High Rise Adobe Buildings

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ABSTRACT

Adobe material has been used in architecture from past to present. In traditional building materials, it is used in many functions such as carrier element, wall filling, roof cover in the building system. It is widely used especially in rural areas due to many factors such as being easy to produce, low cost, environmentally friendly and healthy. Adobe has been used in both civil and religious buildings all over the World. It has been used as low-rise especially in earthquake zones and in Turkey, but it can also be used as multi-storey in places where there is no earthquake zone.
In the study, the earthquake zones in the World are shown on the world map, and the effects of adobe buildings in earthquake zones are mentioned. Then, especially from Africa, which is not an earthquake zone, to the Djenne mosque, which was included in the World Cultural Heritage list by UNESCO, to the Bobo Dioulasso Grand Mosque and Shibam settlement in Yemen, which is on the UNESCO World Cultural Heritage list, defined as high (5 to 11 floors) in the Arabian Peninsula. In the evaluation section, it has been tried to compare these examples with the ancient settlements that took place in the history of adobe building in Turkey and the structures that are commonly seen today. In the evaluation, the seismicity conditions, the construction years of the buildings and their current usage situations are included. The study was completed by concluding that the adobe structure is long-lasting and the height of the building depends on the earthquake zone.

Keywords: Adobe Building, High adobe building, Earthquake effect on adobe building, Civil-religious adobe building

1 INTRODUCTION

Earth is a building material that has been used for thousands of years with the human need for shelter. Today, it is used in many parts of the world with different techniques and applications. The reason for this is that it is an economical and ecological building material. Adobe buildings are suitable and comfortable for human health and do not harm the environment. With these features, they are extremely sustainable structures and have been used for ages [URL 1].
The mudbrick was built in many civil, religious and official building types and at different heights. Stone is an accessible building material in Turkey, especially in religious and official buildings, stone or stone-brick mixture was preferred in general, and wood was used from time to time. Adobe was mostly used in civil architecture. In the World and in Turkey, adobe is widely used in buildings that are not high. The fact that these geographies are earthquake zones has made it necessary for the buildings to be low-rise. However, high adobe structures can be encountered, especially in countries such as Yemen and Mali, which are not in earthquake zones. The use of high adobe buildings in these regions has developed due to certain environmental conditions, and this development has created very good solutions in terms of meeting the requirements. For example, the reason why the buildings are high in Shibam was developed to create a safe environment against attacks in the region.

The aim of the study is to draw attention to the relationship between the low-rise use of the adobe building, which is generally used in rural areas and is remembered as a low-rise building type, with the earthquake zone. It is to give examples that it is used as multi-storey or high in geographies that do not have earthquake zones.
The method of the study generally includes a literature review. The data obtained by scanning has been transferred with tables and photographs and the relationship between the use of high rise buildings in the earthquake zone and the characteristics such as construction year and height has been tried to be analyzed. Since it is desired to draw attention to the use of high rise adobe structures within the scope of the study, two regions where these structures are used were selected. Within the scope of the study, the architectural, structural and material features of the sample buildings were tried to be included, the castle structures were excluded from the scope of this study. The study was limited to the samples of Africa – Arabian peninsula, which is not an earthquake zone, and other samples from the world were not included in the scope of the study.

2 EARTHQUAKE REGIONS IN THE WORLD AND ADOBE BUILDING

It is seen that the earthquake zones marked in red on the world map are quite high 'Fig. 1'. In particular, it is stated that 90% of the surface area of Turkey is an earthquake zone [1]. Apart from this general feature, geography and the ground feature of the land are of course important and show differences. Depending on this situation, there may be limited areas with solid ground that are in the earthquake zone. Therefore, in this study, general approaches are mentioned and special regions are not taken into account.

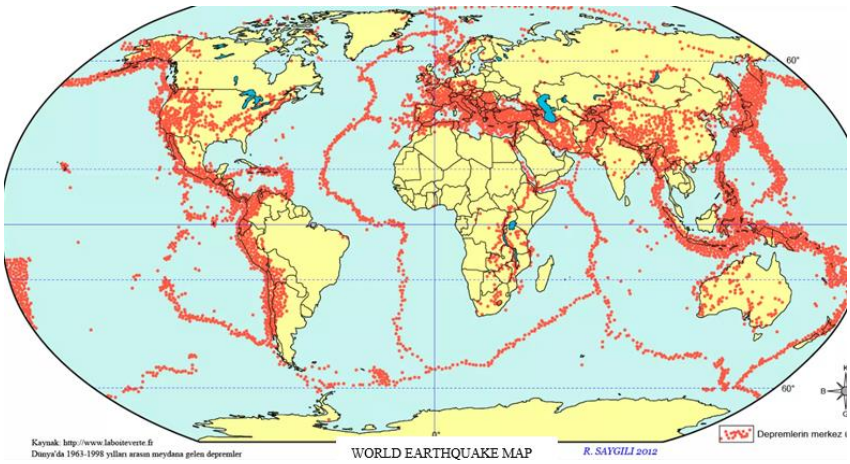
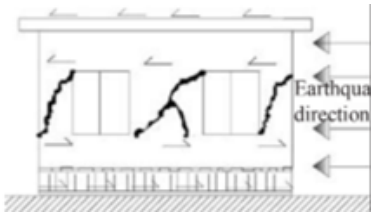
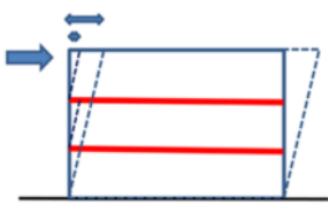


Figure 1. Earthquake epicenters on world map [URL 2]

In Turkey, some measures have been tried to be taken in the construction system in order to reduce the earthquake effect on the buildings. For example, in order to reduce the earthquake load effect that affects the structure laterally, horizontal beams (hatıl) are used in masonry structures [Table 1] [2].

Table 1. Earthquake behavior in masonry structure walls

		
Formation of earthquake damage in a masonry wall [5]	The use of beams in masonry buildings [2]	The amount of earthquake load absorption with beams [2]

Prof. Dr. Bilge Işık is trying to create horizontal fracture planes to reduce the earthquake effect on the wall. For this, a full-size structure was tested on the shaking table with a horizontal friction layer on the load-bearing wall every 40 cm from the ground upwards. And this building had a Shake Table Test performed by the General Directorate of Disaster and Emergency Affairs (2009) 'Fig. 2 a' [3].
There are two approaches in her experimental work on the adobe wall. 1. Creating a horizontal layer on the wall to extinguishing the energy. 2. Extinguishing earthquake forces by forming lines at 50 cm intervals on the existing building walls with the "Surface Shear" method 'Fig.2 b' [4].

Figure 2 a. Condition of Masonry Building After Earthquake Applied 8 Times [3]

Figure b. Creating a fracture plane [4]

According to this study, in order to prevent diagonal cracks due to earthquakes, horizontal fracture planes are created on the wall and the diagonal fractures are controlled and the earthquake effect is absorbed. In this regard, an experiment was carried out by applying biaxial pressure on a horizontally reinforced and unreinforced mud-brick sample at ITU 'Fig 3 a'. As a result of the experiment, cracks did not occur on the wall with horizontal reinforcement. Cross-fracture occurred in the unreinforced specimen 'Fig 3 b'. This experiment showed that the systems applied in the horizontal direction and created a fracture plane absorb the earthquake load [6].

Figure 3 a, Example of unbroken Wall **b**. Diagonal crack formation [6]

Measures to be taken against earthquakes in masonry walls have been tested and solutions have been developed and this is very important. Because in Turkey, single or two-storey adobe structures are also demolished in earthquake zones and loss of life occurs. In the masonry system, the building walls are load-bearing and the load-bearing walls are generally extended by 10 cm towards the lower floors on each floor 'Fig. 4'. For this reason, earthquakes may pose a problem in terms of vertical load transfer in multi-storey high buildings.

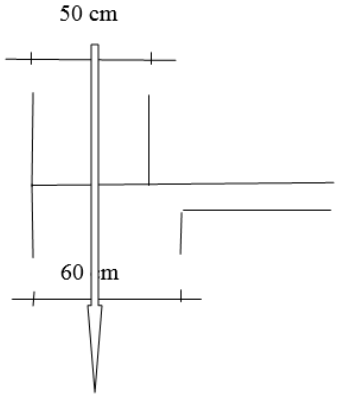


Figure 4. Load transfer on the wall in the masonry system

Despite the precautions taken on the walls, it is recommended to build low-rise adobe structures in traditional applications in Turkey and in earthquake zones, and all applications are in this direction. Therefore, it is accepted that the adobe construction system is suitable for low-rise buildings in earthquake zones.

3 HIGH RISE ADOBE BUILDINGS THROUGH THE EXAMPLE OF AFRICA AND THE ARAB PENINSULA AND THE SITUATION IN TURKEY

In this section, examples of high adobe buildings are given and the applications in Turkey from history to the present are briefly mentioned.

3.1 High Adobe Building in Africa and Arabian Peninsula

In cases where there is no earthquake zone in the world, adobe structures can be applied as multi-storey. In this study, three examples, which can be defined as multi-storey or high, are included. The first of these is the high-rise adobe buildings in Shibam, Yemen. The second is the Djenne mosque, which is a religious building in Mali, and the third is the Bobo Dioulasso Grand Mosque also is a religious building in Burkino Faso, West Africa.

3.1. 1 Shibam

Shibam is a town of 7,000 inhabitants in Yemen. Shibam was dissolved as a multi-storey building to protect it from bedouin thieves, making it the first high-rise apartment block city in the world [7], [URL 3]. Although the town is located in the River floodplain, it survives with its strong environmental walls and maintenance. [URL 4]. All buildings built here are made of mud brick. The number of floors of approximately 500 of these buildings varies between 5 to 11. Some buildings here exceed 30 meters in height 'Fig. 5'. In the years it was built, there was generally only one family living in each building. The lower floors of these residences are used as cellars and warehouses, while the upper floors contain living areas and bedrooms. It is stated that most of these buildings have one or two rooms on each floor. 'Fig. 6' shows that since the ground floors of the buildings are warehouses, there are no windows on these floors. The streets were built one or two meters wide to protect them from climatic conditions and attacks from the environment 'Fig. 7'. In this dense urban texture, houses were built adjacent to each other 'Fig. 8'. Constructing these high buildings adjacent to each other provides an increase in their strength as a result of the structures leaning against each other [8; URL-5]. Buildings in Shibam date back to 1500 BC. During the period of use, all these buildings have survived to the present day by undergoing repairs almost every year 'Fig. 9'.

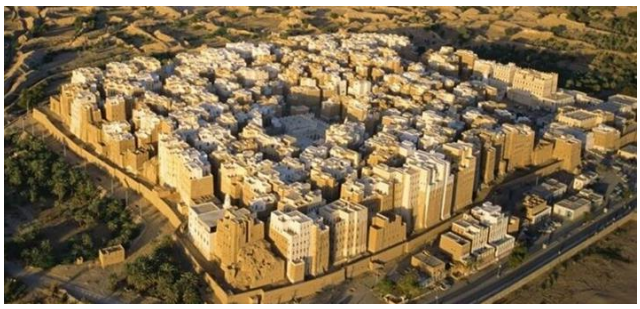



Figure 5. General view of Shibam town with multi-storey buildings [URL-5]

Figure 6. Facade views of ground floors without windows [URL-6, 7]


Figure 7 a, b. Narrow streets for protection [URL-5, 6]

Figure 8. Adjacent housing in Shibam [URL-6; 7]

Figure 9. Building repair [URL 8]

3.1.2 Mali Djenne Mosque

The Djenne mosque is located in the capital of Mali. The construction of the Djenne mosque began in 1280. In the following period, it underwent many repairs and reached its current state in 1907 as a result of the renovation works. This mosque was included in the UNESCO cultural heritage list in 1988 'Fig. 10' [URL 8].

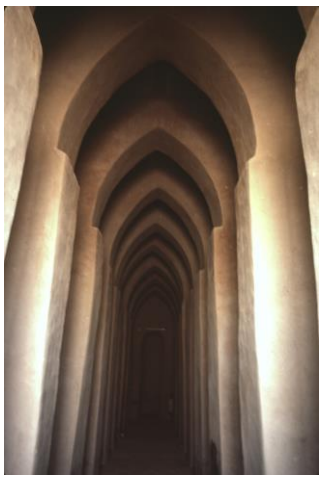

Figure 10. General view of Djenne Mosque [URL 8; 8]

The mosque was built with local construction techniques. In the construction of the mosque, oil added soil (Faray), which can be reached from the immediate surroundings, and wood material is

used. In the Djenne mosque, Sudano-Sahelian architecture (Sudan-French) style was used, as is generally the case in West African countries. In this style, there are towering, rhythmic columns and similar supports. The Djenne mosque plan is rectangular, its roof is supported by 90 wooden columns [URL 9]. There are 114 earthen-baked chimneys called 'ladis' for ventilation in the mosque and ceramic covers that can be closed in the rainy season are used for these chimneys 'Fig. 11'.

Figure 11. Ventilation chimneys on the roof [URL 10]

There are three minarets in the mosque and a spiral staircase in each minaret. 3000 people can fit in the Kingdom Hall [URL 11; 12]. There are hundreds of decorative woods on the adobe walls. While these woods provide a decorative appearance, they are used both during repair and provide rigidity in interior flooring connections and wall structures [URL- 13; 14]. The interior of the building has a dim light. Figures 12 a, b, c. shows both the amount of light and the structural wooden beams. The building is located in the delta of the Niger River and in the rainy season the area is flooded. It was built on a platform with a height of three meters to protect it from this effect 'Fig. 13'. Also during the annual plaster festival of the Grand Mosquée, the residents of Djenné contribute to the re-plastering of the mosque against the water effect of the structure 'Fig.14'. Since the necessary repairs were made to the Djenne mosque, the building can still be used today.



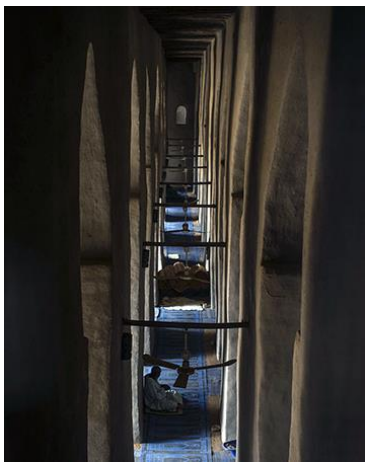


Figure 12 a, b, c Inside view of the mosque [URL 15; URL 16; URL 17]

Figure 13. The platform on which the mosque is placed [URL 18]

Figure 14. Wooden overhangs on the facade [URL-19]

3.1.3 Bobo Dioulasso Grand Mosque

The Great Mosque of Bobo-Dioulasso was built between 1812 and 1832 and has been repaired since then. The building has an area of 1100 m^2 and rectangular in plan. It is an impressive example of the Sudanese-Sahelian architecture prevalent in this region and is the largest building of this style in Burkina Faso. Soil called laterie, sheabutter and wood were used as materials. Laterite is a rock and soil mixture containing iron and aluminum found in rainy and hot tropical regions [URL 20]. The feature of Sudano-Sahelian architecture is that it has round and soft forms and wooden bars protruding from the walls. In the construction of this Mosque, wooden beams (yiri) were used horizontally and these beams were taken out. These beams are important both as carriers and have an aesthetic effect. There is a tower showing the mihrab and the qibla on the east façade, and a second tower on the north façade that functions as a minaret 'Fig. 15'. The mosque has an open courtyard and a masjid. An additional building was built in 1952, it was renovated in 1982, and the courtyard was covered with a tin roof in 1983. When the mosque is damaged during the rainy seasons, it needs to be repaired. Cement has been used instead of mud in the repair of the mosque, and its original structure has been damaged [URL 21; URL 22].

Figure 15. Bobo Dioulasso Grand Mosque [URL 22]

The interior of the mosque is plain and dim, with mahogany wood used for the ceiling 'Fig. 16 a, b' [URL 23]. Heigh rise information of the building could not be accessed. In the photograph in Figure 17, when the door height is accepted as approximately two meters, it can be accepted that the height of the minaret is approximately 15 meters. The mosque is still used today with regular maintenance.

Figure 16 a. View from inside the mosque [URL 24]

Figure 16 b. Ceiling view [URL 25]

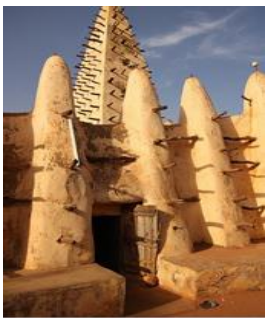


Figure 17. Mosque door view [URL 26]

3.2 Adobe Building in Turkey

Since the Neolithic age, mud has been used in many parts of the world such as Africa, Asia, Europe and South America. It is known that the use of adobe bricks started 9000 years ago in Çatalhöyük in Turkey, and it was used in many historical settlements such as Çayönü, Aşıklıhöyük, Beycesultan, Boğazköy and Troya [9]. Soil has been used by people from every socio-economic level of the society for different purposes such as houses, religions and tombs throughout history in Ancient Egypt [10], [11]. It was observed that different adobe production techniques were used in the excavations made in the first settlements in Aşıklıhöyük, where adobe building material was used. In one technique, the mud was applied wet on the wall by hand shaping. Another technique applied here is the pouring into mold technique. Here, previously dried or used adobe blocks were thrown into the mud placed in the mold and masonry was made. In practice in the lower layers of Aşıklıhöyük (earlier periods), tuff stone fragments were put into the wall molds instead of mudbrick [12]. Societies living in the B.C. 7400s applied the mud in a rectangular shape for shelter needs. By creating a wall with this material, they called this technique the 'pise technique'. The earliest example made with this technique was found in the cities of Temrik and Tell M'lefaat in Mosul, Iraq. Chaldeans and Sumerians also used adobe in that region [13]. Curtain walls, partition walls and beams were built with mudbrick blocks in Jordan at the same time as Çatalhöyük. In this process, it was difficult to make adobe in large sizes due to shrinkage. In order to prevent this, the process of mixing straw was encountered in Egypt. Again in Babylon, asphalt was added to the soil to increase water resistance [14]. The mudbrick, which has been used for thousands of years in Turkey and its surroundings, has been used in single or two-storey buildings since those ages. In this usage process, depending on environmental factors, sometimes it was made only with soil, and in some regions it was applied as a mixture according to the geographical features. For example, there are different uses such as mud bricks on both floors, but sometimes with wooden supports, and in some cases the use of stone on the ground floor and soil on the upper floors. However, as a result, they were applied as one and two storeys, except for the general use, slope and different features. These general application conditions were accepted in the comparison of Turkey's adobe buildings and high adobe buildings in the evaluation part of the study.

4. EVALUATION

In this section, it has been tried to compare high rise adobe buildings and low-rise adobe buildings that are widely used in Turkey. The most important of these comparisons is that the structures are affected by earthquakes. Traditional adobe buildings in earthquake zones are generally built as one or two floors. In Table 2, the locations of multi-storey or high adobe buildings on the world earthquake map in Africa and the Arabian Peninsula are determined and the heights of these buildings and whether they are in earthquake zones and the situation in Turkey are shown.

Thus, it is possible to see that the limitations of being in an earthquake zone have continued since that period. The location of the examined buildings on the world map was marked and copied on Google maps, and the point belonging to the same settlement was shown on the earthquake map with a blue ring. The position of Turkey is shown in the table with an additional line to compare with the buildings examined.

Table 2. The place of Turkey and the examined buildings in the world earthquake map

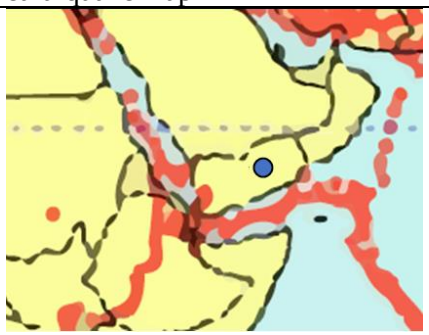
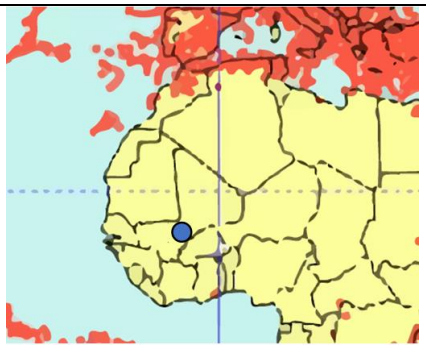
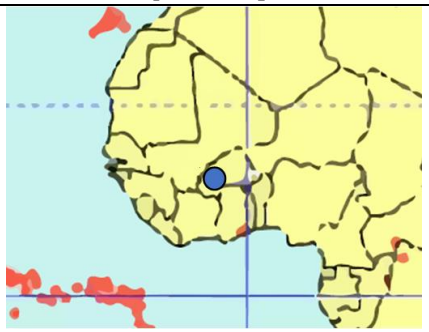
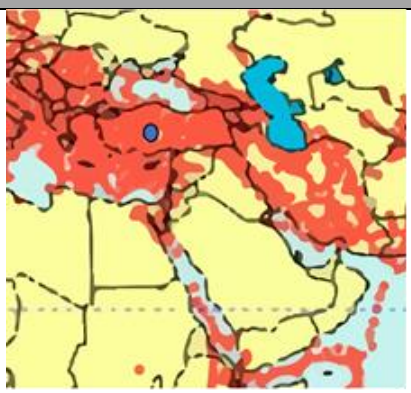
Line No.	Building name	The location of the building on the map	The location of the building on the earthquake map
1	**Shibam**	 Location of Shibam on the map URL 27	 Shibam's location on the earthquake map
2	**Djenne Mosque**	 Location of Djenne Mosque on the map [URL 28]	 The location of the Djenne Mosque on the earthquake map
3	**Bobo Dioulasso Grand Mosque**	 Location of Bobo Dioulasso Grand Mosque on the map [URL 29]	 Location of Bobo Dioulasso Grand Mosque on earthquake map
4	**Turkey**	 Location of Turkey (Çatalhöyük) on the map [URL 30]	 Turkey's place on the earthquake map

Table 2 shows us that none of the buildings in lines 1, 2 and 3 are in the earthquake zone, whereas almost all of Turkey in Line 4 is in the earthquake zone. This result proves that multi-storey or high adobe buildings are not in the earthquake zone.
The heights of the buildings examined in the third section are given in Table 3.

Table 3. Building heights of examined adobe structures

Building	*Height*
Shibam	5-11 floors building height of **30 meters and above**
Djenne mosque	**16 m**
Bobo Dioulasso Grand Mosque	~ **15 m**
Çatalhöyük	Generally **3 m**
Adobe building in Turkey	Single or double storey around **3/7-8 m**

When Table 3 is correlated with Table 2, it shows that the building heights in non-seismic areas are more than twice that in areas with earthquake zones.
Table 4 has been arranged in order to see the lifetime of the buildings discussed in the study and whether they are still used today.

Table 4. The dates and current conditions of the adobe buildings examined

Building	*Year of construction*	*Current status*
Shibam	1500's and later	in use
Djenne mosque	1280-various repairs-1907	in use
Bobo Dioulasso Grand Mosque	1812-1832	in use
Çatalhöyük	B.C. 7400	Historic area - Tourist area
……- Nowadays	Adobe building in Turkey	in use

In Table 4, lines 1, 2 and 3 are all still in use. Of course, the use of Çatalhöyük in Turkey is not an expected feature, since it is a 9000-year-old settlement.
Civil architectural examples, besides those that have been used for many years depending on the maintenance conditions, many of them have been abandoned and have begun to collapse.
Table 4 shows that adobe buildings can be used for many years if necessary maintenance conditions are met. Of course, most of the examples selected here were repaired over time as they were private buildings. This proves to us that adobe buildings can be quite long-lasting if the necessary conditions are met.

5 CONCLUSION

Soil has been used as a building material in many different ways from past to present. The reason why it is used so widely is that it is economical, easy to apply and easily accessible.
It is thought that adobe buildings in societies are mostly located in rural areas and low-rise applications. It is seen that the reasons for low-rise use of adobe structures are mostly related to their location in the earthquake zone.
When the positions of the multi-storey or high adobe building samples on the earthquake map are examined, it is seen that they are not in the earthquake zone.
In addition, the study shows that the life of the buildings is extended with routine maintenance in areas exposed to water, and that the examples that are maintained other than ancient buildings can be used for many years. It is known that all three samples discussed in the study were exposed to water and were affected. But it is seen that these buildings are still in use today.

In addition, many studies have been carried out on the weakness of the soil, especially against water, and developments have been achieved in this regard.
The fact that multi-storey and high adobe buildings built many years ago are still standing shows us the strength of this building material.

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