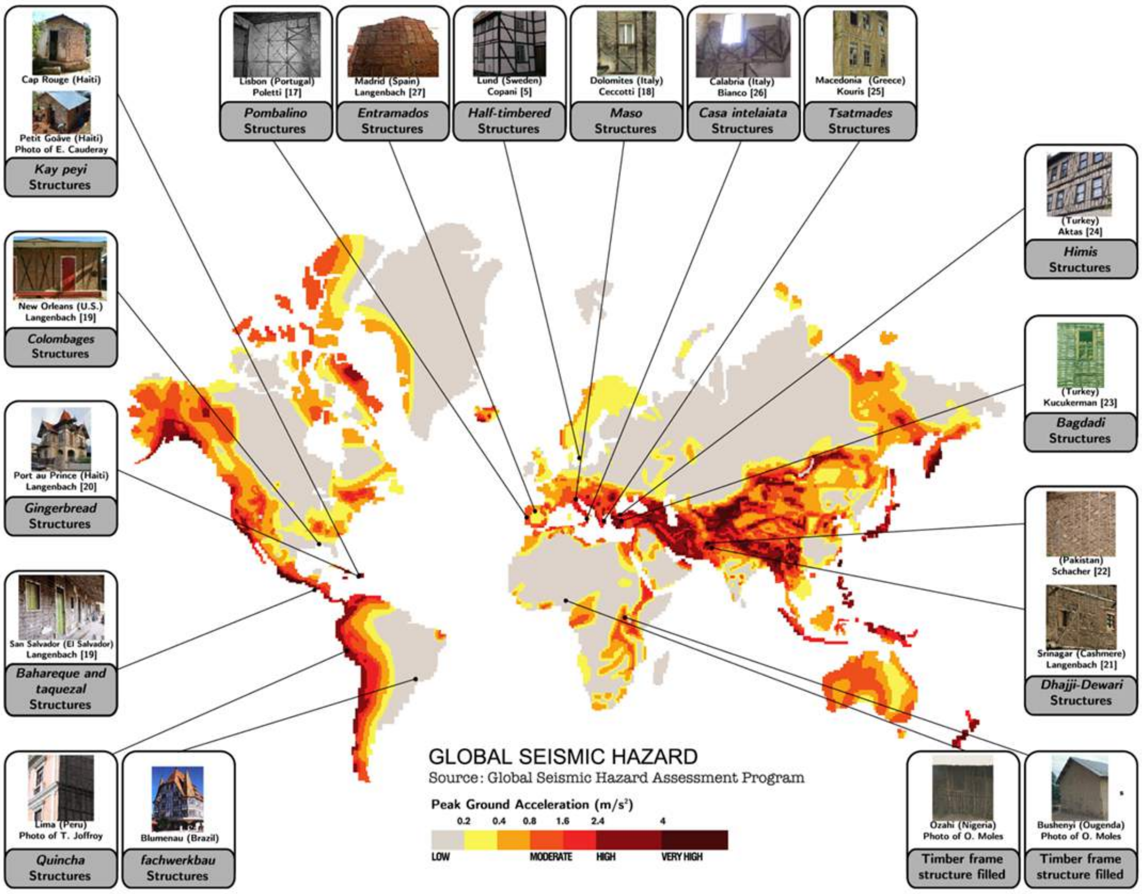


**Figure 1:** Timber Frame structures suitable to the local constraints and potential, Base map: exhibition 'Volcans, Séismes, tsunamis, vivre avec le risque'' – Palais de la découverte (Paris) – October 12th, 2007–May

11th 2008. [14]

The World Housing Encyclopedia [15] is another project of the earthquake engineering research institute (EERI) and the International Association for Earthquake Engineering (IAEE), which collects existing construction practices in the earthquake regions, with particular attention to types of vernacular buildings. Its primary objectives are to understand the seismic vulnerability of these construction systems and the reasons for their good or poor seismic performance, as well as providing recommendations for retrofitting [16,17].

Research conducted to date on the vernacular heritage has mainly concerned the construction types, while research on possible seismic reinforcement interventions was focused primarily on the analysis of monumental structures.

However, in recent years there has been a growing interest in the experimental characterisation of the seismic behaviour of the most representative vernacular construction systems [18-21], as well as for seismic reinforcement solutions for vernacular constructions based on modern techniques and materials [22-24].

A new innovative solution for retrofitting the vernacular structures is the seismic isolation. This technology allows the preservation of the construction materials and construction typology by interposing an isolation layer between the ground and the building. Seismic isolation is now established and well-studied by many authors in the last 20 years as pointed out by [26]. It is an open-loop control strategy because the building will not be interested by the seismic excitation that will be filtered by the isolation devices (Figure 2).

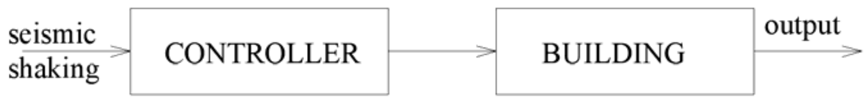


**Figure 2:** Open-loop control diagram [25]

## 2 SEISMIC ISOLATION

A good strategy for the seismic protection of structures is the base isolation, an open loop control approach, that consists in decoupling the movement of the upper-structure with the one of the ground. By doing this, it is possible to control the dynamic behaviour of the building by increasing its period of vibration. This is done by using a device that acts as a filter for the acceleration experienced by the upper-structure [25]. By following the indications of [27], it is possible to outline the linear theory for a system with two degrees of freedom (2DOF) shown in Figure 3. It is possible to use this approximation because, if the isolation system is well-designed, the structure will dynamically behave as a rigid body.

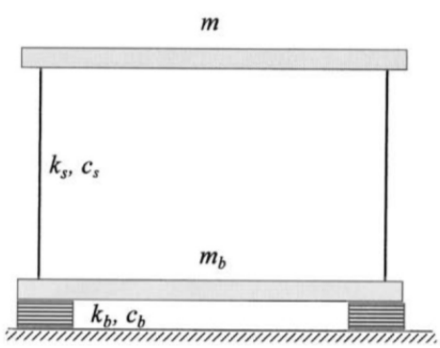


**Figure 3:** Mechanical parameters of a 2DOF base isolated system [27]

With m, $k_s$ and $c_s$ are represented the mass, the stiffness and the damping of the structure respectively, while with $m_b$, $k_b$ and $c_b$ are represented the mass, stiffness and damping of the base story on top of the isolation devices. With $u_s$, $u_b$ and $u_g$ are indicated the absolute displacement of the structure, base and ground, and with the letter v are indicated the relative displacements with respect to the ground motion. In Equation (1) are indicated the equations of motion for the system represented in Figure 1.

$$\begin{cases} m\ddot{v}_b + m\ddot{v}_s + c_s\dot{v}_s + k_s v_s = -m\ddot{u}_g \\ (m+m_b)\ddot{v}_b + m\ddot{v}_s + c_b\dot{v}_b + k_b v_b = -(m+m_b)\ddot{u}_g \end{cases} \tag{1}$$

It is possible to define the mass ratio γ as:

$$\gamma = \frac{m}{m+m_b} \tag{2}$$

The damping factors $\beta_b$ and $\beta_s$:

$$2\omega_b\beta_b = \frac{c_b}{m+m_b} \qquad 2\omega_s\beta_s = \frac{c_s}{m} \tag{3}$$

And the ratio between the frequencies $\omega_b$ and $\omega_s$ as ε:

$$\varepsilon = \frac{\omega_b^2}{\omega_s^2} = \frac{m\,k_b}{(m+m_b)k_s} = \left(\frac{T_s}{T_b}\right)^2 \tag{4}$$

**2.1 Isolator devices**

The two noteworthy seismic isolator devices are the elastomeric bearings and the friction pendulum system.

The elastomeric bearings are made by alternating rubber layers with circular steel plates. The rubber gives the device a high lateral deformation but with small vertical displacements thanks to the steel plates. The critical parameter for the correct behaviour of these devices is the horizontal stiffness [27].

**Figure 4:** Elastomeric bearing (FIP Industriale catalogue)

The Friction Pendulum system (FPS) is instead a device that functions on the principle of the pendulum. In Figure 5 it is shown the cross-section of an FPS. The slider, usually covered with low friction material, is moving on a stainless-steel concave surface.

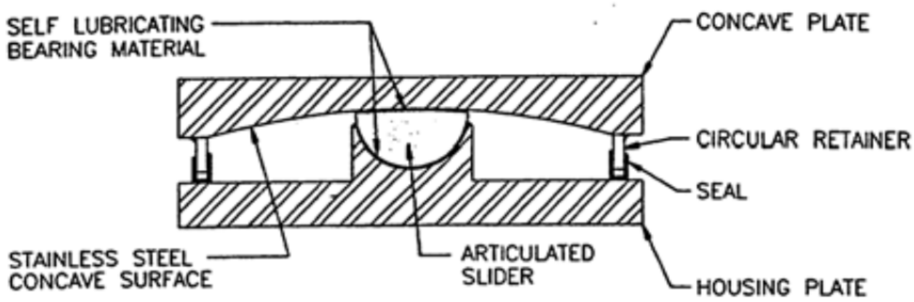


**Figure 5:** Friction Pendulum System [28]

The restoring force F depends on the frictional force acting on the sliding surface that is itself a function of the weight W acting on the surface and of the friction coefficient μ. On the other hand, the period of the isolated system T depends only on the radius R of the concave surface. By following the notation introduced in Figure 6, it is possible to express the restoring force F and the period T as shown in Equations (5) and (6).[27]

$$F = \frac{W}{R}u + \mu W\ \mathrm{sgn}(\dot{u})F = \frac{W}{R}v_b + \mu W\ \mathrm{sgn}(\dot{v}_b)F = \frac{W}{R}u_b + \mu W\ \mathrm{sgn}(\dot{u}_b) \tag{5}$$

$$T = 2\pi\sqrt{\frac{R}{g}} \tag{6}$$

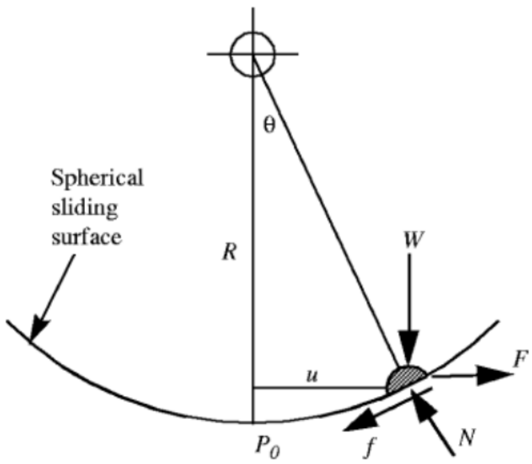


**Figure 6:** Forces acting on an FPS [29]

The definition of the coefficient of friction is variable with the velocity, as well as the normal force acting on the sliding surface.

The value of the friction coefficient μ is dependent on the velocity of sliding [30] and on the pressure applied to the slider [31]. The latter depends on the weight of the upper-structure, on the vertical component of the seismic excitation and on the P-Δ effects that the upper-structure exert on the isolation device[32].

In the case of vernacular structures, the FPS devices lead to limit the transmitted shear to the maximum base shear that the upper-structure can withstand. Another advantage is that the FPS dynamic properties do not depend on the mass of the upper-structure.

While the overall seismic behaviour of FPS isolated structure is well known in the literature [26], in [33] is presented an exhaustive study for the FPS subjected to near-fault seismic excitation. This study can be transposed to the vernacular structures because most of them has been built in areas subjected to near fault events. The analyses were done with and without a vertical component of the earthquakes L'Aquila 2009 and Emilia Romagna 2012 on a SDOF system. In Figure 7 it is shown the ratio between the base shear calculated considering the vertical seismic component $F_V$, and the base shear calculated without the vertical component F. It is evident that the transmitted shear to the upper-structure increases linearly as the vertical pick ground acceleration ($PGA_V$) increases. In Figure 8 is shown the ratio between the horizontal displacements with ($u_v$) and without ($u$) vertical component. It is evident that the displacement is not influenced by the $PGA_V$ for values of R greater than 1.

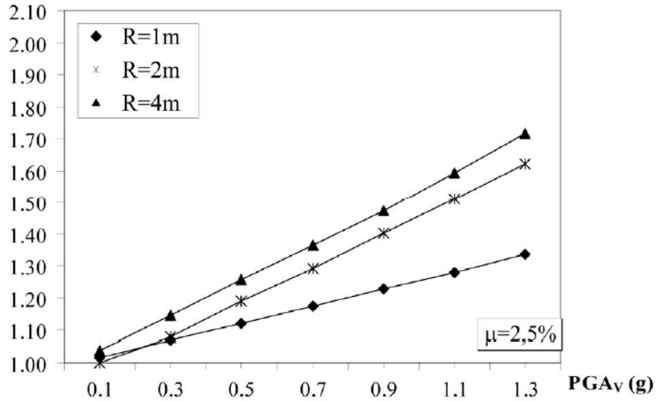


**Figure 7:** Ratio $F_V/F$ calculated for L'Aquila 2009 [33]

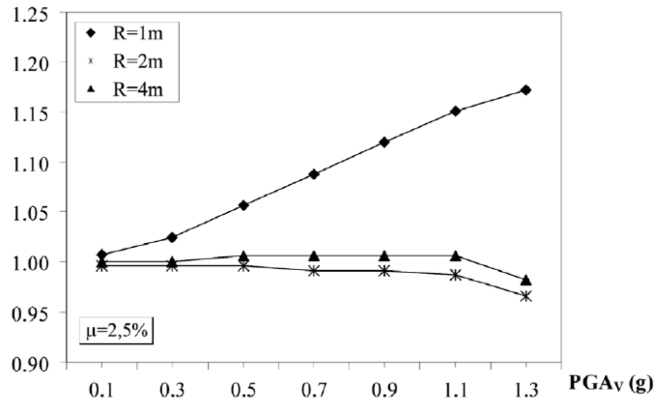


**Figure 8:** Ratio $u_V/u$ calculated for L'Aquila 2009 (right) [33]

The described results show the advantage that can be obtained by using the FPS to protect non-seismically designed buildings such as the vernacular structures.

## 3 VERNACULAR STRUCTURES IN TURKEY TIMBER – FRAME HOUSE

In Turkey it is possible to find a considerable number of different types of vernacular architecture: in the north, it is found the Timber-framed structures, on the plateau of Central

Anatolia it is possible to find houses made of mud and in the southern mountainous stone buildings. This variety of forms, techniques and construction materials depends on the many populations that have settled over the years in the Asia Minor plateau, a region composed of a collection of transhumant cultural areas that have been colonized throughout the centuries.

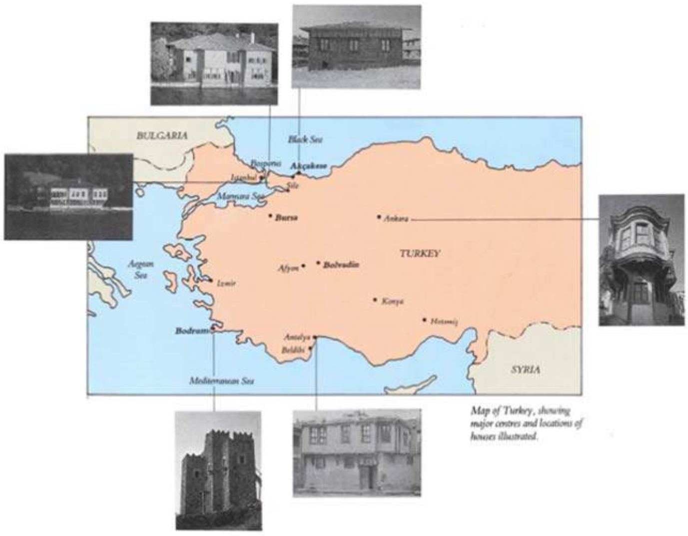


**Figure 9:** Map of Turkey, showing the location of the illustrated houses [34].

Historically the term *"Turkish house"* defines a specific type of building that extends over the vast territories of the ancient Ottoman Empire, from the Balkans to the Arabian Peninsula. The first buildings were built about five hundred years ago, but most of them were destroyed by natural events. The oldest structure that has survived today is the *Amcazade Huseyin Pasa Yalis* house, built in the seventeenth century.

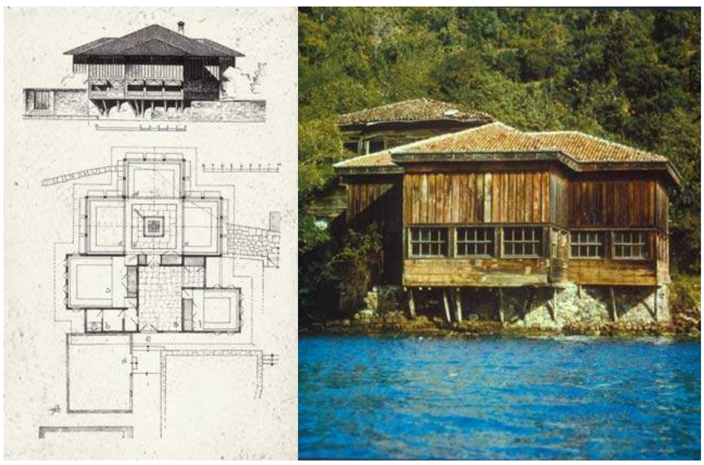

**Figure 10:** Amcazade Huseyin Pasa Yalisi, Istanbul, I699· One of the oldest surviving examples of the Turkish House. [35]

Despite the substantial variations in size and configuration that have taken place according to regional peculiarities, there are some fundamental characteristics that define the Turkish house as a distinct, fixed and tested typology over the centuries.

One of the most used construction types is the timber frame and infill construction, with the filling material ranging from brick to wood, plastered or coated in wood for the more refined houses. Another feature is the robustness of the ground floor, reserved for the storage of hay, animals, etc., on top of which is built a lightened slab that protrudes from the lower level. The lightened slabs sit on wooden poles.

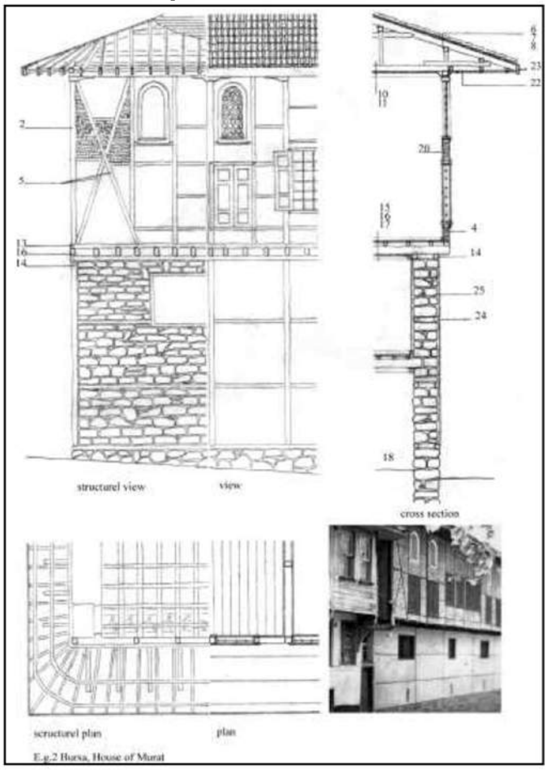


**Figure 11:** Hursa, House of Murat [36]

Thanks to the work of the Turkish architect Eldem's and his work Turk Evi (Turkish House) [37] it was possible to identify the evolution of Turkish architecture, and the layout of the different rooms, functional Turkish lifestyle and culture. The typical Turkish house shown in Figure 11 consists of two floors: the entrance floor, and the first floor.

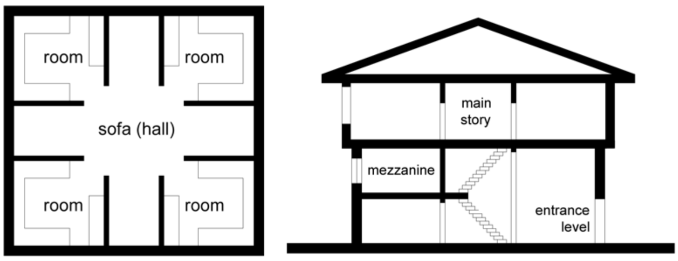


**Figure 12:** Plan and cross-section of a typical two-story Turkish house, based on Eldem Studies [37]

The “sofa” is defined as a shared space, in which all family members are involved in daily activities (Asatekin1994). All the rooms on the ground floor are connected directly to the sofa, each adjacent room was intended for a single couple living in the house, so every "room" was like a house for a couple. The rooms and the sofa also differed externally by the size and shape of the windows.

In Turkey, almost every year, a destructive earthquake occurs. Furthermore, it is one of the countries with the shortest return period for earthquakes that cause loss of life. In general, earthquakes in Turkey are superficial, and therefore they are more destructive than earthquakes in the open sea, even if their magnitude is lower [38].

The wooden buildings were built in Turkey until 1960 circa; later, reinforced concrete structures were preferred, abandoning the construction of wooden buildings. In 1999, the earthquakes of Kocaeli and Duzce brought attention again to the traditional buildings because the reinforced concrete structures were heavily damaged while the traditional buildings had relatively good performance during the seismic event.

**Figure 13:** Failure and damage of *himis* building [39]

The official post-disaster reports do not present detailed studies on wooden structures, but in the aftermath of the 1894 Istanbul earthquake, both experts and ordinary citizens were impressed by the effectiveness of wooden buildings. The director of the Athens Observatory, called to study the earthquake, concluded that wood structures exceeded the performance of masonry buildings, even if they were old and poorly constructed [40].

Although the type of traditional wooden buildings varies in the different seismic zones, the following damages have been observed in timber-frame buildings during the destructive earthquakes in Turkey: cracks and falls of plaster, mortar failure, loosening or non-connection of masonry parts, large lateral displacements, misalignment of the masonry filling, loosening or failure of the foundation connections to the structure.

Timber-frame buildings functioned well in terms of life safety. The small weight of the wooden buildings and the distribution of the interior spaces allows the creation of large voids following the collapse; also, the detachment of stone elements causes fewer victims than concrete blocks.

## 4 PROPOSED STRATEGY FOR RETROFITTING USING BASE ISOLATION

The timber-frame houses, as previously described, were more efficient than masonry houses during a seismic event, but the goal that needs to be achieved is the safeguard of these assets because they are part of the culture of the Turkish people.

The conservation of cultural heritage, as discussed in the principles of the Venice Charter, should preserve the identity of cultural heritage considering, among other aspects, the preservation of materials and the static behaviour of the structure. This problem is not trivial in the case of seismic areas, such as Turkey. The use of FPS isolation devices allows a reduction of the seismic excitations transmitted to the structure by acting as a low-frequency filters, hence controlling the maximum shear transmitted to the upper-structure.

In the following section, the proposed retrofit system is discussed by considering a typical "Turkish House".

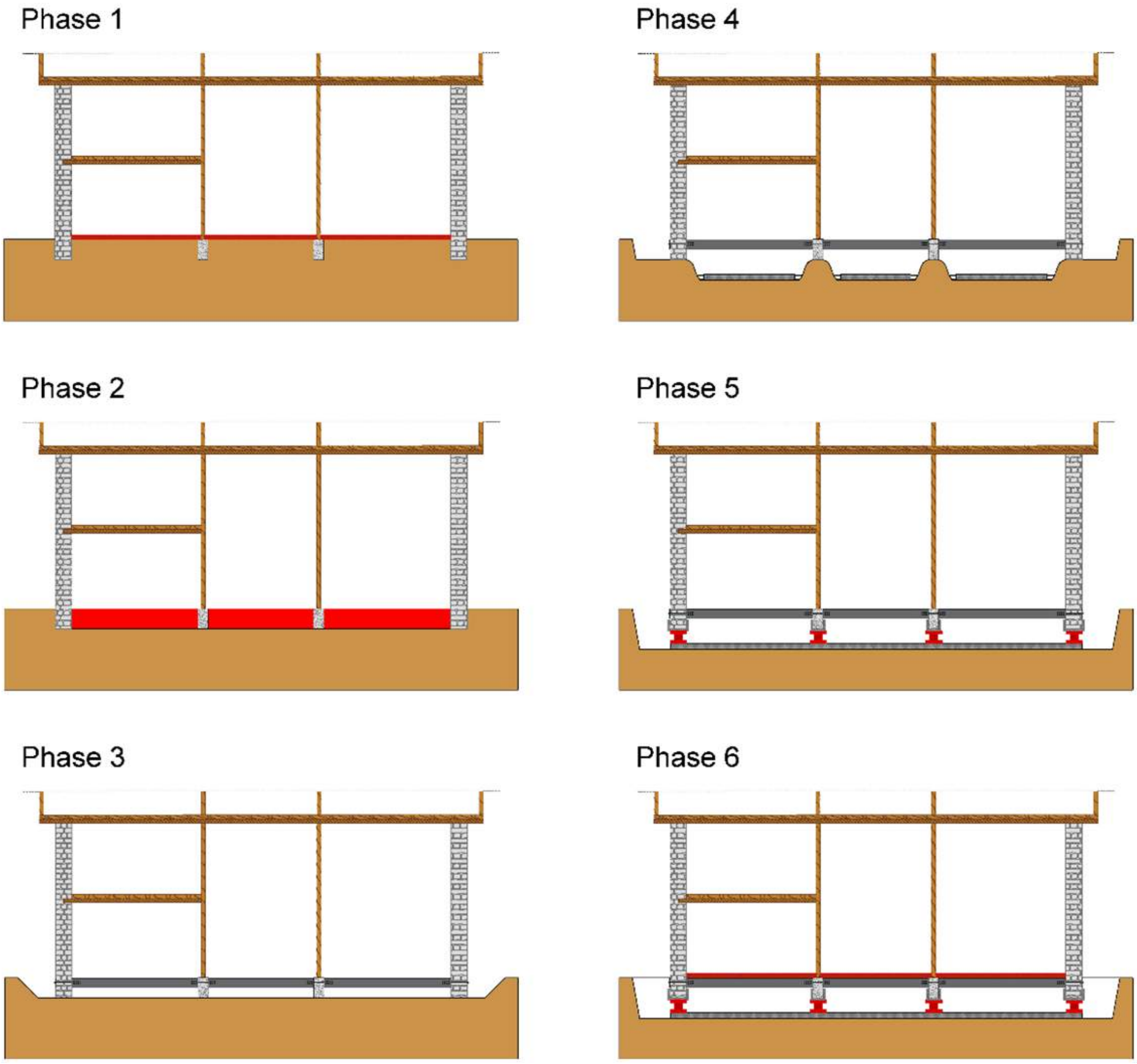


**Figure 14:** Phases of the installation process proposed for the isolation system

The retrofitting process can be divided into six phases:

1. Removal of the wooden floor level of the ground floor;
2. Preliminary excavation up to the level of the current foundation from inside the structure, to be carried out without using machines, thus having higher accuracy;
3. Stiffening of the base level of the structure with a lattice of steel beams, this system allows to leave unchanged the static behaviour of the structure;
4. Excavation for a depth appropriate to allow the start of the construction of the reinforced concrete slab that will serve as a new foundation, the bars are left out of the concrete to connect them with adjacent strips;
5. Advancement of the excavation with the connection of the foundation slab, construction of the isolating system;

6. Reinstallation of the wooden floor, leaving the possibility of inspection and maintenance of the insulators.

In the case of large structural aggregates, ENEA and University of Torino [41] has patented a seismic isolation structure for existing buildings able to isolate the structure below the foundations level. This technique can also be considered to preserve relevant archaeological or architectural constructive parts of the structure, such as the foundation systems, etc.

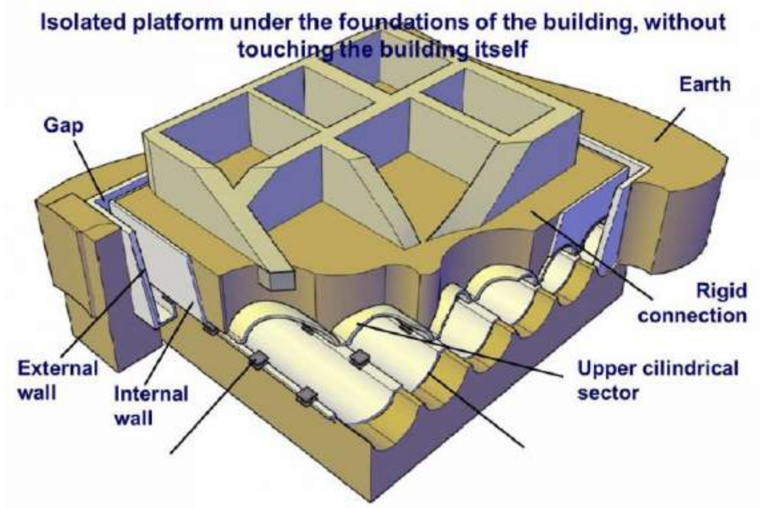


**Figure 15:** 3D design of Isolation system patented by Enea and University of Torino. [41]

The technique involves the excavation of a trench to the side of the area of interest where a particular contrast structure is made. Subsequently, tubes are inserted horizontally along the entire length involved in the intervention. Then, a discontinuity plane is created in correspondence with the horizontal diametral plane, on which the seismic isolation devices are inserted.

## 5 CONCLUSION

The paper describes an innovative strategy to seismically retrofit existing structures built with poor-quality materials by using friction pendulum isolation devices (FPS). The FPS is widely used nowadays in the case of new buildings, with several applications tested in real seismic events. The FPS devices allow the control of both shear and displacements of existing structures even in the case of not well-known structural weight. The devices can be installed without altering the structural behaviour of the existing architecture by conserving the original materials and structural details.

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# CHAPTER III

# DOCUMENTATION

# ARCHITECTURAL CHARACTERISTICS AND CONSTRUCTION TECHNIQUES OF WOODEN MOSQUES IN THE EASTERN BLACK SEA REGION IN TURKEY

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**Keywords:** Wooden mosques, restoration, vernacular architecture, Eastern Black Sea Region

## Abstract

*The diverse vernacular architectural elements in Turkey, by means of material choice, architectural style and constructional techniques is formed by Anatolia's multicultural background and different geographical and climatic conditions in every region. Eastern Black Sea Region is one of the regions where the traditional villages are settled in woods, close to the streams. Timber frame with stone filling and log wood are the typical construction systems used in the civil architecture examples in this region.*

*Other than the civil architecture, there are also wooden mosques dating back to the 19th century. These mosques were built as a gathering religious space for the near-by villages and serve the local congregation mainly during the Friday prayer. Today, some of these mosques are abandoned and some of them are still in use.*

*Most of these two-storey wooden structures have unadorned façade design, hipped roofs with wide eaves, and wooden sash windows. Besides, they were built without a minaret which makes them look like a traditional house. The main prayer hall reflects the centrally-planned mosque design from the Ottoman period. Under the sloping roof, a wood panelling covered ceiling or a dome as a secondary layer situated above the main the prayer hall. The women's prayer space is generally separated, typically relegated to the rear mezzanine level. Contrary to the simplicity on the façades, there exists a quality wooden carving workmanship in the interior decoration.*

*This research paper aims to investigate the architectural characteristics and construction techniques and details of wooden mosques in Eastern Black Sea Region through a case study in Muratlı Village, in Borçka - Artvin. Conservation and restoration issues are also discussed together with other wooden mosques located in this territory.*

## 1 INTRODUCTION

The Black Sea Region has a wet and damp climate, and broad beech, hornbeam, chestnut, oak, fir, pine tree forests. Due to the climatic conditions and the affluence of forest areas, the main building material has become wood and the use of wood has revealed a style of architecture specific to the region. In addition to the region-specific residential architecture, there are wooden log mosques that reflect both the rural architectural characteristics of the area and the characteristics of the mosque architecture of the period in question.

Wooden mosques spread to a wide geography extending from the province of Kocaeli all the way to the province of Artvin. Due to the Geographical conditions and cultural characteristics spread out by migrations, there are also examples of wooden log mosques in the areas similar to the Black Sea region. There is a wooden mosque built at the beginning of the 20th century in the town of İskilip, within the province of Çorum [1]. There are also examples of wooden mosques in the provinces of Kocaeli [2], Kastamonu [3] and Sakarya [4]. Likewise, there is also a wooden log mosque with wooden minaret in the village of Elmalı, founded by the Caucasian immigrants at the end of the 19th century in the town of İznik in Bursa [5]. In addition, there are upgraded examples of wooden mosques, *tekke* (Islamic monastery) and small mosques in İstanbul [6].

Most of the academic studies on wooden mosques in the Black Sea region have been carried out in the departments of theology and art history. In recent years, documentation and protection studies have begun in the field of Architecture. Zorlu [7] carried out a detailed study on the construction techniques, plan typology, material properties and ornamentation style of wooden mosques in the province of Trabzon. He classified the ladies' quarter floor over the sanctuary floor according to the I, L, U and O plan scheme. Özgen et al. [8] conducted a study on the construction technique, plan, ornamentation and conservation of the Hüseyin Hoca Mosque in the Kalkandere town of the province of Rize. In his master's thesis prepared within the restoration program, Uzun [9] Samsun investigated the architectural features and conservation problems of the wooden mosques in the town of Kavak in the Samsun province and proposed a restoration project for the Dere Mosque. In his master's thesis prepared within the restoration program, Furtuna [10] investigated the wooden mosques in the town of Çarşamba in Samsun and assessed it in the context of vernacular architecture. It was built as a place of worship within the village; where several villages were merged, it was also used a place of worship commonly between the villages for Friday and *Bayram* (Religious Festival) prayers [11].

The architectural heritage available in the rural areas in our country has been gradually disappearing. In the villages where traditional houses are abandoned and new one are built, the existing wooden mosques should be documented and repaired in order for them to be able to sustain their existence. In this connection, the customary building traditions and general characteristics of wooden log mosques which are widespread in the Eastern Black Sea region have been conveyed together with examples from the region. A wooden log mosque from the Artvin region, which was not academically studied before, was selected as a case study and its architectural features were explicated in detail. The conservation problems specific to the region and wooden mosques were addressed and proposals for the conservation of wooden mosques were offered.

## 2 GENERAL CHARACTERISTICS OF THE RURAL ARCHITECTURE IN THE EASTERN BLACK SEA REGION

The basement floors and the ground floors are stacked stone walls in accordance with the condition of the ground where the building is situated since the region generally has inclined topography. The buildings in the Black Sea region were built on stone foundations with wooden carcass (Fig.1) and wooden masonry wall (Figs.2-3) technique. In the wooden carcass system, the walls are constructed by a technique known as "eye stuffing" which is filled with a square cut stone in each cavity or as "amulet stuffing" with triangular cavities filled with beads and small stones [12].

**Figure 1.** Artvin/Borçka/ Korucular Village, Kazım Durmuş House [29]

**Figure 2.** Artvin/Ardanuç/ Aşağıırmaklar Village, İsmet Altun House [30]

**Figure 3.** Artvin/Ardanuç/ Aşağıırmaklar Village, Yusuf Ekinci House [30]

In the log timber masonry system, on the other hand, the walls are bonded with logs or clear-cut timber. The technique of insert called "karaboğaz" is used at the corners of the masonry wall built with logs (Fig.4). In the masonry walls built with timber, the "kurtboğaz" insert technique is used at the corners (Fig.5). and "çalmaboğaz" at the intersection of three walls [12].

Although the roofs of the traditional structures have Turkish style tiles on, it is known that the roof covering was also made of timber in the period when they were first built. Today these unique examples are seen in the mountain houses. This technique is called "Hartama / Bedevra / Pedavra" (Fig.6) [13]. Laths are obtained by splitting the pine wood with the ax for the timber cover. Due to the fibrous texture of the pine tree, fine gutters form on the thin timber (bedevra) and the rain water flows easily since it is a kind of resinous tree [30].

In the Black Sea region, while the houses are built with clear-cut timber, structures such as stables and haystacks are built with logs. In addition to these, the structures used as food warehouses and built on four wooden standings and called “seren/serander/serander” were built in the timber masonry technique in the same way as the houses (Fig.7).

**Figure 4.** Detail of “karaboğaz” in Yusuf Ekinci House [30]

**Figure 5.** Detail of “karaboğaz” in İsmet Altun House [30]

**Figure 6.** Detail of “bedevra” in uplands of Artvin/Borçka [31]

**Figure 7.** “Seren” in Artvin/Borçka/ Aralık Village [30]

## 3 GENERAL CHARACTERISTICS OF MOSQUES MADE OF LOG TIMBER IN THE EASTERN BLACK SEA REGION

Most of the mosques in the Black Sea region were built in the 19th century. There are usually no minarets on the mosques in the countryside where some villages commonly use it. In those mosques with one, the minarets were built externally adjacent to the building [14]. These mosques have Classical Ottoman period plan scheme. In the shrine (mihrab) axis, there is the entrance and the narthex. The idea of central worship area is seen in these mosques available in the countryside as well. The harim (sanctuary) is covered with a bellied ceiling or a dome over it.

### 3.1 The Plan Characteristics

The Black Sea Region’s wooden mosques were built as one or two storeys. The ground floor of mosque was used as a madrasah or the madrasah was constructed as a separate building. Many of these madrasahs have not reached the present day. In some of the mosques, a living room is arranged in the portico for imam-prayer leader [15].

Wooden mosques have a square or rectangular plan scheme. The upper floor, which is used as a women's lodge, generally has a U plan scheme. In some mosques, the upper floor is arranged on one side only. The main worship area, the sanctuary (harim) in front of the shrine (mihrab) is as high as two stories. The portico of the mosques are located on the entrance side of the shrine, on the two L-shaped facades or on the U-shaped three facades (Table 1). In some mosques, the portico was closed off and attached to the mosque.

### 3.2 Construction Techniques and Facade Characteristic

The Black Sea Region has large forested land, sloping topography, rainy and moist climates. The natural structure has been influential in shaping the local architecture. As it is the case in the traditional structures in many parts of Turkey, the mosque were built on a stone foundation to take measures against dampness likely to come from the ground. According to the slope of the land where the mosque is located, half basement floor was arranged in stone masonry technique. There are also examples of mosques where the ground floor of the mosque is stone masonry on the slopes, and the upper story wooden float is the log timber. The lodge (mahfil) is supported by the posts [11,15].

Wooden mosques were made of timber 4-5-6 cm in thickness acquired from trees such as elm tree, chestnut and oak tree. The timbers were combined with a "kurtboğazı" insert technique that would extend 20-30 cm out of the corner of the building. Treenails (dowels) made from black rosehip or comer woods were used to connect the [11,15]. Structural strengthening was achieved by using posts in door and window spaces in the log system [16].

The flooring of the mosques is generally made out of wood. The ceilings of the mosques are generally flat with wooden veneer. There is a square or rectangular ceiling rose on the worship place which is two stories high. In some of the mosques, there is a wooden dome that is arranged within the roof construction of this section and supported by wooden posts. This dome is not externally visible, hidden within the roof. Apart from the flat ceiling and the dome, there are also the mosques where the ceiling is not covered and the roof construction is visible.

The roofs of the mosques are called wooden pyramidal roofs also locally referred to as the "four shoulder roof"[1]. In the period when they were first built, the roofs of the mosques were covered with wood veneer (*hartama*). They were later replaced with Turkish style tiles. Today,

[1] The traditional name of each surface of the roof in Earstern Black Sea Region is called “omuz” (shoulder) [13].

roofs of the many mosques are covered with roof tiles. Due to its rainy climate, it has wide fringes. The bottom parts of these fringes are covered with wood [11,15].

The characteristics of the wooden base of the log timber mosques also constitute the facade characteristics. With the wooden walls and posts, wooden guillotine windows, tiled covered hipped roof, it has a simple facade reminiscent of the wooden houses in the region.

### 3.3 Architectural Elements and Ornamental Characteristics

Unlike the simplicity of the facades of the log timber mosques, there is an enriched wooden workmanship in the interior. The two-winged, engraved, patterned wooden entrance door of the mosques is the only decorative architectural item on the facade. The doors are painted with ochre or madder or left unpainted.

Mosques have hand-carved floral patterns on their dome-shaped or bellied flat wooden ceilings. On the flat parts of the ceilings, geometric patterns were created by laths.
The wooden shrine, pulpit and ambo are embossed or carved. Floral and geometric patterns were used. In some of the mosques, the shrine niche protruded on the facade. In the wooden mosques, patterns such as Star of Davut (Mühr-ü Süleyman / 6-pointed star), seven-arm candlestick, ram horn, arrow, four arrows and six arrows were taken from the Turkish Tribes such as Caspian and Karai [11].

### 3.4 Examples of Log Timber Mosques in the Eastern Black Sea Region

The wooden mosque in the Camili village of Artvin's Borçka district was built by the villagers in 1855. The mosque with a square plan was built on a stone basement with two layers of wooden platform. It has a wooden minaret [17]. The wooden mosque in Fındıklı village of Artvin's Borçka district was built in the 18th century. The square-shaped mosque was built on a stone foundation with a 2-storey log timber technique on stone foundations. It has no minaret. The shrine niche is visible on the façade [18].

The Sahil mosque, located in Hüseyin Hoca Village of Rize's Kalkadere, was built in 1824. The mosque located in the Of district was moved to this village in 1977 and removed in the same village in 2012. The mosque with a rectangular plan was built on a stone foundation with a 2-storey log timber technique. It has no minaret [19].

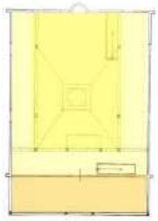
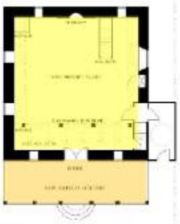
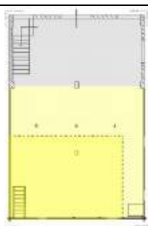
The Mithat Pasha Neigbourhood Mosque, located in the Bölümlü Town of Trabzon's Of district, was built in the mid-19th century. The mosque in the Of district was moved to this village in 1977. The square-schemed mosque was built on a stone foundation with a 2-storey log timber technique. The sanctuary (harim) is 7,20 x 7.70 meters, total ceiling height is 4.70 meters, the height of the lodge story is 2,10 meters. It has a wooden minaret [20].

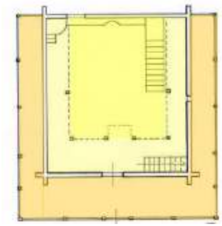
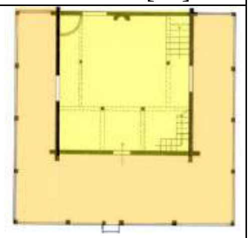
The wooden mosque in Şenyurt Village of Ordu’s Kumru district known as the Old Mosque was thought to built in the end of 19$^{th}$ century or at the beginning of 20$^{th}$ century. The square-schemed, two-storey log timber mosque was built with pine-tree. The portico surrounds three facades of the mosque. The pulpit end ambo was renewed [14].

It is anticipated that the Laleli (Old) Mosque, located in the town of İkizce of the Ordu Province, was built in the 16th century in dendrochronology. The square-shaped mosque was built on a flat land with a single-story log timber. The wooden floor beams were placed on the rubble stone foot to allow the building to move away from the soil ground [14,21].

The Gökçeli Mosque, located in the Çarşamba district of the Samsun Province, was built in 1206 during the Anatolian Seljuk period. It is considered to be the oldest wooden mosque in Turkey. It was restored in 2007. The mosque has no ceiling covering and the roof system is visible from the sanctuary (harim). Roof construction was decorated with hand-drawn patterns with madder [22] (Table 1).

**Table 1.** The Log Timber Mosques Examples in Middle and Eastern Black Sea Regions

| **LOCATION/ NAME** | **PHOTO OF FACADE** | **PHOTO OF INTERIOR SPACE** | **PLAN SCHEME** |
|---|---|---|---|
| Artvin/Borçka **Camili Village Mosque** |  Masonry and log timber facade [23] |  Plastered ceiling dome [23] | |
| Artvin/Borçka **Fındıklı Village Mosque** |  Southern façade and shrine [18] |  Ceiling detail [18] |  Plan scheme [18] |
| Rize/ Kalkandere<br><br>**Hüseyin Hoca Village Sahil Mosque** |  Northern façade and the two-storey portico [19] |  Ceiling detail [19] |  Plan scheme [19] |
| Trabzon/Of<br><br>**Mithat Paşa Village Mosque** |  Northern façade and portico [24] |  Ground floor plan [20] |  First floor plan [20] |
| Giresun Melikli Village<br><br>**Tahtalı Mosque** |  Log timber façade [25] |  Woman's prayer hall [25] |  Plan scheme [25] |

| | | | |
|---|---|---|---|
| Ordu/ Kumru<br><br>**Şenyurt Village Mosque** | <br>Northern facade and portico [14 | <br>Woman’s prayer hall [14] | <br>Plan scheme [14] |
| Ordu/ İkizce<br><br>**Laleli (Eski) Mosque** | <br>Façade and foundation [21] | <br>Portico [21] | <br>Plan scheme [21] |
| Samsun/ Çarşamba<br><br>**Gökçeli Village Mosque** | <br>General view of teh mosque [22] | <br>Interior space and painted walls [22] | <br>Portico [22] |

## 4 WOODEN MOSQUE OF MURATLI (MARADİT) VILLAGE IN BORÇKA, ARTVİN

The first settlement in the Artvin region was established by "hurrians" from Central Asia from the 2nd century BC. In the course of time, the Urartians, the Scythians, the Arşaks become dominant in this region. This region remained under the rule of Byzantine in 576 B.C, under Islamic Army and Umayyads, Caspian Turks and Bagrats in 645 B.C. The region was occupied by the Great Seljuk State in the 11th century and by the Ottoman State in the 16th century. During the Ottoman-Russian War of 1877-78, it was captured by the Russians, later ruled by the Armenian, British and Georgian administrations between 1918 and 1921; and in 1921, they were freed from the occupation and attached the Ottoman Empire again. In 1923, after the establishment of the republic of Turkey, today’s town became the province of Çoruh [32]. In 1956, its name was changed and became Artvin [26].

Borçka is one of the districts of Artvin, situated on the Çoruh River valley and bordered by Georgia. The village of Muratlı is situated on the border of Georgia of Borçka along the Çoruh River (Figs.8-10). The former Georgian name of the village is Maradit. After the Muratlı Dam was built, a part of the village, a new mosque and a tea plant were flooded.

**Figure 8.** Muratlı Village [33]

**Figure 9.** Aerial photo [34]


**Figure 10.** Geographical map [35]

## 4.1 History of the Muratlı Mosque

The Muratlı Village Mosque is located in the center of the village near the river. Today, it is open for worship (Figs.11-13). There are totally four inscriptions; two on the entrance door of the sanctuary (harim), one on the pulpit and one on lodge (mahfil) story. According to the inscription on the original entrance gate of the mosque, it was built by the (Master) Ahmet Usta (son of Reşid) in 1846 (Hijri [Islamic calendar], 1262)[2]. The wooden pulpit of the mosque, according to the inscriptions, was built by Sağıroğlu Hüseyin Ağa and lodge (mahfil) story by Uzunhasan Zade Hüseyin Alemdar in 1847 (Hijri 1263). They reported that it was destroyed by the Russian invasion in the region at that time and repaired afterwards [17].

**Figure 11.** Mosque of Muratlı Village [26]

**Figure 12.** North Façade- Entranca of [30]

**Figure 13.** The new minaret [30]

## 4.2 Plan Characteristics of the Muratlı Mosque

It was built on a sloping land with a two-storey in the log timber technique. Due to the sloping of the land, there is a half basement floor facing east and south. The wooden minaret of mosque was demolished due to the wind and a new reinforced concrete minaret was built in the northwestern corner of the mosque in 1979 [26].

It has a square-resembling rectangular plan scheme. The lodge story of the mosque is U-planed. The lodge story is reached by two wooden stairs on the north wall. The northern part was expanded with attachment of the narthex.

The main worshiping area (harim) has the external measures of 15,25 x 12,80 m and the narthex is 3,15 m wide. The narthex, which was arranged on the entrance side only in the north direction, was closed off afterwards when it was in the form of a two-storey 9 wooden post portico. The internal posts on the lodge (*mahfil*) floor are also carved. The lodge (*mahfil*) floor is surrounded by wooden safety rails. The lodge (*mahfil*) and floor moldings are wood-carved. The narthex in the ground floor was closed off later by addition of one room on both sides and the entire upper floor was included onto the lodge floor [17,26]. Today, the mosque became completely closed off by installing new doors in the middle part of the narthex. The ceiling height is 4.70 m, the diameter of the dome is 5 m, and the height is 6.50 m (Figs.14-20).

[2] The date 1846 might be the production date of door. If so, the mosque could be constructed in the first half of 19th century. According to General Directory of Foundations determined that the constructed in the beginning of 19th century. According to the experts of Trabzon Museum date is 1845; according to the experts of Erzurum Museum date is 19th century [17].

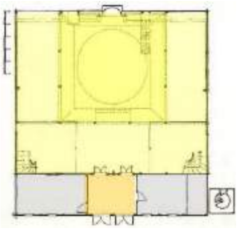


**Figure 14.** The plan scheme of the mosque [26]

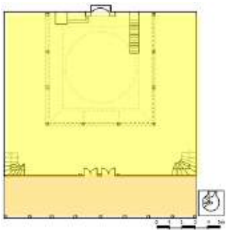


**Figure 15.** The ground floor plan restitution (Reproduced from [26])

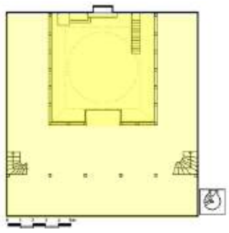


**Figure 16.** The first floor plan (Reproduced from the plan in [26])

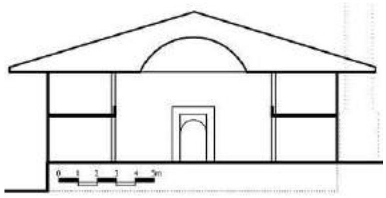


**Figure 17.** The section of the mosque (Drawn by author)

**Figure 18.** The two-storey prayer hall - *harim* [30]

**Figure 19.** The main prayer hall and woman's prayer hall [30]

**Figure 20.** The wooden post and capital [30]

## 4.3 Facade Characteristics of the Muratlı Wooden Mosque

The facade characteristics of the mosque are constituted by the walls built in the log timber technique, sash windows, 2 m wide fringes and the minaret. Body of the minaret made of cut stone is square, its body is cylindrical, and the cone is conical. There are three rings in the body of the single-balcony minaret and a three-ring base under the balcony. Minaret body is plastered (Fig.21).

The old shrine on the southern facade of mosque protrudes and continues up to the fringe. There are totally 8 windows on both sides of the shrine niche, with two windows on each story. There are 11 windows on the east facade and 11 windows on the west facade. There are 8 windows that are not aligned on the walls of the narthex, closed off on the northern facade. The façade of the mosque was later painted in white and brown colors. There are wood carving ornaments in wooden posts and groundsills in the corner of the mosque (Figs.22-24).

**Figure 21.** The western façade, masonry minaret, tile covered roof and and roof [30]

**Figure 22.** The eastern façade [30]

**Figure 23.** The southern façade [30]

**Figure 24.** The joint of beams and post [30]

### 4.4 Architectural Elements of the Muratlı Mosque

The ceiling of the lodge (mahfil) floor is a flat beaded ceiling. Top of the sanctuary (harim) of the mosque which is two-storey high is covered with a wooden dome. There are 10 wooden posts in the ground floor supporting the lodge (mahfil) floor. On the lodge (mahfil) floor, there are 17 woodenpost supporting the dome [17]. The wooden dome is arranged on the hipped roof and is not externally visible (Figs.25-26).

On the northern facade of the mosque, two original entrance doors with double wings were made of walnut tree. The doorway is circularly arched. Wooden door wings and gate posts are have floral patterns (Fig.27).

**Figure 25.** The prayer hall and dome [30]

**Figure 26.** Wooden dome and ornaments [30]

**Figure 27.** Wooden doors [30]

The shrine (Fig.28), pulpit (Fig.29-30) and ambo (Fig.31) of the mosque are made of walnut tree. In front of the old shrine protrusion, there is a rectangle shaped carved shrine niche measuring 2,78x2,15 m. The top of the shrine's niches is covered with a half-dome The nine-step pupit measures 3.30x0.71 m. The shrine has circular arch and no door wings. There are flower, pistol, medallion, six-lever scale, knife and moon star patterns on it [17].

**Figure 28.** The wooden shrine [30]

**Figure 29.** The wooden pulpit [30]

**Figure 30.** Detail of the wooden pulpit [30]

**Figure 31.** The wooden ambo [30]

### 4.5 Conservation Issues

Among the problems seen in the Eastern Black Sea Region in general are the increasing numbers of hydroelectric power plants in recent years, the projects of dams and coastal roads and destruction of the nature. The coastal roads made it easier to access the surrounding provinces, but interrupted the connection with the settlement areas [16]. Another important problem is the constant internal migration and declining young population in the rural areas. This eventually leads to a decrease in agricultural production in the rural areas and to the departure of the villagers from their villages. In recent years, the Eastern Black Sea region has become one of the preferred destinations for alternative cultural tourism such as nature and highland tourism. New types of buildings such as guesthouses and restaurants have emerged in the villages that are on the tourism route. Besides, the maintenance of the traditional building production technique and the newly built reinforced concrete houses have destroyed the traditional texture of the villages.

In addition to the general problems of the region, the wooden mosques also have problems regarding their usage by the public and material use in their construction. The fact that some mosques fail to function as worshiping places causes them to experience rapid destruction over time and eventual destruction. Faulty and inadequate repairs made on the actively functioning mosques, reinforced concrete attachments, external facade plastering, biological deterioration in the wooden material over time, painting of the wooden walls and architectural elements, inability of the wood to breathe lead to the loss of the originality of the mosques.

## 5 EVALUATION AND CONCLUSION

The mosques, many of which were built in the 19th century, are the representatives of the centrally planned worship places of the Ottoman architecture. The exterior facades of the Black Sea Region wooden mosques are plain as the traditional houses. The carrier system construct has added an aesthetic to the facade. The only ornamental architectural elements on the facade are the carved entrance doors. Contrary to the plain arrangement on the exterior facade, the interior is rich in wood carving and decoration.

The wooden mosques are advantageous because they are public spaces and still have value of use in comparison to the houses in terms of restoration and preservation. In many villages, as there are the old wooden mosques as well as new ones, the wooden mosques can serve new functions in line with the social, cultural and educational needs. Care should be taken that the new function does not change the original architecture.

In the Eastern Black Sea region, restoration programs can be introduced at the universities in the region to contribute to the protection of both wooden mosques and rural architecture. Furthermore, research and practice centers on the preservation of traditional structures should be established. Wooden building masters should be trained and knowledge of traditional building production should be transferred to the future generations.

When the wooden mosques are restored, the carrier body walls can be renewed, but precautions should be taken to extend the life of the original wooden elements such as the shrine, pulpit, ambo and ceiling rose. Any repairs made with poor quality paint should be blasted and the breathing of the structures should be ensured.

The International Wood Committee of ICOMOS[3] published "Principles tor the Conservation of Wooden Built Heritage" charter in 1999. One of the recommendations in this chartes is to encourage the protection of original forests and establish woodlands to get appropriate timber for repairing wooden structures [27].

While Eastern Black Sea Region is located in the 3 and 4 Degrees earthquake zone, the Central and Western Black Sea and Eastern Marmara regions are in the 1st and 2nd Degree earthquake zone [36]. Documentation of wooden log mosques, the characteristics of the bearing systems and the engineering works to be carried out regarding the earthquake behavior can pave the way for the studies on the prevention and conservation of these cultural assets against the disaster risks in the earthquake-prone areas.

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# AN EXAMPLE OF 19TH CENTURY ISTANBUL MANSIONS; THE CİHANGİR KADİRİ LODGE MANSION

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**Keywords:** Traditional, 19th century Houses, Lodge Mansion, Wooden Frame, Central Hall

## Abstract

*The Turks in Anatolia and the other regions in which they were sovereign developed a housing architecture peculiar to them. In the creation of this architecture geographical conditions, historical situations and ways of life were influential in addition to Anatolia's being in an earthquake zone. The earliest examples of mansions built with wood frames to resist earthquakes began to be produced in Anatolia in the 16th century, and this production continued until the middle of the 20th century. At the beginning, the plans of the mansions which were built with open halls as an indication of country living and tradition changed over time and completed the development process with plans of enclosed interior halls that suited city living and central halls.*

*The Kadiri Lodge in Istanbul's Cihangir district is a religious complex that has existed since the 17th century. Today the wooden mansion in which the Lodge's seyh lived with his family is important among the various buildings that make up this complex. It is thought that the mansion was built in the first half of the 19th century during the reign of Sultan Mahmut II and it has a plan that the stairwell and rooms that surround the side of a square-shaped hall with bevelled corners created. It was built on sloping land as a four—story building with a basement floor with a hamam, ground floor, main floor for living and an attic / cihannüma. The basement level walls were built from rubble; the other floors' walls were built of earthquake—resistant, wooden frames against earthquakes and the floors are wooden joisted. The wooden frame walls were covered on the outside with wood and on the inside with plaster made of lath and plaster work. The interior spaces had walls decorated with pencil work and lathed wood on the ceilings.*

*The building which experienced two big earthquakes in 1894 and 1999 and survived these disasters unfortunately was ruined in a fire in 1997 and the attic/ cihannüma partially burned. In this study the architectural formation and the problems of protecting the Kadiri Lodge Mansion which is one of the few wooden buildings left of the mansions of Istanbul and is face to face with the danger of being destroyed will be studied and documented.*

# 1 INTRODUCTION

The “Kadiri Asitanesi” or “Kadiri-hane Tekkesi” (dervish lodge) is a complex in Istanbul’s Tophane district on Kadiriler Yokuşu and is made up of various “tarikat” (mystic sect) buildings. The “asitane” name of the complex which was first established at the beginning of the 17th century as a dervish convent happened because the “Kadiri Tarikat’s” headquarters were in Istanbul. The tomb that belonged to Rumi İsmail Efendi (d. 1631), the founder of the “Kadiri Tarikat” is inside this complex and strengthens the correctness of this status [1]. The complex on island that is bounded by “Kadiriler, Süngü , Türkgücü” and “Tombaz” Streets is located on sloping land (Fig. 1-3). In the complex that over time has been burned, destroyed, rebuilt and added to the buildings, there are a stone “ tevhid-hane” (great hall) or mosque, a wooden “meşruta-hane” (mansion) reserved for şeyh’s family, the şeyh’s house, a “hamam” (Turkish bath) that belongs to the mansion, a mausoleum, a “hazire” (enclosed graveyard) and two fountains. The “tevhid-hane” (great hall in which the tariqat’s rituals were performed), which is the main building of the complex, over time has been enlarged and surrounded with wooden-framed reception areas “selamlık” from the east and the west (Fig.4,5). The “hazire” and tomb are on the north of this building and the şeyh’s house and mansion are on the west (Fig.6, 7). The “tevhid-hane” and the mansion are reached via a ramp with stairs that begin from “Kadiriler Yokuşu” (Fig.8). One of the fountains in the complex is on “Kadiri Yokuşu” and is the İsmail Ağa Fountain found on the courtyard wall while another fountain, which is on the ground floor of the “selamlık” section of the “tevhid-hane” (Fig.2, 8) Aside from these buildings there are gardens that are on different levels south of the “tevhid-hane” and in the west of the mansion and şeyh’s house (Harem garden). The dining hall “taam-hane” which existed in the past and was on the east of the “hazire” and the “gusulhane” for ritual washing section have been rebuilt today.


**Figure 1:** Kadiri Lodge at the Pervititch Map [2].

**Figure 2:** “Kadiri” St. and courtyard door, 2018.

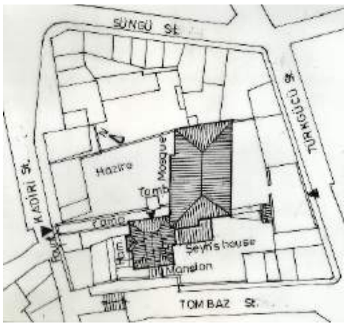


**Figure 3**-The location plan **Figure 4, 5**-The “Tevhid-hane”, 1997 and wooden “selamlık” 2018.

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**Figure 6**- The mansion and tomb, 2018. **Figure 7, 8**- The mansion and Şeyh’s house, 1990 and the ramp, 2018.

## 2 BRIEF HISTORY

The “Kadiri Tekkesi” was built through a philanthropic individual named Hacı Piri in 1630 who donated his own land to Şeyh İsmail Rumi who had founded the Rumi branch of the Kadiri Sect[1]. In a fire that broke out in Tophane in 1765, the “Kadiri Tekkesi” burned and was rebuilt in 1766 by Sultan Mustafa III. Unfortunately in another Tophane fire that broke out in 1823 the “Kadiri Tekkesi” buildings again burned and were completely destroyed. Sultan Mahmud II had the “Kadiri Tekkesi” rebuilt the same year in 1823. During the reign of Abdülhamid II in 1893 the “taamhane” (dining hall) section and the şeyh’s house[2] were added to the “tekke” and in 1894 the “tevhid-hane” and mansion were partially restored and repaired[3] [3].

In the Republican period after 1925 when the “tekkes” and dervish lodges were closed, the “tevhid-hane” was used only as a mosque and the mansion was used as the residence of the “Kadiri şeyh” and his family [4]. In a fire that broke out in 1997 the wooden parts of the “tevhid-hane” and the “selamlık” area completely burned down (Fig.9). The fire spread to the mansion and the “cihannüma” (attic floor), and the main living floor (first floor) of the mansion were partly ruined. The mansion the same year was repaired through the effort of the şeyh’s family and, while the roof was enclosed, it was prevented from being more ruined (Fig.10, 11). It is

[1] For this reason the tevhid-hane in the “Kadiri Lodge” in the past was known as the Hacı Piri Mosque after the name of the person who donated his land which was a garden as the part used today as the mosque. It is known that in the Byzantine period the St. Makaveon Church was here [3].

[2] The Şeyh’s house was built for the 16th Şeyh Ahmed Muhyiddin Efendi of the “tekke” [4]. This house is a two-story, wooden-framed building. The facade’s formation is different from the facades of the mansion and on the wood-shuttered windows there are triangular pediments.

[3] On the wall on the east of the road with the staircase, there is a ”tuğra” (signature) of Sultan Mahmud II who rebuilt the “tekke” and the other “tuğra” of Abdülhamid II who repaired and added new parts is on the arch of the courtyard entry door [3] .

understood, relying on the Pervititch map, that the "taamhane" and "gusulhane" for ritual bathing which were known to have existed in the past were in ruins in 1927; however, it is not known when they were torn down.



**Figure 9-** "Selamlık" after 1997 fire. **Figure 10, 11**-Mansion, Şeyh's house and entrance of the mansion, after 1997 fire.

## 3 ARCHITECTURAL FORMATION OF THE KADIRI LODGE MANSION

The mansion which is known as the "meşruta-hane" where the "Kadiri" şeyhs' families sat together in the "Kadiri" lodge largely protected its particular characteristics from the first half of the 19th century when it was built until the present. The mansion wasn't damaged in the earthquakes of 1894 and 1999 that Istanbul experienced; however, because it was wooden it was partially destroyed in the fire that broke out in 1997.

The mansion is a building that is three-stories and in addition has a "cihannüma" floor on the roof. Because of the slope of the land it is perceived as three stories or as two stories (Fig.12, 13). The building's entrance floor has been settled on a level on which the sloping road in ramp form rose from the "Kadiri" Yokuşu (Fig.14). From this level one enters the mansion's entry floor and below this floor is the basement floor that opens on the harem garden while above is the first floor which is used as the main living floor and part of the attic floor. In the southwest corner of the mansion is the masonry "tevhid-hane" and in the southeast corner is the two-story wooden-framed şeyh's house; on the north is the one-story masonry "hamam" and cistern, and on the west is the harem garden with a pool. Between the mansion and the tevhid-hane there are passageways on the ground floor and first floor level and between the mansion and the first şeyh's house at the ground and basement floor levels there are passageways. Likewise a tie exists between the tevhid- hane's ground floor and the first floor of the şeyh's house. From the basement floor of the mansion a passage way is provided to the hamam and an exit to the harem garden.



**Figure 12-** Mansion from the west, 2018. **Figure 13, 14**-Mansion from the east and the ramp with stairs, 2018.

### 3.1 Plan Characteristics

The main floor of the mansion for living (first floor) has the plan type of a central hall (Fig.15). In each of the bevelled corners of the central hall there is a room, in between the eastern and western rooms there are the extensions of the hall; “eyvan”s (alcoves). In the western “eyvan”, a three flight staircase is located and it provides the communication between this floor and entrance floor. On this floor two semi-circular balconies that were the same width as the side arms of the staircases were partially carried straight on the side arms. On the north and south of the central hall out of necessity in place of the “eyvan”s, there are corridors that stretch in front of these places with lavatory, room and staircase places. Thanks to these corridors that were created secondarily outside the hall which was the place for passing and gathering, there were the sections used in the mansion’s north as the “harem” and in the south as the “selamlık” areas.

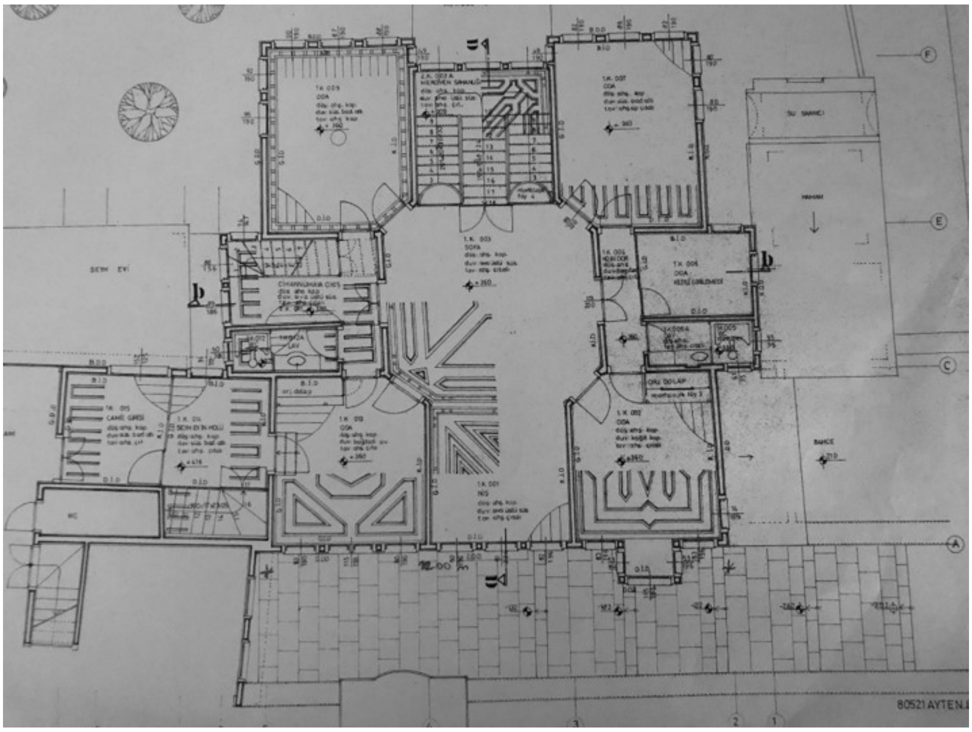

**Figure 15-** Survey of the main (first) floor (1980).

The entrance (ground) floor has the same plan design as that of the main floor for living (Fig.16). However, the entrance hall while the central hall’s east “eyvan” was separated from the hall with a wall (Fig.17). On this floor too one sees that the north and south “eyvan”s were closed to the hall in front of the room and lavatory places that were placed against the “eyvan”s; secondary corridors were found that paralleled the hall wall. The stair place which is inside the western “eyvan” and begins from the entrance floor has two arms on the sides as far as the landing level and after the landing level it goes to the main living floor as a single arm in the centre (Fig.18, 19). The room found in the southeast corner of the hall both provides the connection with the “tevhid-hane” and the “şeyh’s” house and descends to the basement floor by the staircase here. As for the second staircase that descends in the basement floor it has been settled on the entrance hall. As for the kitchen area that stretches as far as the garden wall in a projecting part in front of the western “eyvan”, it is understood that it was a portion added to the plan design afterwards.

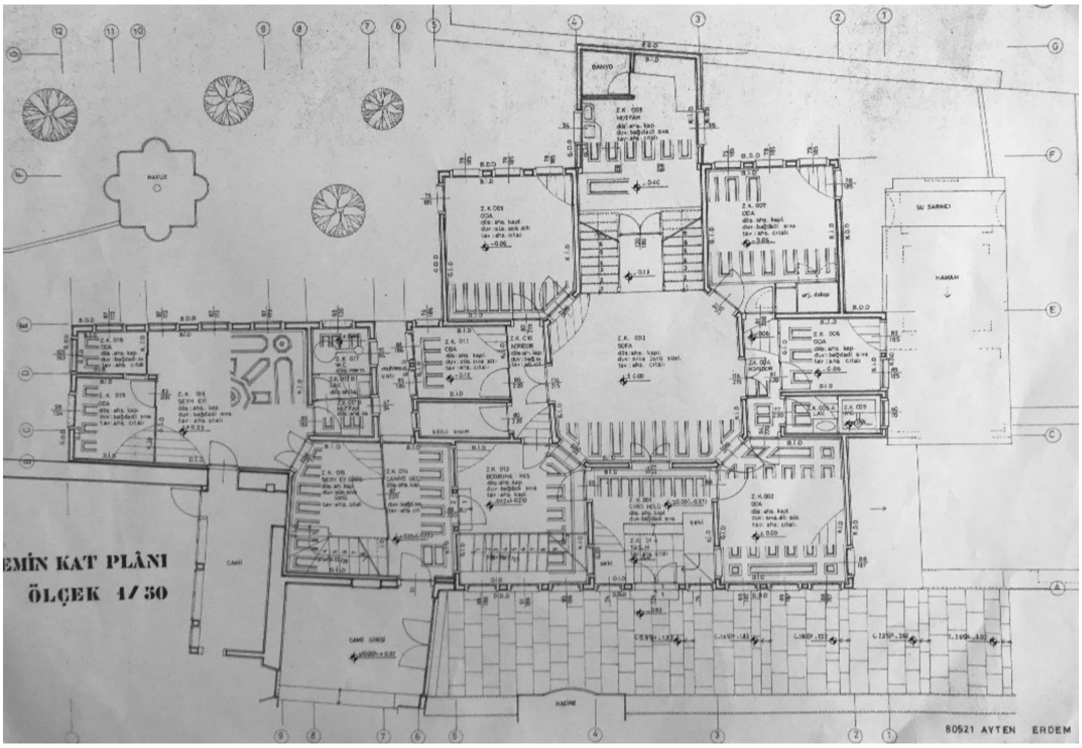


**Figure 16-** Survey of the entrance (ground) floor (1980).

  

**Figure 17, 18, 19**- The eastern and western side of the ground floor hall and the balcony of the stair place, 2018.

The attic floor is made up of two rooms that have placed back to back in an east-west direction and a balcony that is in front of the room on the west (Fig.12, 21). The balcony was enclosed with coloured glass and metal joinery at an unknown date but probably at the beginning of the 20$^{th}$ century. It is thought that the kitchen and toilet spaces which are found adjoining the south side of this floor were added.

The basement floor plan has the central hall and four “eyvans” in a form that suits the floor design of the upper floors (Fig.20). The basement floor and the harem garden are at the same level; as for each of the rooms in the northwest and southwest corners. In the western “eyvan” there is a door that exits to the garden. The exit staircase to an upper floor is inside the east eyvan and from the south “eyvan” one passes to the ground floor of the “şeyh’s house” and from the north “eyvan” one passes to the “hamam”. The “hamam” is a one-story, stonewalled structure in two parts and with a wooden roof; in the west there is a vaulted cistern.

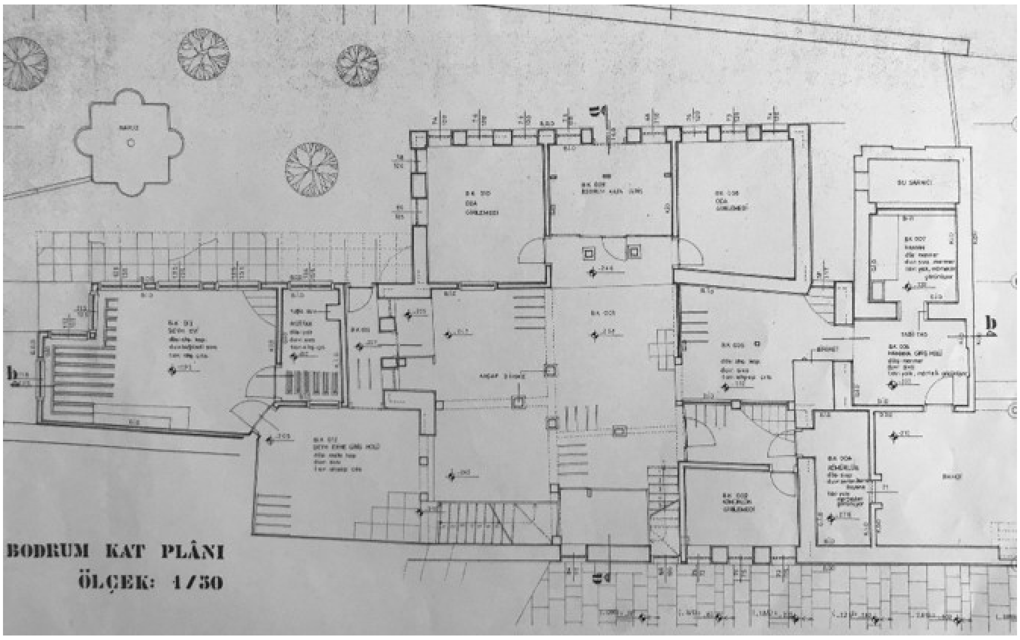


**Figure 20-** Survey of the basement floor (1980).

### 3.2 Construction System

The mansion was constructed with the basement floor of stone rubble and the other floors were built as a wooden structure (Fig. 21). At the basement floor level the 50-centimeter thick stone rubble created the external contours of the building. The interior partition walls of the rooms that were placed on the garden side were built as a wooden-framed wall 17-18 cm thick. As for in the places that came under the partition walls of the entrance floor, wooden posts and girders that sat on stone pedestals as carriers. Only on the north and southwest stone walls of the basement floor window spaces with brick arches were created. The ground floor covering of this floor was Malta stone and the ceilings were covered with lathed wood.

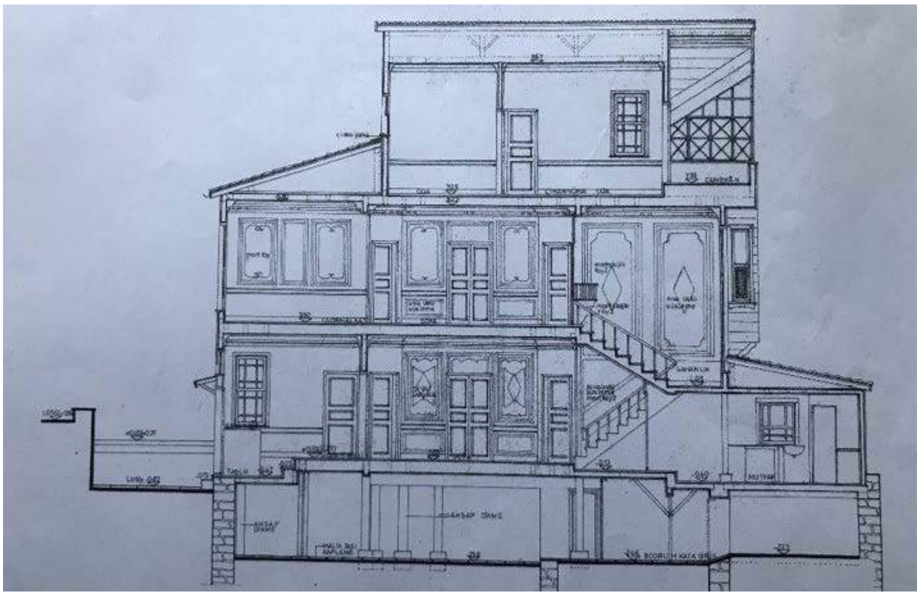

**Figure 21-** A-A section, survey (1980).

All of the walls except for the basement floor main walls are constructed with wooden- frame system. From the inside the wooden-structured external walls are plaster on split wood; from the outside it is covered with horizontal wooden boards. Both sides of the interior walls were plastered while the split wood was being nailed down. On the main living floor in the "eyvans" and in the rooms found in the northeast and southeast corners and in the central hall there are geometrically designed wooden ceilings (Fig. 22); in the southwest corner room, decorated brackets and bed moulding ceiling were used and as for in the other parts covered board-and-batten type ceilings were used. As for the entrance floor, all the ceilings were made in the covered board-and- batten style (Fig.23). The floor coverings which were made of wooden joists were board covered. Entrance to the rooms was provided by single wing doors and to the corridors double-winged, panelled doors. The entrance floor and the first floor's room and hall walls were decorated with painted decorations (Fig.24); however, today the designs can't be determined because whitewash has been applied to the decorations in some rooms. The building has been covered with semi-cylindrical tiles on the hipped roof.

**Figure 22**- First floor hall (1980)

**Figure 23, 24**- Ceiling and painted decoration in the entrance floor hall.

### 3.3 Facade Characteristics

The mansion's showiest facades are the east facade where the entrance door is found and the west facade where the staircase "eyvan" is reflected outside. All the facades with the exception of the basement floor have been covered horizontally with wooden materials. The east (entrance) facade is perceived as two-storied, the west facade as three-storied and the other facades are seen as partially three-storied; the "cihannüma" floor rises from the middle of the four hipped roof with semi-cylindrical tiles. All the facades have been covered horizontally with wooden materials; a wooden strip which is a little below the eaves level has encircles horizontally. One sees that the roof is without eaves.

On the eastern (entrance) facade at the level of the main living floor, the room on the right side carries to the road with a bay window that has been placed right in the middle (Fig.25-26). On the facade where the threesome and rectangular window organization dominated, at the main living floor level the windows in the middle of the threesome group are double arched in the rooms that were different from the others and in the hall it is arched. On the ground floor too it is seen that with the entrance door in the centre of the facade the windows on the two sides of the door are arched. It is understood that the original window woodwork was sliding (hung) wing and every wing with the help of the half-batten in different dimensions were separated into nine sections. It is thought that the wooden lattices that exist in the building's ground floor windows were on all the windows in the past.

**Figure 25:** Survey of the entrance (eastern) façade, 1980.

**Figure 26**- Entrance façade, 1997.

**Figure 27**- Survey of the western facade of the mansion (1980).

**Figure 28**- Western facade (2018)

The western facade is pointed towards the harem garden and Tombaz St (Fig.25, 26). It is seen that the rooms on both sides of this facade has projections at the main living floor level and the projections are supported by wooden cantilevers. The room windows are rectangular and the “eyvan” windows are both arched and made higher than the room windows. The attic floor’s enclosed balcony appears in the forefront with wooden eave decorations in the art nouveau style and with a glass facade.

Because the building's southern facade partially became attached to the "şeyh's" house and the mosque, it isn't totally visible. The north facade too is attached to the "hamam" at the basement floor level and it is opened to the outside with a few windows.

## 4 CONSERVATION PROBLEMS OF THE LODGE MANSION

The "Kadiri Tekkesi" buildings were rebuilt according to the architectural style of the period in 1823; the new buildings that were added and built according to the architectural style which was fashionable in 1893; and the repairs, largely protecting their characteristics, would come towards the end of the 20$^{th}$ century. In this period, the "tevhid-hane" and the mansion as a headquarters and family residence continued their original functions. A short time later after rebuilding and repairing, the earthquake of 1894 which was one of the most violent of Istanbul city's earthquakes occurred and it is claimed to have registered nine in force. The buildings that could be saved from this violence were wooden structure buildings [5] and as a result the "Kadiri" lodge mansion also remained standing because of its construction system. Relying on the survey of the mansion conducted in 1980, it is possible to say that it has not undergone very important changes up to this date; however, one observes that some window woodwork was renewed, the kitchen was added, the attic's balcony was enclosed with a metal-work window, a wooden division between the staircase eyvan and the central hall separated the one from the other, painted decorations found on the walls of some rooms had been covered with whitewash and the lathed wood of the ceiling of the room found in the southeast corner of the main living floor had been destroyed.

In 1997 in the fire that broke out because of electric contact in the wooden "selamlık" section that wrapped a portion of the "tevhid-hane", the wooden parts of the "tevhid-hane" and the "cihannüma" (mansion's attic) floor completely and the ceilings of main living floor partially were destroyed. Because it was winter time the "Şeyh of Tekke" had emergency repairs carried out through his own initiative. During this repair that was done without the approval of the Preservation Council and the Foundations Directorate, the elements that were destroyed because of the fire were not made in their original form (Fig.29-31). Separately characteristics that still existed in spite of the fire were changed. For example on the facades the covering board used was narrower, the roof that didn't have eaves was built with eaves and the mouldings which was a little below the level of the eaves was destroyed.

Right after this repair, Istanbul experienced the 1999 earthquake of 7.4 in strength but the mansion succeeded in remaining standing because of its being a building with a wooden frame. However, the building that has survived until today has not been newly repaired and the damage that the fire and unconscionable repair gave to the mansion has not been removed.

**Figure 29, 30, 31** - Central hall and northeast room of the main floor and "cihannüma" after the 1997 repair.

## 5 CONCLUSIONS

The “Kadiri” Lodge mansion is one of the examples typical of 19th century houses. The central hall plan type used in the mansion is shown as the latest development of the Turkish house plan type. In the plan organization large rooms being found in the corners, “eyvans” alongside small rooms, lavatories and secondary corridors being placed between these rooms, the use of staircases with three arms and the staircase being completed with small balconies are characteristics specific to the houses of this period. Not finding cabinets used for storage in the rooms is the sign of the beginning of furniture being used in traditional houses. Separately, not finding a fireplace, the raised platform, and the ceilings made of covered boards and battens and modillion show that the Turkish room has been distanced from the classical order and shape. As for on the facades of the houses of this period and because of it the “Kadiri” mansion, the top windows have been removed, the windows have been lined up in group form, the hall windows have been differentiated from the room windows in form and height, in place of window shutters the use of lattice has come to the fore and it seems that the facades’ quality of wall construction has been hidden by being enclosed with wood planks.

The number of wooden buildings in Istanbul today that have survived, especially the 18th and 19th century houses, is very few. The “Kadiri” mansion which is one of those buildings and the particular values we have discussed above have been able to survive very violent earthquakes for 195 years through its wooden frame construction system. As a conclusion, in order to pass the particular characteristics of the mansion which is in a rather dilapidated condition today to future generations, it is recommended that it be repaired in a knowledgeable way on an emergency basis.

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# DOCUMENTATION OF CONSTRUCTION TECHNIQUES AND CONSERVATION PROBLEMS OF AHMET CELALEDDIN PASHA MANSION BUILT IN 19$^{TH}$ CENTURY IN ACIBADEM, ISTANBUL

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**Keywords:** Timber Frame, Mansion, 3D Digital Modelling, Istanbul, Vertical Brace, Without Infill, Earthquake

## Abstract

*Ahmet Celaleddin Pasha Mansion, built in the last quarter of the 19$^{th}$ century, is located at the Anatolian side of Istanbul, in Acıbadem district. The building is one of the best and most qualified example to reflect the architectural features and timber construction techniques of its era. Despite some user interventions and conservation problems due to the weather conditions, authentic architectural details of the building are preserved. Since one of the main reasons for deterioration of the structural integrity is earthquakes, no determinable decays have been observed from outside due to the 1894 and 1999 İstanbul Earthquakes.*

*In this research, Ahmet Celaleddin Pasha Mansion has been documented firstly by the analysis of its construction techniques and materials (the vertical and horizontal timber frame structure, the exterior and interior architectural features, staircases, balconies and superstructure). Afterwards, the analysis was converted to 3D digital modelling. The aim of this study is to understand the mansion's structure and to compare it with the construction techniques and architectural features of the 19$^{th}$ century traditional timber-framed houses in Istanbul. In this context, the mansion was measured through conventional and optical measurement methods, visual observations and photography. In addition, 3D digital model of the timber structure was created using a licensed drawing program. The parts that can not be observed from outside are drawn from parts which are clearly seen through the damaged parts of the structure and arranged according to the determined axle dimensions. These differences are indicated on the 3D digital model.*

*Another aim of this study is to, with the help of the 3D digital modelling, identify the positive features of the construction techniques of Ahmet Celaleddin Pasha Mansion that are instrumental to its earthquake resistance while taking its traditional timber framed systems into account. It is expected that 3D digital model will contribute to the restoration process while preserving its authentic architectural characteristics by using the contemporary conservation principles.*

## 1 INTRODUCTION

The timber-frame house tradition has continued in Istanbul until the first quarter of the 20$^{th}$ century thanks to its simple construction details, easy constructibility, adaptability of the changing art style of the era and its being a suitable structure design for earthquake zones [1]. The fires in the Ottoman period, the modernization movement and regulations after the Imperial Edict of Gülhane in 1839, and timber being more susceptible to biological deterioration led to a change. The timber-frame structures gave way to masonry techniques widespread for residences built in İstanbul. As a consequence of immigration movements in 1950 and a change in property ownership laws in 1965, reinforced concrete became the preferred construction system.

Historically, many timber-frame houses have been built in Istanbul; specifically on the banks of Bosphorus and Golden Horn, in Prince's Islands and in the Anatolian side summer residence districts, according to changing artistic styles and traditional construction techniques. Acıbadem district is one of the places where the tradition of timber-frame buildings of 19$^{th}$ century can be seen. It is located on the slopes overlooking Bosphorus in the Anatolian side and were visited frequently by sultans for hunting and entertainment purposes. Due to the development movements in the 1960s, Acıbadem lost its “residence district” character due to an ever-increasing population, the new transportation networks and land subdivision [2]. As a result of the changing economic and cultural conditions, timber-frame house has left its place to reinforced concrete apartments and residence.

A restoration project is being developed as a part of an ongoing postgraduate thesis for Ahmet Celaleddin Pasha Mansion which is a qualified examples of timber-frame mansions built in a grove in Acıbadem district. The mansion has been exposed to atmospheric, biological deterioration and interventions but it survived until our day. However, no documents on how the mansion was affected by the earthquakes of 1894 and 1999 were found. In this study, the load-bearing system was investigated and positive features of traditional timber-frame construction were identified.

## 2 EVOLUTION OF TIMBER FRAMED STRUCTURES IN 19$^{TH}$ CENTURY

In the first half of the 19$^{th}$ century the timber-frame system changed as a result of the utilization of steam powered parallel blades in the United States and Western Europe as well as the improvements in technical and industrial developments [3]. A timber-frame without infill, which is closely placed thin vertical braces, had been used and proved more resilient than timber-framed building with adobe or brick infill (*hımış*) and this change took place in the last quarter of the 19$^{th}$ century in the timber-frame system in Istanbul [3]. This system is defined as one of the traditional Turkish timber residential construction techniques expressed by Langenbach. He defined this technique as ‘*100% timber with closely spaced studs and joists covered on the exterior with sawn wood cladding and on the interior with lath and plaster over a hollow wall*’ [4]. As Acar emphasizes, Langenbach mentions that this system is similar to the ones in the USA and Canada [5].

Timber-frame house without infill is more prevalent and can be seen in Göztepe, Yesilkoy, Bakirkoy, Kızıltoprak, Erenköy, Bostanci and Prinkipo Island districts [5]. Rationalization of the timber frame in Istanbul was a process that started without the industrialization and mechanization of timber production, after the establishment of the Ahırkapı Timber Factory in 1893, this technique was applied to the houses of bureaucrats and merchants in the city [6]. This technique made buildings such as five-storey high Prinkipo Island Hotel in The Princes’ Islands and prefabricated mansions which was called ‘kurma’ mansion [6]. In addition to this, workshops made possible the production of standardized studs, beams, covering planks, window/door frames and decorative timber molding elements [6]. The construction of timber framed walls without infill consisted of a sill, studs and diagonal and vertical braces [6]. The grid-braced timber framed structure has the standard oak studs (cross-section diameter 20x16 cm) resting on the sill were distanced 1,5-2 m. from each other and supported with standard diagonal braces, the pine vertical braces (cross-section diameter 5x16 cm) placed 25 cm apart was strengthened with horizontal braces and the system had simple joints with factory-produced wire nails [5]. In low-income neighborhoods, the vertical timber framed system continued with the use of hand-shaped structural elements since the system was cheap and easy to build [5]. However hand-shaped principal studs and carelessly placed thin vertical braces caused uneven distribution of the load through the frame and emergence of a ‘loose and unstable’ against the factory produced studs or braces [3].

Although the construction date of Ahmed Celaleddin Pasha Mansion is not known precisely, it is thought to have been built in the last quarter of the $19^{th}$ century. The documentation showed that the mansion is constructed without infill, vertical timber framing technique. In order to better understand it, the timber framed structure is modeled in detail by transferring it to the digital medium.

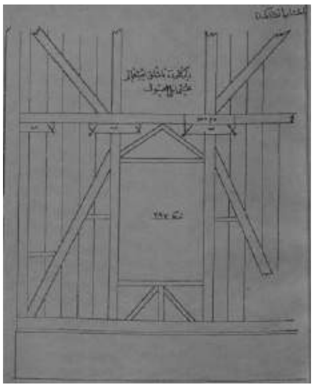

**Figure 1:** Ottoman timber frame with closely placed thin vertical and diagonal braces [5]

**Figure 2:** Prefabricated timber house Stcherbakoff in Çengelköy (Istanbul), 1955 [6]

**Figure 3:** Ahmet Celaleddin Pasha Mansion, 1955 [7]

## 3 ARCHITECTURAL FEATURES OF AHMED CELALEDDIN PASHA MANSION

Ahmed Celaleddin Pasha Mansion is located in Çilekli Street of Acıbadem district and is built on a sloping land within a parcel of 202,582 $m^2$. The building, which was built as a residence in the last quarter of the $19^{th}$ century, was used as a military service building between 1944 and 1958 and remained out of use afterwards. The surface area of the ground floor is 275 $m^2$ and it is built upon a 150 $m^2$ masonry basement. The surface area of the first floor is measured as 284 $m^2$. Although the construction system and materials of the building had serious deterioration, the spatial design and construction system of the building retained its originality.

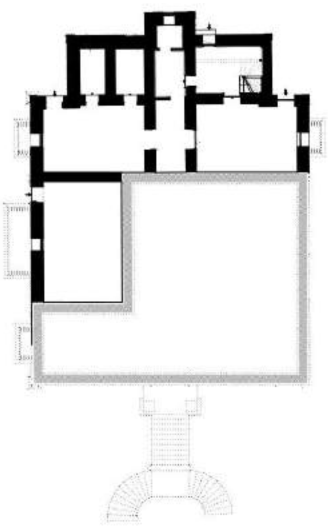

**Figure 4:** Basement floor

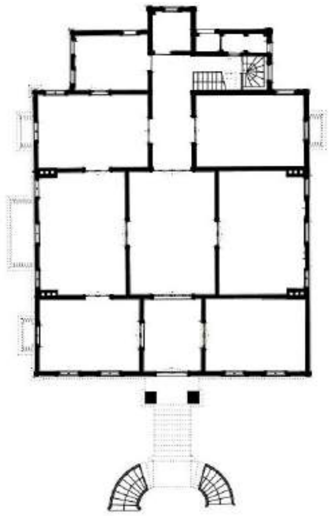

**Figure 5:** Ground floor

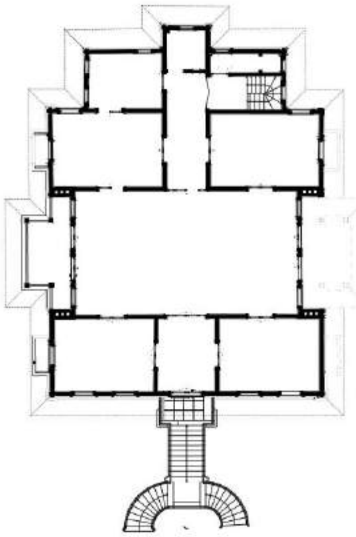

**Figure 6:** First floor

## 3.1 Plan

The mansion has a symmetrical plan with respect to the entrance axis in the east-west direction and there are no oriel in the basement and ground floor. On the first floor, on the north and south facades, there are balconies with rectangular shapes in different sizes. On the ground floor plan, there are three circulation spaces in different dimensions along the axis of symmetry in the east – west direction which have doors connecting them. Western facade of the mansion ends with bathroom and lavatories. To the south of the axis of symmetry, there are four rooms which are connected to each others by doors and circulation spaces. In the south, there are only three rooms with circulation spaces. The unique timber staircase to the north-west of the mansion provides access to all floors. The first floor is designed similarly to the ground floor except for the large room (*sofa*) that leads to balconies on the north and the south facades. The basement can be accessed via the three separate entrances in the western facade of the mansion or by the northwestern staircase which connects all floors. On the basement floor, there are seven rooms separated by unique masonry walls. In addition to these rooms, there is an independent room on the south facade of the entrance, which has no direct connection with other rooms on the floor. It is thought that all the rooms in the basement are designed for service and utility purposes. Along with these, all the rooms on the floors are in rectangular shape although they differ in dimensions and directions.

**Figure 7:** East facade

**Figure 8:** West facade

**Figure 9:** North facade

### 3.2 Facades

Facades of the mansion generally reflect a neoclassical style features. Floors with differences in height are separated by timber moldings. The floors' facades above the plastered stone-wall basement have timber cladding. The marble stepped staircase which is located on the east facade's axis of symmetry leads to the first floor and through the entrance below the staircase it is possible to gain access to the basement directly. In the north and south, the facades are animated through the use of balconies supported by wooden brackets. Marseilles-tiled hipped roof is finished with a large wooden eaves supported by wooden mutules. Wooden guillotine windows and wooden winged doors in the height varying according to the floors are decorated with wooden moldings and the top parts of the windows are highlighted with key stones. Wooden mutules on the facades, the wooden brackets (Figure 10, 11) and the guillotine window details are the same as the ones in the book '*Sanâyi'I İnşâiye ve Mi'mâriyeden Doğramacılık, Marangoz ve Silicilik İ'mâlâtına Âid Mebâhis*' written by Ali Talat in 1927. This indicates that in the last quarter of the $19^{th}$ century there is standardization in the architectural features [8].

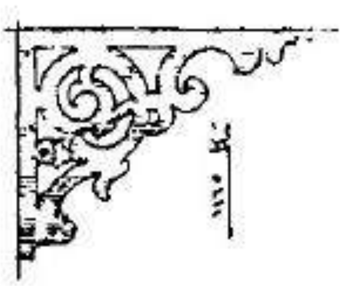

**Figure 10:** Timber bracket [8].

**Figure 11:** Timber bracket of Ahmet Celaleddin Pasha Mansion

### 3.3 Construction techniques and materials:

The ground floor of the mansion is built in traditional masonry construction while the upper floors are built in timber framed structures without infill. In this part, the basic construction elements and materials of Ahmed Celaleddin Pasha's Mansion are described; such as walls, floors and roof. The measurement was taken from the parts of the building where the cladding was lost and fell off from the facade of the mansion.

No evaluation was made regarding the foundations of the building. The basements of the load bearing stone masonry walls have 65 cm thickness and the interior partition walls have 55 cm thickness. The inside and outside surfaces of the walls are plastered. The ground and first floor exterior walls which have 22 cm thickness are covered with timber boards and plastered inside. The both sides of the interior partition walls are lathed and plastered. The thickness of some partition walls is measured as 17 cm. On both floors adobe bricks 9x10x20 cm are used between the vertical braces (4x12 cm) in the bathroom and lavatory area walls. Principal posts of walls in the ground floor have a cross section of 17x17 cm and vertical braces' cross section is 4x17cm. The spacing of principal post and vertical braces differ according to the openings in the facade. The principal posts and vertical braces' rest directly on the masonry wall without the sill. Since the basement is rubble, there is no unique floor covering design. All the rooms are covered with timber floor planks except for the entrance hall on the ground floor and bathrooms and lavatories on the both floors, which are covered with mosaics.

Floor beams on the ground floor are measured as 8x24 cm or 8x26 cm. All the ceilings are covered again with timber boards except for the basement and the ground floor bathroom and lavatory which have plastered and painted ceilings. Ceiling timber boards are painted. Every ground floor space is decorated symmetrically with different geometric-shaped timber laths. The first floor ceilings are painted, coated with gypsum over lath and plaster. The timber structure elements of the hipped roof could not be measured because of the height. The tiles that fell from the roof marked with 'Guichard Freres Seon S' Henri Marseille', were used.

## 4 CONSERVATION PROBLEMS OF AHMET CELALEDDIN PASHA MANSION

Ahmed Celaleddin Pasha Mansion has a qualified construction technique as one of the few timber-frame mansions of 19$^{th}$ century in the Acibadem district. It was officially registered as a cultural asset in 1987 and it survived until today. However, there has not been any architectural documentation effort and no preventive or provisional application has been implemented for its preservation. According to archival researches, in 1955, while it was under the military administration the roof was repaired and the outer facade was painted. At that time, it is known that there was plumbing and electrical wiring in the mansion installed at an unknown date prior to 1955. It has been observed that deterioration due to the interventions is not at a level that would destroy the architectural integrity of the mansion, however, over time, external factors such as atmospheric conditions and biological deterioration have caused serious deterioration in the load-bearing system and materials (Figure 13).

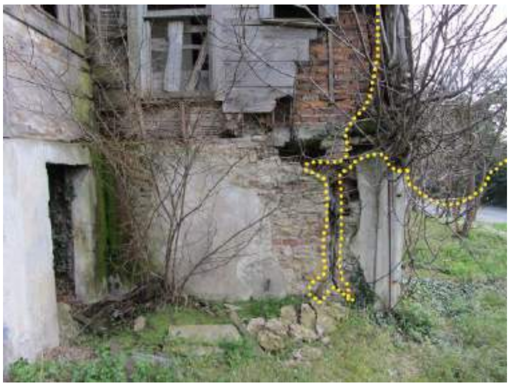

**Figure 12:** Vegetation

**Figure 13:** Biological deterioration

The 25 m2 of the roof in the western part of the structure is collapsed also the balcony and the eave located at the symmetry axis of the north facade. When the roof collapsed, the basement was destroyed and the deviations occurred on the vertical and horizontal load-bearing system. Due to the floor problem in the northern part of the eastern front, there was maximum deflection on the facade. The lack of sill on rubble stone basement walls caused the quick deterioration of the timber principal posts and vertical braces. The internal staircase that provides access to the floors has begun to lose its carrier character due to the weakening structure system. Wood stems and trunks of the plants on the outer surface of masonry walls in the basement to the west and south facades have caused structural cracks in the walls (Figure 12). Ground water in the basement floor and the water coming from the collapsed roof lead to salinization in masonry material and biological deterioration in timber material.

It has been observed that the deterioration of the floor structure, except for the collapsed parts, is mostly due to the deterioration of the timber material. The original wooden floors of the ground and the first floor are covered with 9 cm wide timber floor plank. The original wooden door and window surfaces are contaminated. Most of the glass in the windows were broken. The original sanitary installation and coverings in wet spaces have been replaced with new materials. Due to the electricity and heating system, the installation spaces were opened in ceilings and flooring, and radiators were hung on the walls. The plaster on the wooden ceiling covers is swollen, the plaster on the wall are either peeled off or bloated.

In the eastern part of the north facade, the ground floor and the first floor spaces are renovated using some material similar to the original. The decay that is observed is mainly due to material deterioration caused by atmospheric conditions. Some of timber facades on the ground and first floor have changed during renovations and on almost all of the other parts these surfaces are observed to underwent color changes, pollution, etc . In addition to this, water leaking from the worn surfaces of the timber facade coatings has accumulated in the wood and caused biological deterioration. Some components are missing from the wooden molding, mutules and balcony parapet on the front. The windows are missing the wooden shutters. The authentic balustrade system the entrance stairs was replaced with an unqualified metal one, the marble steps were colored and contaminated, and in some places marble pieces were broken. In the western facade of stone masonry basement, the plaster flaked off due to vegetation, at the other parts plastered surfaces were contaminated. At the parts of the masonry wall the stone or brick surfaces has been worn away. The downspouts made of plastic material and cables on the front also causes visual pollution.

## 5 3D MODEL OF TIMBER FRAMED STRUCTURE WITHOUT INFILL AND ITS EARTHQUAKE RESISTANCE

The mansion preserved its original timber construction and materials even though it faced various natural or human-caused deformations. To be able to better determine the favorable behavior of the timber-frame structures against earthquake loads the structure is modeled in 3d with the help of drawing software in a computer.

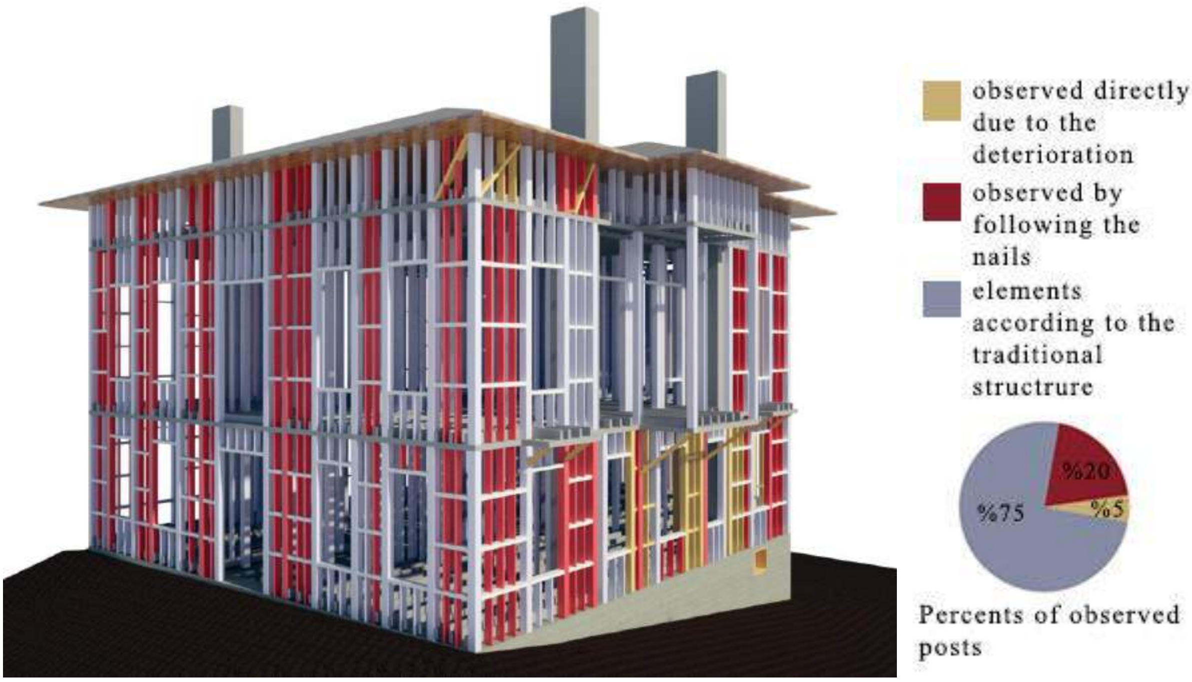


**Figure 14:** 3D model of Ahmet Celaleddin Pasha Mansion

For modeling, it was attempted to determine locations of the principal posts, vertical and diagonal braces from the nails on the timber boards based on observations made and photographs taken on site. Thanks to the missing timber covering exposed the interior of the structure, the cross-sections and spacing of timber posts are measured. Because of the new covering on the original wooden flooring, the location of the nails of the wooden floor beams could not be detected. The floor beams are measured from the settled sections and the direction is determined according to the original wooden ceiling coverings. All these determinations are transferred to the digital model. The posts determined by following the nail tracks are indicated with red, and the posts observed directly due to the deterioration, and the ones placed in places where there should be according to the traditional structure system are indicated with the color blue. 25% of the stud axles of the timber-framed structure without infill were detected.

Studies on earthquake resistance of structures in Turkey mostly take timber-framed buildings with adobe or brick infill (*hımış*). In this study, the positive features of the timber-framed structure without infill, which is closely placed thin vertical braces construction without filling are shown while using results obtained from the limited number of other studies on this topic.

A timber-framed structure needs to have many important features to come together in a harmony to resist the dynamic loads such as earthquakes. Some of these features are a continuous and strong foundation, the quality of the timber elements forming the construction (post and beam, sill, vertical brace and diagonal brace, headings ...) and their joints. It is also necessary to pay attention to the quality of masonry and mortar on the foundation walls or fillings and to the appropriate detail of the timber system on the foundation walls and to the equal and symmetrical distribution of the masses and rigidity in the design and sections. Finally attention must be paid to the place and number of the openings on the walls [9]. If one or more of these properties are not present or suitable for various reasons, earthquake loads may cause serious damage to building, floors, timber frames, filling materials, coating materials, by windows, roofs or floors.

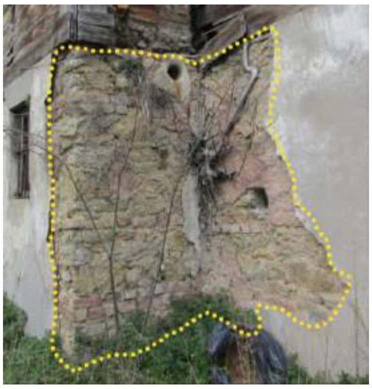

**Figure 15:** Faulty workmanship 1

**Figure 16:** Faulty workmanship 2

In Figure 15 shows that the alternate wall construction with two or three courses of brick in alternation with stone courses is not supported by timber runner beams, but in Figure 16 it is seen that the principal posts and vertical braces sit directly on the masonry wall since there is no timber sill. This situation brings the risk of timber-framed structure slipping from the supports when a sudden load comes at the moment of the earthquake.

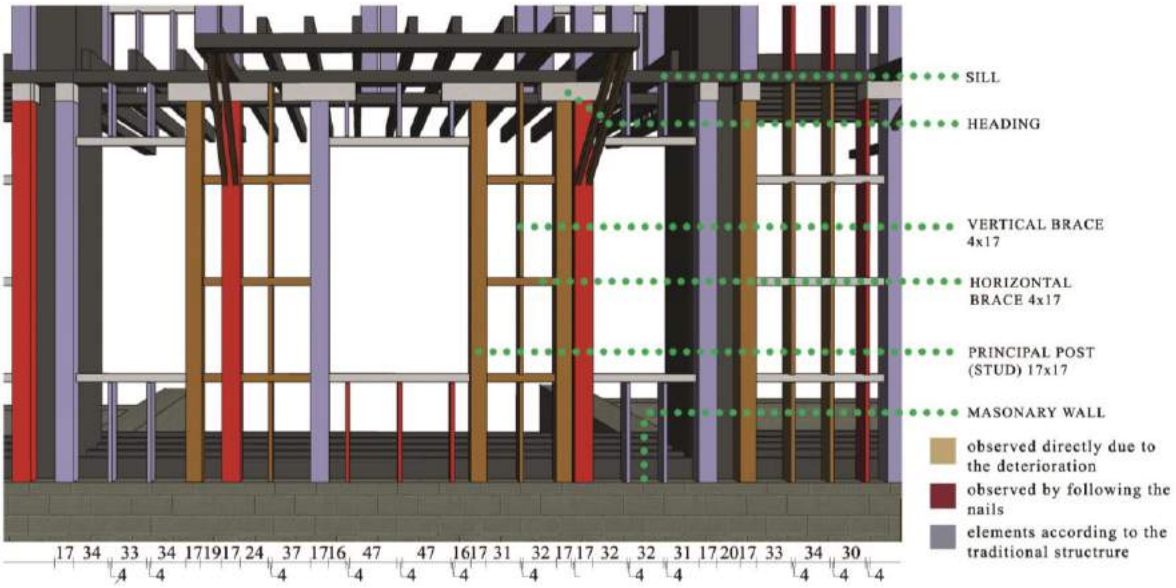


**Figure 17:** 3D model of timber framed structure without infill from north facade

In Figure 17, it was seen that the principal posts of 17x17 cm were placed at intervals of about 110 cm and the supporting vertical braces of 4x17 cm were spaced 32 cm apart in the wall of the without infill vertical braced timber framed structure. While the posts continued along the floor continuously, the vertical braces were supported against lateral forces by horizontal braces of dimensions 17x8x32 cm. The joints were made with iron nails. The timber posts are also connected to the upper floor with timber headings. (Figure 17, 19) The details of the joints have not been determined. However, the details of the joints will be better understood studies made during the restoration. Thanks to these joints, the timber frame absorbs the energy accumulated during the earthquake more than masonry or reinforced concrete buildings and distributes earthquake energy and provides ductility [10]. The timber-framed roof of the mansion is also a favorable feature of the structure against earthquake forces. Since the structure must be able to absorb or stand to earthquake loads from all directions at the time of an earthquake, the plan of construction must be as simple and symmetrical as possible [11]. Ahmet Celaleddin Pasha Mansion's center of mass and center of rigidity are close to each other, thus preventing the effect of twisting.

**Figure 18:** Space ZK-07, timber structure

**Figure 19:** Space 1K-05, timber headings

The balcony on the northern facade of the building which was carried by decorated wooden brackets seen in the photographs of 1988 (Figure 20), was destroyed at an unknown date. Ali Talat expresses decorated timber brackets (Figure 10, 11) are not carriers and should only be used as ornaments [8]. In this example, interventions and faulty workmanship were found to damage the construction system of the structure in addition to the effect of earthquakes. As a result of the abandonment of the building, the chimneys and floors were destroyed due to lack of maintenance.

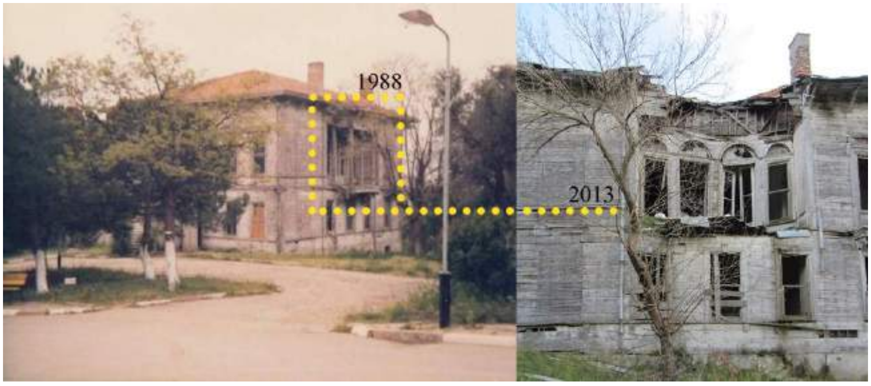


**Figure 20:** North Facade

The without infill vertical braced timber-framed structure is more lightweight in comparison to the adobe filled timber-framed structure. It can be built quickly and economically, and is more resistant to earthquakes. After the earthquake of 1894, it is known that without infill timber-frame construction earthquake dwellings were built quickly in the Yıldız Palace opposite the court member's masonry building [6]. Moreover, a timber-framed structure without infill is less affected by earthquake loads because it is lighter since it uses only timber material. Certainly, even in recent earthquakes, not every wooden structure has survived without serious damage, but there are almost no instances where the structural failures of wooden buildings has resulted in fatalities [4]. In addition, the debris after and incident can be removed more easily [9].

## 6 CONCLUSION

Cultural assets are the most tangible and comprehensive instruments that convey the cultures of civilizations to the future. Architecture can tell the stories of the civilizations past and its history lesson; provides us with the knowledge of the people of a certain era, their lifestyle, technical and aesthetic achievements in art, their capacity of workmanship and is an evidence of the extent of their ability to build structures. In this context, when examined in detail, Ahmet Celaleddin Pasha Mansion, which was dated at the end of the 19$^{th}$ century, was found to be one of the timber-framed structures without infill that became industrialized and rationalized after the industrial revolution. In the documentation, the 3D model of the mansion was developed to determine the details of the construction system. The materials used and the construction technique is thought to be the positive features of the timber-framed structure and the main reason why the mansion survived until today without collapsing or receiving any great damage to its structural integrity after the major earthquakes of 1894 and 1999.

While the positive technical features of the mansion, such as being lightweight and having high ductility is good against earthquake loads; timber framed structure have also, some disadvantages, have been revealed by the digital 3d model such as timber posts standing directly on the masonry wall. It is believed that these determinations will directly affect the decision to intervene in the structure system during the restoration. However, to obtain more accurate results, it is recommended to remove coverings by expert architects and restorers and to update the drawings after analysis made for the supporting system, as stated in Article 3 of the Principles for the Conservation of Wooden Built Heritage (2017) [12]. Laboratory tests are also required for material analysis. These test methods should be applied by selecting from the methods specified in Article 2 of the same document. To make the necessary static calculations in accordance with the charter: '*Conservation, reinforcement and restoration of architectural heritage requires a multidisciplinary approach.*' in General criteria of Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage (2003), earthquake engineers and civil engineers who specialize in traditional timber-framed structure should conduct an interdisciplinary study [13]. A holistic conservation approach should be developed for conservation and restoration of the building, while taking into account the principle mentioned in 1.5. '*Restoration of the structure in Architecture Heritage is not an end in itself but a means to an end, which is the building as a whole.'* [13]. In the restoration of Ahmed Celaleddin Pasha Mansion the intervention approaches described in Principles for the Conservation of Wooden Built Heritage (2017) and ICOMOS Turkey Architectural Heritage Conservation Charter (2013) should be taken into consideration. [12,14] During the restoration, in accordance with these principles, the existing original timber elements should be used at the maximum level, and in the cases where it needs to be strengthened, the old parts must be replaced with timber elements of the same size and characteristics. Where necessary, modern techniques should also be used. After the restoration, periodic maintenance and repairs should be done especially for the continuity of timber materials. In order for structure to maintain its continuity value, suggestions should be made for functions that will not harm the original architectural characteristics and will not cause heavy burdens.

The digital model can be useful for buildings whose structure system is damaged or needs to be carefully analyzed in terms of architecture. It is thought that due to the digital model making simulations, calculations of the load transfer in the timber structure against the earthquake and taking right intervention decisions can be possible. For this reason, it is thought that, in addition to the two-dimensional drawings, it will be appropriate to request three-dimensional drawings by the relevant conservation boards, while using modern technologies to prepare restoration projects of large-scale damaged timber structures. In this context, in the precept put forward by Conservation Boards no.660 of 1999, under the heading of the " Principles of preparation of the Survey - Restitution - Restoration projects; it is suggested that in addition to the survey drawings, 3d modeled demonstrations and static calculation should to be included. On the other hand, in our country there is no code (principle) for timber structures. The procedure of analyzing, designing and intervening in a timber structure has to be defined by the regulations will lead to qualified protection and preservation process with due respect their cultural significance.

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# EXAMINING THE POTENTIAL AND LIMITATIONS OF CLOSE-RANGE PHOTOGRAMMETRY WITHIN SCOPE OF FAÇADE IMPROVEMENT

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**Keywords:** Close-Range Photogrammetry, Cultural Heritage, Documentation, Façade Improvement,

## Abstract

*In recent years, point cloud data is often preferred in the documentation of various types of structures such as historical and conventional buildings. Image-based documentation carried out by means of point cloud generated by using Close-Range Photogrammetry (CRP) enables to represent these assets in a realistic way. In this study, documentation was performed with the help of CRP technique in a street called as "Jewellers Bazaar" in Tokat province. Photographs were taken along the street suitable for photogrammetric studies to create surface model. 3D models belonging to the buildings were scaled with the coordinates of the control points marked on the surfaces. Orthoimages that would serve as a base for architectural drawings were obtained by projecting to vertical. These processes were carried out for the buildings on both sides of the street. Thereafter, architectural drawings were made on orthoimages for use in the quantity calculations. The accuracy of the study was investigated by means of field and model coordinates of the control points. As a result of the study, it was determined that CRP method is more advantageous than traditional ones, especially in limited time. However, it was reached that environmental conditions such as amount of illumination available during photography and height and alignment of buildings directly affect the qualitative and quantitative accuracy of the results.*

## 1 INTRODUCTION

Historical buildings are structures that have remained as cultural heritage from the past and documentation of these constructions need to be performed to prevent and transfer them for the future generations. Documentation is also preferred in recent years with the aim of providing an integrity with other structures such as traditional buildings emerged as a result of the cultural disarray with the past. Documentation for making buildings with varied characteristics similar to each other is performed as façade improvement studies.

In parallel with the developments in software and hardware technology, the techniques used in documentation are advancing. At this point, point cloud data is preferred to be able to fully reflect the façade of a structure as completely as possible. Point data in which metric information is included provides precise positioning as well as ensuring a realistic product with the thematic information it possesses. One of the most preferred methods for obtaining the point cloud is the Close-Range Photogrammetry (CRP), which is an optical system. Although it is possible to perform documentation by producing 3D model of surface without using point cloud [1, 2, 3], 3D model can be created with dense point cloud generated from photographs by using image matching algorithms [4, 5]. In addition to such image-based methods, Terrestrial Laser Scanning (TLS), which is an active system, can also be utilized for documentation purposes [6, 7]. In this study, documentation was carried out by applying CRP along a street for the purpose of façade improvement. The products which are the basis for the architectural drawings were produced with the integration of the terrestrial geodetic measurements and photographs taken based on terrestrial photogrammetric principles. Architectural drawings were performed both as planned and current situation. Positive and negative aspects of CRP for documentation studies to be done within the context of façade improvement were revealed.

## 2 STUDY AREA

Study area indicated in Figure 1 is the street called as “Jewellers Bazaar” located in the central district of Tokat province. The study area is located in one of the most central regions of the city. There are also some cultural heritages in the vicinity of the study area.

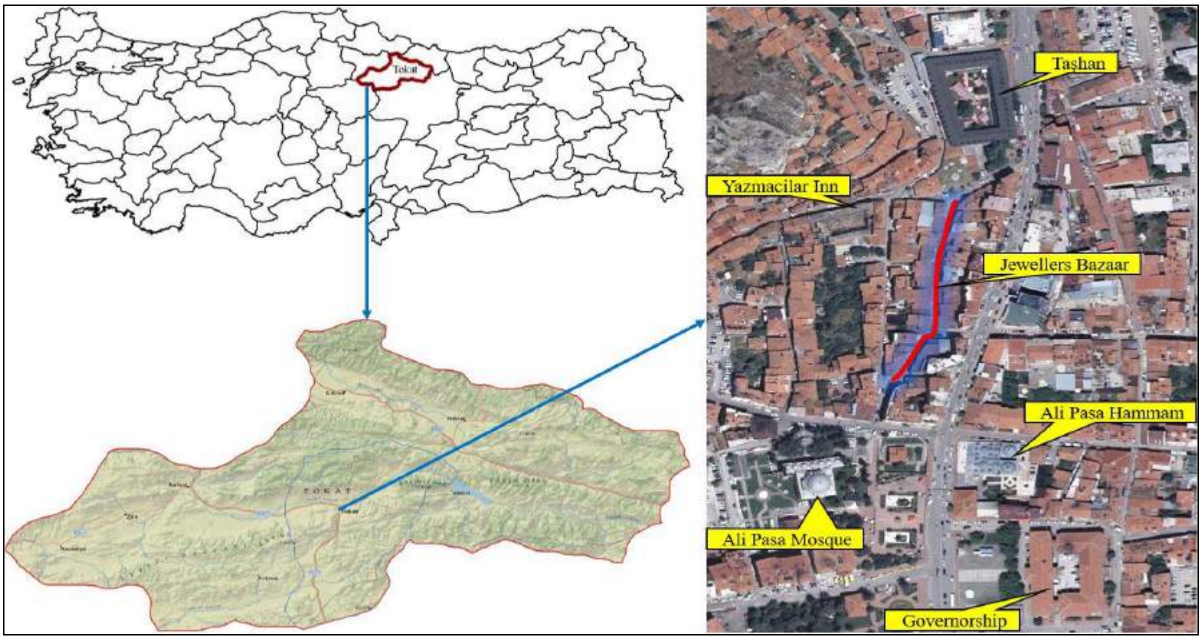


**Figure 1:** Study area

The Jewellers Bazaar houses businesses in varied sectors as well as a large number of jewellers. The street has approximately length of 250 m. There are many buildings at different heights on both sides of the street. There is an irregularity and complexity along the street. Some views of buildings in the study area are presented in Figure 2.


**Figure 2:** Some views of buildings in the study area

## 3 PHOTOGRAMMETRIC APPLICATION

CRP technique was used in the production of orthoimages which are necessary for architectural drawings. A CRP application generally consists of 3 steps as preparation for field work, field work and evaluation of data obtained in the field.

### 3.1 Preparation for field work

Camera calibration process was performed in preparatory phase before field work in order to control whether the camera shows signs of deviation from the values on the instrument prospectus. Each non-metric camera has a shutter release life and it is likely that interior orientation parameters change along with increased photography depending on the usage over time. In this study, used camera for photography is Sony a6000 which is a Digital Single-Lens Reflex (DSLR) camera without mirror system. Although mirrored DSLR devices with larger and heavier body are generally preferred for documentation, it is also possible to use mirrorless ones in photogrammetric studies [8, 9]. The calibration process was realized with the help of calibration object consisting of 100 measurement points and 4 target points. The focal length of the camera was calculated as 16.02 mm (16 mm in prospectus) according to the calibration performed with a total of 13 photographs, 12 from 4 different directions and 1 from the top.

### 3.2 Field work

Field study was carried out for all façades on both sides along the street. A linked traverse network was designed as it would fit the topography of the street. Namely, traverse points were determined according to the curvatures of the street. In this way, geodetic measurements were made directly across the façades. Used total station to measure control points was Trimble M3 DR2. Control points were marked on the surfaces so that at least 3 of them will be visible between two photographs in succession. Both target papers marked on the surface and specific regions like window or door corner were used as control points. Photographs were taken with approximately 80% overlapping rate in both horizontal and vertical directions. Photography was performed with a remote control which triggers the shutter and on the tripod to achieve maximum clarity and to reduce vibration to a minimum level at the time of exposure. Photographs were obtained from the same distance as far as possible for both sides of the street. As in geodetic measurement, movement between two photography depending on the base distance was made considering the topography of the street and the locations of the buildings. General view of traverse points, measured control points, some photographs taken for façades and geodetic measurement are indicated in Figure 3.


**Figure 3:** (left) Traverse points (red) along the street and measured control points (green) and (right) some images for field study

### 3.3 Evaluation of data obtained in the field

Photographs and coordinate information are integrated with each other in order to obtain the final product in the CRP. A 3D surface model of an object is obtained from 2D photographs. The point cloud is generated from overlapped photographs by means of image matching algorithms. The first-produced is weak point cloud which can be also called "conjugate". The latter is the dense point cloud obtained by the densification of the first one. It forms a solid model, referred to mesh model as well, by filling the gaps with the help of interpolation from the closest points. Texture model is obtained by covering the mesh model with photographs. Thereafter, it is scaled by the help of 3D coordinates of control points which are marked and measured in the field. Finally, orthoimages are produced for architectural drawing by projecting to vertical. Commercial software Agisoft Photoscan was used to manipulate and evaluate the data. Nowadays, many photogrammetric software supports the point cloud generation from photographs. Orthoimages, which form the basis for the drawing, were produced separately for different parts. The criterion for determining the parts is the change in the linearity of buildings continuing next to each other.

## 4 RESULTS AND DISCCUSSIONS

Two drawing operations in Autocad software were performed on the orthoimages obtained after the documentation as current situation and planned. Drawings were made on a total of 14 orthoimages separately and merged later. Figures of the drawings are indicated in Figure 4 and Figure 5. Current situation represents the actual status of buildings along the street. It is a linear representation of the complexity and irregularity in the street. Everything on the surface is shown in this drawing to the smallest detail. The planned design represents the what kind of silhouette the street will have after the façade improvement. The planned design is obtained considering the existing situation. So, it is built on the current situation. Therefore, modifications and changes are shown in this drawing. Figure 6 and Figure 7 represents some examples taken from the 3D animation created for the planned drawing. 3D animation is useful in terms of visual interpretation of the study.

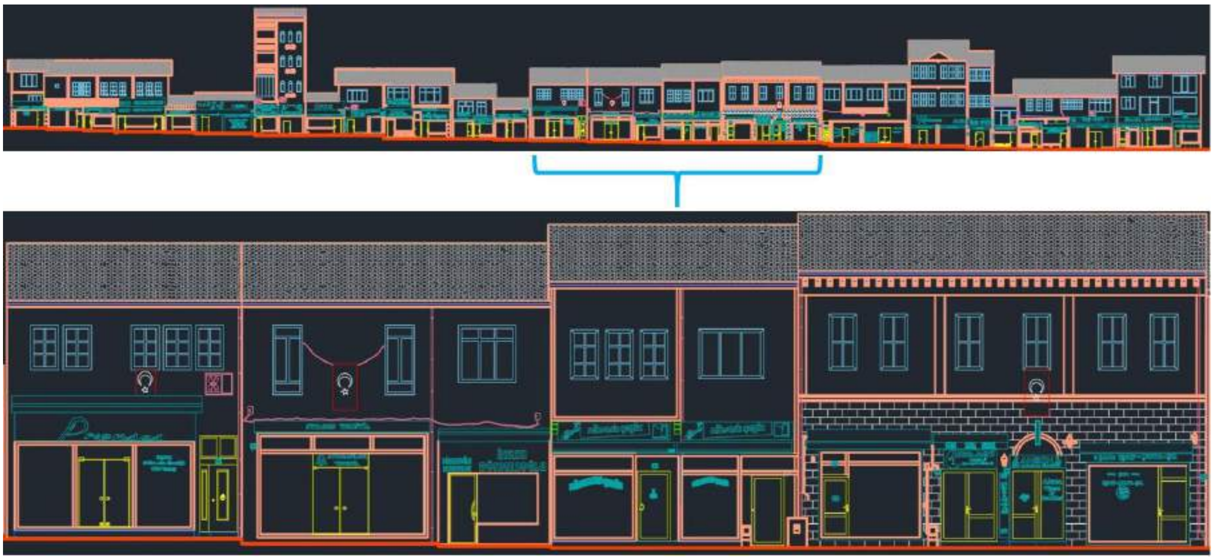

**Figure 4:** (upper) Current situation of right side of the street and (bottom) a zoomed view of a small part

**Figure 5:** (upper) Planned situation of right side of the street and (bottom) a zoomed view of a small part

**Figure 6:** Some views from 3D animation

**Figure 7:** A part of the general view of the street in 3D animation

The accuracy of the architectural drawings depends on the accuracy of the CRP study. The accuracy of the CRP study is assessed by using the raw coordinates of the control points and the model coordinates. The raw coordinates correspond to the measured values, while the model coordinates correspond the correctly accepted values. For the accuracy of the 3D model, the error calculation is performed separately in 3 axis directions. These errors based on differences between raw and model coordinates constitute the model error. There are 14 3D models, 6 of which belongs to the left side of the street, 7 which belongs to the right side of the street and 1 which belongs to the middle façade. Accuracy assessment was made separately for 14 models. Model error values range from 1 cm to 3 cm according to error calculations.

In order to achieve the desired accuracy in terms of both quantity and quality, some conditions must be appropriate for the CRP study. The fact that the photographs of the surface cannot be taken from the suitable distance due to the narrowness of the street affects the accuracy negatively. Additionally, if there is an obstructive object in front of the façade, it is difficult to obtain photographs, and this can cause a mistake in the drawing because the façade could not be reflected as it should be. Moreover, the lack of adequate lighting reduces the quality of the photographs [10]. As indicated in Figure 8, all these factors are available in this study.


**Figure 8:** The time and conditions under which the taking of the photographs performed

There was no possibility to take photographs during daylight hours because of the people crowd on the street during the day. Therefore, photography was carried out at midnight after the shops closed. It was benefited from the light to the extent that the lighting poles located in the middle of the street allow. Sitting benches and sometimes lighting poles were obstructive objects for overlapped photographs. In the photographs belonging the upper parts of the higher buildings, the lighting lamp can be included in the framing. Similarly, sitting benches, dustbins and flowerpots fixed on the floor may be included in the lower parts of the surfaces. Since the street is not wide enough, the required distance was not met in some regions.

## 5 CONCLUSIONS

In this study, documentation procedure carried out by means of CRP technique for façade improvement was examined. Performed documentation was a study required by Tokat Municipality to be completed within a maximum 3 days. When considered as a whole, CRP is more advantageous than traditional methods for studies that need to be completed in limited time. Also, it is possible to intervene against adverse conditions. Photography with decreased ISO value in cases where there is insufficient illumination is one of the most obvious examples of this.

Parts of the buildings that cannot be obtained by CRP the are roofs. Photographs to be taken from the air are needed to eliminate this deficiency. It is necessary to incorporate un-manned aerial vehicles as an aid to the documentation studies. It is very unlikely that building façades in this kind of study area would be modeled effectively by an aerial vehicle. In this respect, CRP to be performed as terrestrial photogrammetry and aerial photogrammetry will be complementary to each other in documentation studies. Apart from all this, TLS technique which provides the similar products with different theory for the same purposes can also be used in such type of studies.

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# A COMBINATION EXAMPLE OF TERRESTRIAL AND UNMANNED AERIAL VEHICLE (UAV) BASED PHOTOGRAMMETRY FOR 3D DOCUMENTATION: ZILKALE

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**Keywords:** Documentation, Digital Photogrammetry, Unmanned Aerial Vehicle (UAV), Computer Vision.

## Abstract

*Three-dimensional (3D) documentation is essential for the maintenance, protection, monitoring of cultural heritage sites. This study focuses on the 3D digital documentation of the Zilkale historical sites which is located in the Rize Province. In this study, 3D digital documentation of this historical structure was carried out with a combination of Terrestrial Photogrammetry and Aerial Photogrammetry. A total of high resolution 692 images were taken using by an Unmanned Aerial Vehicle (UAV) and a terrestrial photographic camera. Evaluation of large number of high resolution images are difficult, time consuming and generally impossible using traditional photogrammetric evaluation software. For this reason, computer vision based digital photogrammetric software which evaluates a large number of images was used. Homogenous control points were established in the study area to increase the spatial accuracy of the photogrammetric evaluation. These points measured by the CORS-RTK method were included in the photogrammetric evaluation process and high accuracy and resolution 3D digital model of Zilkale is generated.*

## 1 INTRODUCTION

Traditional documentation is the production of the simplest form of information about the historical monuments. For this purpose, the geometry is realized in CAD data model on horizontal and vertical axes. This type of conventional documentation is the simplest and clearest representation of the structure. Therefore, information is easily understandable and transferable. Traditional or photogrammetric survey methods were widely used in the documentation process.

Photogrammetry allows to reconstruct and determine the object properties without contact with the objects. Using photogrammetry, the positions and shapes of objects are reconstructed from the images. Photogrammetry is a survey method used for mapping of façades of buildings, determination of cracks, anomalies, deterioration analysis, damage evaluation and deformation studies, state control of structures before and after restoration and architectural studies [1]. However, information obtained from the products in the documentation processes performed with classical photogrammetric approaches is 2D and cannot carry out the information transmission exactly about the structure. Classical photogrammetric platforms require hard office works and expert opinion. With the advances in computer and photogrammetric evaluation technologies, faster, more effective, accurate documentation of cultural heritages can be realized. Classical photogrammetry has undergone a remarkable evolution in recent years with its transformation into ‘digital photogrammetry. Digital photogrammetry is a well-established technique for acquiring dense 3D geometric information for real-world objects from stereoscopic image overlap and has been shown to have extensive applications in a variety of fields.

Different photogrammetric platforms have been carried out to document cultural heritage such as Terrestrial Laser Scanner (TLS) and UAV images. These platforms have advantages and disadvantages relative to each other. In recent years, digital photogrammetry studies have become increasingly widespread with the use of data generated from images obtained by means of UAVs. They were used in different disciplines due to many advantages such as speed, cost and accuracy. UAV supported studies can provide precision in the terrestrial photogrammetry and it is possible to apply many different fields due to rapid data collection and evaluation advantages. Although evaluation of these dense high resolution images is highly difficult, this problem has been removed using of integration digital photogrammetry and computer vision technology.

Although the advantages of using computer vision such as the ability to process, evaluate, and accurately produce dense data, main advantage of it is minimum manpower. By means of computer vision based image processing methods, photogrammetric evaluation processes can be produced with higher accuracy. Moreover, dense point clouds and 3D models are produced in a definite reference system.

In this study; 3D model of a historical castle is generated by using terrestrial and aerial photographs taken by UAV. UAV-images and terrestrial images have been processed using computer vision approach. The accuracy assessment of the produced point clouds has been performed. The obtained total error is calculated around of centimeter, which is sufficient for many studies which are based on these point clouds. Additionally, this study has demonstrated that there is a potential of integrating terrestrial and UAV based photogrammetry for three-dimensional digital documentation.

## 2 DATA AND METODOLOGY

Unmanned Aerial Vehicles (UAV) are defined as motorized air vehicles that are physically non-human. In the past years, use of spatial data generated from images obtained by UAVs studies became considerably widespread in digital photogrammetry studies. Nowadays, all steps can be performed fully automatically from the takeoff to landing in the UAV systems used for photogrammetric purposes. Digital cameras, hyperspectral cameras, thermal cameras and LIDAR systems have been integrated into UAV systems. In this regard, the use of UAV can provide significant contributions to mapping and measurement studies. Thus, contribution of disaster management, natural resource management, harvest estimation, forest inventory, topographic mapping and 3D modeling etc. studies of UAV based digital photogrammetry studies was approved in practice [2].

In today's technology, the resolution of the images obtained from the satellites do not reach the high precision in the image resolutions obtained by using the UAV. In today's technology, the resolution of the images obtained from the satellites are less than the image resolutions obtained by using the UAVs. In this respect, they are alternatives to terrestrial measurement techniques for image precision. Most advantage of using UAV is that they can be used in high-risk situations without risking human life and inaccessible areas. In some situations, UAV are the only alternative such as bad weather, inaccessibility etc. UAV systems perform more narrow data acquisition than the satellite images. However, the high resolution, speed and flexibility offered by the large scale removes this disadvantage [4].

There is no standard workflow for images taken by UAV. These images can be evaluated by classical photogrammetry or computer vision based digital photogrammetric techniques. Although the photogrammetric basis of these methods is the same, the use of different algorithms in computer vision based digital photogrammetric techniques reveals a new point of view in evaluating the data.

Speed, accuracy and miniaturization are the advantages of computer vision based digital photogrammetric techniques which can perform automatic or semi-automatic evaluation with minimum manpower. Nowadays, commercial and noncommercial softwares have implemented its own algorithms for performing the internal and external orientatian, so that the images are geometrically orientated with great success). In order to evaluate the images with computer vision based digital photogrammetric technic software, we start by loading the images with the internal and external orientation parameters defined in the programs. Initial processing, point cloud creation, SYM production, orthophoto production in the form of operations can be continued [3]. General workflow of computer vision based digital photogrammetry were displayed in Figure 5.

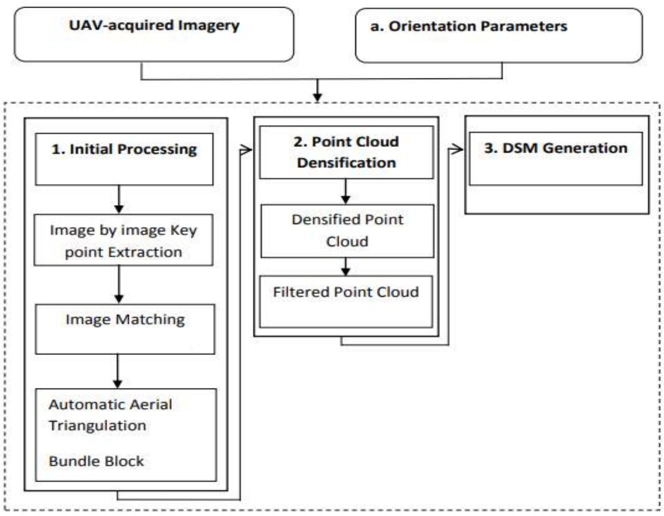


**Figure 1:** General Workflow of Computer Vision Based Digital Photogrammetry [3]

Object recognition algorithms are used in computer vision applications to extract the details of the images. Object recognition can be done with view-based or feature-based. In the view-based object recognitions, image as a template or model of the object is used. Such recognitions are successful under constant conditions. Such definitions are successful under constant conditions. In attribute-based object recognition methods, the approach of extracting the regional attributes of objects independently of the scale is used. Since the extracted attributes are independent of the scale and management of the object, they can be used to match objects or environments that appear at different angles in real images [5].

Stereo image matching is an approach that has been around for years to find matching pixels in the image pair. During the image matching process, the 3D coordinates of the matched pixel are calculated using the interior and exterior orientation parameters of the camera used for image acquisition. Dense point cloud is generated using image matching algorithms. Produced dense point cloud can be classified into Digital Surface Model (DSM), Digital Terrain Model (DTM), Digital Elevation Model (DEM).

## 3 CASE STUDY: ZILKALE

Zilkale is located in Camlıhemsin district of Rize Province in Black Sea Region. It is medieval castle located in the Firtına Valley and it is one of the most important historical structures in the region. Location of the study area is presented in Figure 2. Zilkale consists of outer walls, middle walls and inner castle. It is believed that the castle was built in the 14th-15th century. Because of its history, importance and building structure, it was selected as the study area for documentation using modern tools such as UAV and digital

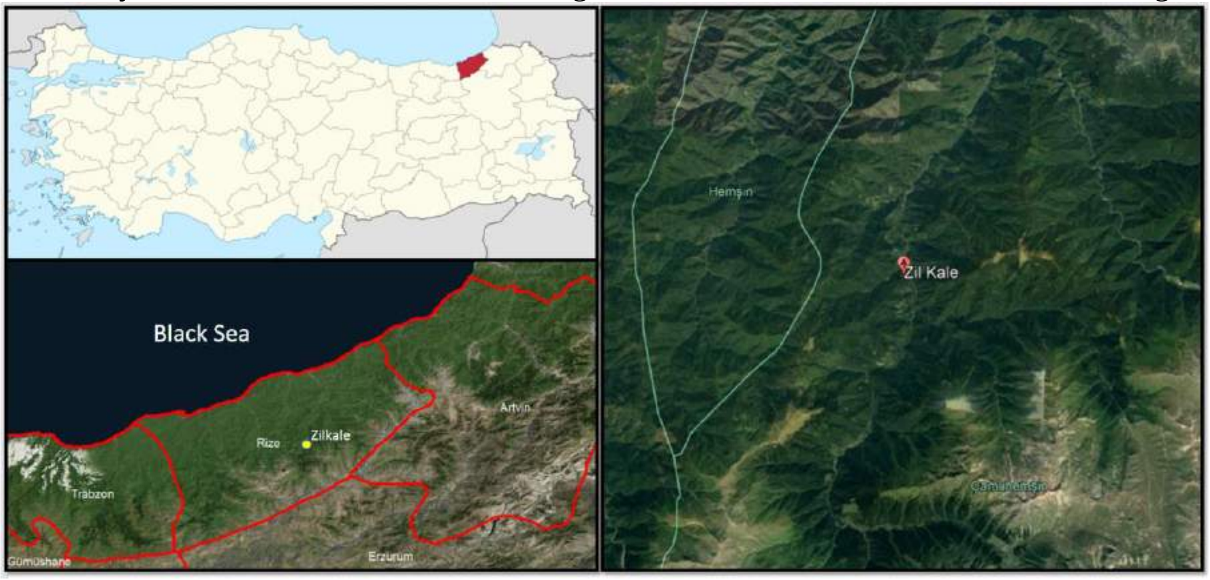


**Figure 2:** Location of the study area

In this study, 5 ground control points (GCP) were placed on the castle walls cover the working area for interior and exterior orientation of photographs taken by UAV. GCPs were designed to be 50 cm x 50 cm in size so they can be displayed clearly during the photogrammetric evaluation phase. In Figure 3, sample of GCP was presented. The GCP zone selection is designed to provide a homogeneous distribution where the view is clear, distant from any object that may cause multipath, and can best be characterized by the characteristics of the study area. Coordinates of these points were collected using CORS-RTK survey method using GPS receiver.

**Figure 3:** Ground Control Point Sample

DJI PHANTOM 4 pro was used as UAV which can perform automatic and semi-automatic flight. PHANTOM 4 is integrated with the GoPro camera for image recording. Used UAV in the study and one of the photographs taken by same UAV have been presented in Figure 4.

**Figure 4:** Used UAV and example of photograph taken by

Technical specifications of the GoPro camera used are given as follows;

*4000*3000 İmage Size
*1/2.3" CMOS sensor
*35 mm focal length
*6mm x 4 mm

## 4 RESULTS

Firstly, for the production of the 3D model of the Zilkale, the extraction of tie points was performed on the images taken by UAV. With the medium accuracy 400 000 key points were produced and the most reliable 10 000 points were selected to be used as tie point. Produced tie points were displayed in Figure 5.

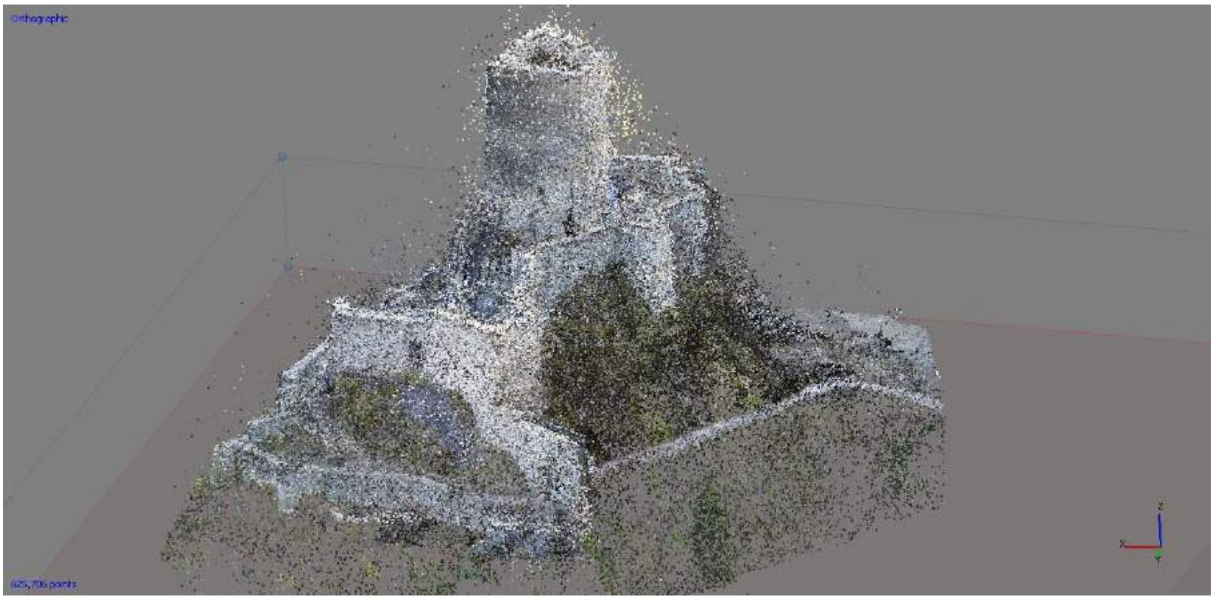

**Figure 5.** Tie points of the Zilkale produced from the UAV based images

In the second step GCPs were replaced on the ground previously were marked on each photographs which cover these points. Using these points interior and exterior orientation were carried out by means of adjustment step. As a result 3D coordinates of each points which are the element of dense point cloud were produced. Produced dense point cloud is presented in Figure 6. In this model, 68 042 734 points were obtained.

**Figure 6:** Dense point cloud and details part of the castle

Applying image processing techniques on dense point cloud textured model was produced. In this model 125 015 faces and 62570 vertices were produced. Draping images on this model tiled model of the historical castle was produced. Produced tiled model is presented in Figure 7.

**Figure 7:** Textured model of the study area

## 5 CONCLUSIONS

This study is presented a case study of documentation of a historical monuments by using of UAV based images together with terrestrial photographs taken by a mobile phone. GNNS surveying technique currently used in low cost UAV (i.e. UAV used in this study), cannot produced the desired accuracy because of their technical limitations. Parallel to the improving technology, if GNNS receiver mounted on the low cost UAV, provide sufficient accuracy, points can be produced with cm accuracy without GCPs. Additionally, if LIDAR systems become affordable and lightened, they might be used with UAV to produce more accurate point clouds. Using all new techniques and methods, producing of 3D documentation of historical monuments will be more effective.

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# COMBINATION OF UAV BASED DIGITAL SURFACE MODEL WITH 3D MODEL OF ITU BICYCLE HOUSE PRODUCED BY CLOSE-RANGE PHOTOGRAMMETRY

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**Keywords:** Documentation, 3D Modeling, Photogrammetry, Unmanned Aerial Vehicle

## Abstract

*Recent developments in photogrammetry have led to a significant revolution in Geomatics Engineering field. Especially, the improvements in the image acquisition techniques have brought a new perspective to produce photogrammetric products such as orthophoto maps, digital surface models and 3D models. In this study, close-range photogrammetric measurements have been done for modeling ITU Bicycle House. Coordinates of control points on surfaces of the building have been determined with surveying techniques and images have been taken with respect to the conditions of close-range photogrammetry. Images have been evaluated in the software and 3D model of the building has been created. In addition, aerial images of the project site have been taken with UAV and a digital surface model of the project area has been created using these images. At the end of the study, the 3D building model has been represented with the created digital surface model. This study has become a proper example for the combination of aerial and close-range photogrammetry.*

## 1 INTRODUCTION

Technological advances of modern era have facilitated various types of engineering applications. Several engineering disciplines have made benefit from these developments. Besides, Geomatics Engineering discipline has improved the ability of obtaining spatial information. Especially, techniques of accessing quantitative and qualitative information from objects has emerged rapidly. Photogrammetry can be accepted as one of these techniques. According to [1], photogrammetry allows one to reconstruct the position, orientation, shape and size of objects from pictures. With respect to this brief definition, photogrammetry science is the fundamental idea behind orthophoto maps, digital surface models, 3D models etc. These photogrammetric products serve different types of engineering applications. For instance, 3D building models are functional for city planning and orthophotos are practical for mapping wide regions. Obtaining 3D models of buildings from aerial or ground based images is a common way of using photogrammetry in the industry. Terrestrial image acquisition is the more preferred technique because of the inaccessibility of building facades from aerial images while architectural modeling.

In this study, it is aimed to bring a solution to the disadvantages of aerial imagery for 3D building modeling. Many studies have shown that, aerial photogrammetry techniques have been inadequate for modeling the building facades because of the insufficient image overlap in low-visibility conditions.

To eliminate this deficiency, close-range photogrammetric measurements have been used to generate 3D model of ITU Bicycle House building. Furthermore, the created model has been shown with a digital surface model which has been produced from UAV based images. This study has proved that, the insufficient view for building facades or building details that cannot be modelled through aerial photogrammetry and can be completed by close-range photogrammetry techniques. These type of combined 3D models are effective, advantageous and practical for sustainable planning and development. Additionally, the final product can be used for emergency management, spatial analysis, cultural heritage documentation and also entertainment purposes when supported with augmented reality technologies.

Through the methods of close-range photogrammetry, specialists can create 3D building models by conducting field survey and image acquisition. In addition, the practical usage of unmanned aerial vehicles (UAVs) enables professionals to create digital surface models and orthophotos.

In this study, 3D modeling of ITU Bicycle House and surroundings using close-range and UAV photogrammetry has been accomplished. Coordinates of control points on surfaces of the building have been determined with terrestrial surveying techniques and images have been taken with respect to the conditions of close-range photogrammetry. These images of the building have been evaluated and 3D model has been created. Using images of the project site obtained by UAV, digital surface model of the area has been obtained. At the end of the study, 3D building model and digital surface model have represented together.

## 2 STUDY AREA

In this study, ITU Bicycle House building in ITU Ayazaga Campus and surroundings were selected as the study area (Figure 1). Ayazaga Campus, the main settlement of ITU, is located in Maslak where is the business and commercial center of Istanbul and covers an area of 247 hectares. The Building is a part of the “Green Campus” project conducted by the ITU Rectorate. This building has become an important facility as a provider of renting, selling and repairing services for bicycle users in ITU Campus.


**Figure 1:** ITU bicycle house

## 3 METHODOLOGY

Recent advances of the computer science have introduced computer vision technology to the engineering discipline. Computer vision can be briefly defined as the ability of acquiring, processing and analyzing digital images by software algorithms.

### 3.1 SIFT algorithm

Professor David G. Lowe from University of British Columbia developed the Scale Invariant Feature Transform (SIFT) algorithm at 2004 [2]. Therefore, SIFT is an ideal feature extraction and matching method for digital photogrammetry (Figure 2). To date, the algorithm has been widely used in robotics, image-based computer graphics, digital photogrammetry, surveying and geodesy.

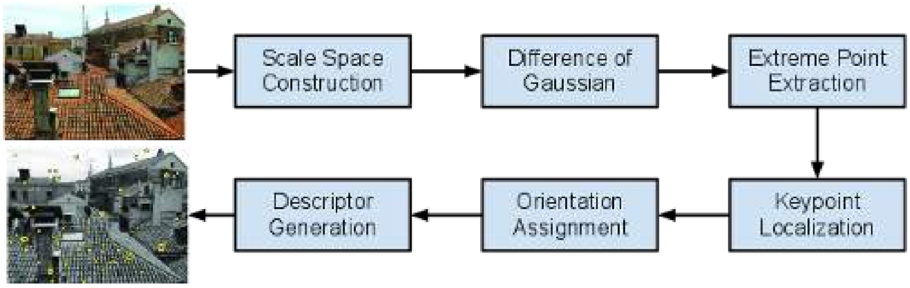


**Figure 2:** Processing pipeline of SIFT

### 3.2 Structure from motion

In recent years, with advances in computer vision and feature-matching algorithms, a new photogrammetric method based on Structure from Motion (SFM) has developed rapidly that requires fewer control measurements and the data collection and processing methods are also more automated and flexible. In classic photogrammetry, the camera positions and orientations or a large number of ground control points with known positions are often required, whereas the SFM method can reconstruct the geometry of the scene and the camera positions and orientations automatically based on the matched features in multiple overlapping images [3].

The main difference between SFM and classic photogrammetry is the use of a new generation of image matching algorithms which allow for unstructured image acquisition. One crucial property of this technology is the ability to recognize conjugate features in multiple images despite the presence of changes in image scale and in view point [4].

Unlike traditional photogrammetry, the camera positions derived from SFM lack the scale and orientation provided by ground control coordinates. Consequently, the 3D point clouds are generated in a relative 'image-space' coordinate system, which must be aligned to a real world, 'object-space' coordinate system. In most cases, the transformation of SFM image space coordinates to an absolute coordinate system can be achieved using a 3D similarity transform based on a small number of known ground-control points with known object-space coordinates [5].

## 4 PROJECT IMPLEMENTATION AND RESULTS

### 4.1 Generation of digital surface model

In this study, Agisoft PhotoScan software has been used for generating the digital surface model. This software and many similar automated software have the capability of generating final products with algorithms running on the background.

Processing UAV image data begins with uploading images into Agisoft PhotoScan and completing the following actions: (1) aligning images, (2) creation of sparse point cloud, (3) creation of dense point cloud, (4) creation of mesh overlay and (5) creation of photo-realistic texture. Subsequent post-editing of the models vary dependent upon the quality of the resulting model.

The first step of generating a digital surface model is aligning images and optimizing cameras to obtain sparse tie point cloud. In this study, the dense point cloud generation process has been performed based on the sparse point cloud which has been generated at the first step (Figure 3). The dense cloud generating step has been done with "Ultra High" quality mode. Agisoft PhotoScan allows user to select different processing quality modes depends on the desired project results. However, decreasing the processing quality of the project will naturally lead to obtaining fewer points at the step of generating dense point cloud.

As a result of missing overlapping images for some parts of the project site, gaps have occurred in the dense point cloud. The point cloud data at such areas have been detected and removed from the final digital surface model. Approximately, 34 million of dense points have been generated from 17,215 tie points. However, this number has been reduced to 17,234,680 in order to reduce the process time of generating tiled model.

**Figure 3:** Dense point cloud of the project site

After obtaining the dense cloud, the mesh building process has been carried out. From this, the target area is divided based on finite point sets to produce a triangular surface mesh where arbitrary points in the region are used to locate the vertex at the side or inside of the corresponding triangle [6].

The triangulated irregular network (TIN) building step has been done at “High” face count mode and 3,446,935 faces and 1,727,180 vertices have been generated. Then, for building texture, mapping mode has been selected as “Generic” and blending mode as “Mosaic (Default)”. Finally, building process of the tiled model has been conducted (Figure 4); the dense point cloud has been selected as source data.

After all, the disadvantage of aerial imagery for 3D building modeling has been detected with this study. Aerial photogrammetry techniques have been inadequately resulted for modeling the building facades. In this study, it is aimed to eliminate this deficiency by using close- range photogrammetry techniques.

**Figure 4:** Tiled model view of the project site

## 4.2 Generation of 3D building model

In this study, close-range photogrammetric measurements and 3D modeling for ITU Bicycle House have been accomplished. Field operations of this study can be grouped into two main categories. These categories are control point measurements and image acquisition.

### 4.2.1 Control point measurements

Measurements of control points have done using total station in a local coordinate system. Two traverse points established in the study area and another traverse point has been produced with direction and distance observations. Three traverse points have been used as station points for measurements of control points. Establishing printed control points on surfaces of the building has not been possible due to the circumstances. Instead of this method, some detail and corner points have been measured without them. The laser distance measurement mode of total station has been used for some unreachable points by the reflector. Consequently, X, Y, Z coordinates of 38 detail points on the building has been determined with using terrestrial surveying techniques.

### 4.2.2 Image acquisition

Image acquisition of the object is a necessary step for generating texture of the 3D model. In this study, all images have been taken with NIKON D300 digital camera. The camera has a 12.3 megapixel CMOS image sensor and resolution of images is 4288 x 2828. Images of the building have taken from 15-20 meters. Also, the image overlap ratio has been considered in this step.

### 4.2.3 Photogrammetric evaluation

Images taken for this study have been evaluated on the PhotoModeler Scanner 6 software and “25” of them have been used. PhotoModeler Scanner provides the tools for creating accurate, high quality 3D models and measurements from images. The software is being used in wide range of disciplines such as Architecture, Geology, Surveying, Biology and Medicine.
Firstly, camera calibration is a compulsory step for such a project. Images of the calibration pattern have been added and the software has determined the interior orientation parameters using these images. After the camera calibration and obtaining the interior orientation parameters, the next step is adding images to the project.

PhotoModeler Scanner allows the user to add or remove images at any stage of the project. For this study, image acquisition has been done at the same time with the measurement of control points. However, it has been noticed that some parts of the building have not been photographed with respect to the overlapping condition. Therefore, new images have been taken and added to the project after another image acquisition session. After adding all images to the project, the process of marking the control points has started (Figure 5).

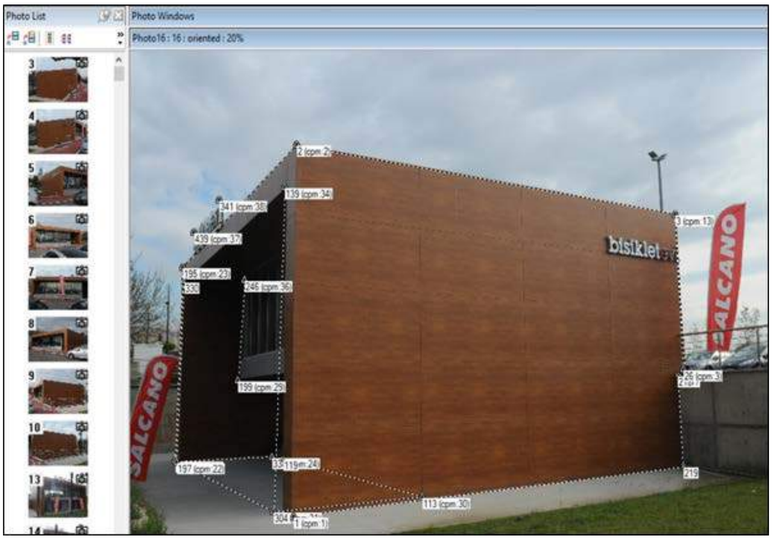


**Figure 5:** Marking of control points

Point file which includes coordinates of control points imported to the project. In order to mark control points, “Mark/Pin Imports” mode has been activated and control points have been marked on each image. After that, point marking residuals have been obtained with “Process” operation. With this operation, software determines the relative positions in 3D space and the relative rotation angles of the cameras. Point marking residual value can be reduced with changing the position of control points in images.

In order to obtain the 3D model, firstly all additional detail points have been marked on each image and referenced (Figure 6). Referencing is the process of showing software that marks on two or more different images represent the same physical feature in space. In a multi-image project, referencing is the key step needed to ensure the project will process properly and to ensure objects get computed with 3D positions. Features must be referenced on at least two images. After all detail points have been marked on images, bundle adjustment has been completed. Then, detail points have been connected and surfaces have been created. These surfaces have been assigned to different layers for better texturing (Figure 7).

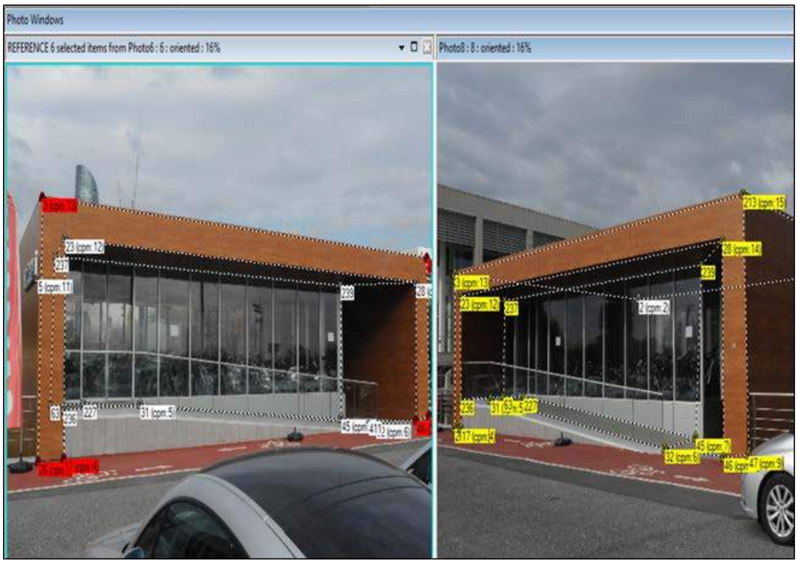


**Figure 6:** Referencing

**Figure 7:** Textured model

### 4.2.4 Generation of combined 3D model

This project consists of a combination of two different 3D models. First model is the digital surface model (DSM) created in Agisoft PhotoScan software with UAV images and the second 3D model is the ITU Bicycle House created in Photomodeler Scanner with close-range photogrammetry techniques. The aim of this study is to combine these two separate models. The models have been combined in Microsoft Windows 3D Builder software that allows the user to view, capture and personalize 3D models. For combining the models, the DSM model and the building model have been exported as ".obj" files and these files have been imported to the 3D Builder software. The models have been adjusted to their exact position in real topography (Figure 8).

**Figure 8:** Combined 3D model

## 5 CONCLUSIONS

In conclusion, obtaining 3D models of buildings from aerial or ground based images is the preferred way of using photogrammetry for engineering applications. Especially, 3D building models combined with digital surface models have important role for digitally visualizing the environment. However, many studies have shown that, aerial photogrammetry techniques have been inadequately resulted for modeling the building facades because of the insufficient image overlap in low-visibility conditions. In this project, it is aimed to eliminate this defi-ciency by close-range photogrammetry techniques.

In this project, close-range photogrammetric measurements have been done for ITU Bicycle House. Coordinates of control points on surfaces of the building have been determined with surveying techniques and images have been taken with respect to the conditions for close-range photogrammetry. Images have been evaluated in PhotoModeler Scanner software and 3D model of the building has been created. Furthermore, aerial images of the project site have been taken by unmanned aerial vehicle and a digital surface model of the project area has been generated in Agisoft PhotoScan software.

Furthermore, the 3D building model has been represented with the generated digital surface model. This study has proved that, the insufficient view for building facades or building details that cannot be modelled through aerial photogrammetry can be complemented by close-range photogrammetry techniques. These type of combined 3D models are effective, advantageous and practical for sustainable city planning and development. Additionally, the final product can be used for emergency management, spatial analysis, cultural heritage doc-umentation and also entertainment purposes with augmented reality technologies. This study has become a proper example for the combination of aerial and close-range photogrammetry.

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