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Earthquakes, sustainable settlements and traditional construction techniques

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Abstract

Urbanization is increasing all around the world due to population growth and big cities receive a high volume of migrants due to economic and social reasons. However, rapid population growth should be prevented in big cities in order to provide comfortable living conditions to the population. When urban planning practices do not catch the speed of urbanization; the tendency towards vertical architecture increases, the amount of green space decreases and problems related to unplanned urbanization come to the fore. These important problems, which have considerably increased recently in Türkiye, may lead greater problems in many respects. The parallel and self-sufficient development of urban and rural areas, which is defined as urban sustainability, is considered as the best-case scenario in urban planning practices. This aim is adopted nowadays by most of the countries in the world as it prevents rapid population growth in cities and depopulation in rural areas. Decisions which are taken to ensure urban sustainability are important for all countries. However, these decisions become even more important in regions with disaster risk. As the majority of Türkiye's land area is under seismic risk, the problems which may arise due to rapid urbanization during an earthquake should be prevented. The damage and losses which could occur during an earthquake and the security, health, education problems which will arise after the earthquake can be solved by preventing dense housing and uncontrolled migration in urban areas. The connection between urban and rural areas should be strengthened. Besides, the social and economic sustainability of the rural area should be ensured. Settlements should be designed away from fault lines with a holistic approach as "*living spaces*" which consist components such as; transportation, infrastructure, green spaces and educational spaces. Additionally; the use of appropriate construction techniques and materials should be accepted as a priority. In this context, it can be mentioned that traditional building techniques, which have been developed over centuries and whose deficiencies have been improved during this period, should be preferred especially in rural areas. In this study, the criteria that gain importance in the construction of earthquake resistant and sustainable settlements are evaluated on Türkiye case. The precautions which should be taken to ensure rural sustainability and to prevent the depopulation of rural areas are emphasized. Within this scope, the importance of protecting the architectural texture and regenerating traditional building culture was discussed in constructing earthquake resistant settlements.

Keywords: conservation, rural region, seismic resilience, sustainability, traditional building systems

1. Introduction

The world has a population of more than 8 billion people and all countries have similar problems regarding urbanization. One of the most prominent among these problems is "employment" which supports the growing population financially. Leading industries and manufacturers that provide employment is usually concentrated in certain parts of the countries. Therefore, the population

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gets denser in some parts of the country and population growth increases especially in cities surrounding these regions. In urban planning practices, the location of important industries and direction of the development of cities is usually foreseen. However, in some cases, urban planning practices fall behind the practical development of cities, leading to “unplanned urbanization”.

According to TUIK data; there is a high unemployment rate in southeastern parts and its surroundings, while there is a low unemployment rate in the coastal and western regions of Türkiye. Accordingly, while unemployment is less in the western and coastal regions, it is more in the southeastern regions. As a result, there is a high migration rate to regions with high employment (TUİK, 2023.03.23).

In TUIK's Urban-Rural Population Statistics for 2022; it is stated that 67.9% of Türkiye’s population lives in dense cities, 14.8% in medium dense cities and 17.3% in rural areas. As a result of the increasing trend of migration to urban areas since the 1950s, cities develop rapidly and sometimes unpredictably. This result with a building stock shortage and create densely populated areas which lack green areas. Besides, unplanned urbanization patterns occur in the undeveloped parts of the city (TUİK, 2023.05.11).

The uncontrolled increase in population and construction in some parts of the city primarily causes problems in providing comfortable living conditions and security in those regions. However, these regions become the focus of much bigger problems in the case of any disaster.

Türkiye has another important problem which is also related to employment and urbanization. Türkiye is an earthquake prone country located in the Alpine-Himalayan orogenic belt. When the global seismic hazard map and the earthquake hazard map of Türkiye are examined together, it can be observed that approximately 95% of the surface area of Türkiye is under the risk of earthquakes (ThoughtCo, 2019).

In the "Building Regulation for Resilience" report which was published by the World Bank (TWB) in 2016; it was stated that the disasters that took place in the world in the last 20 years have affected 4.4 billion people, caused the loss of 1.3 million lives and an economic loss of 2 billion dollars. It was also added that 80% of the losses occur in low and middle-income countries and that legal regulations are not sufficient enough in reducing the risk in these countries (Moullier & Krimgold, 2016).

The most important reason that spreads the disaster risk was stated as rapid urbanization and illegal housing in settlements where legal regulations are not effective. In order to reduce the possible losses in the event of a disaster; building regulations should be established, safety should be increased in new buildings and practices which aim to reduce risk should be adopted in existing vulnerable buildings (Moullier & Krimgold, 2016).

In order to prevent disaster-related losses in Türkiye, where disaster risk is very high and urbanization is very rapid, it is crucial to protect the growth of urban population, to strengthen the existing structures, and to construct new structures in accordance with regulations.

In this study, protecting and encouraging the use of traditional building techniques in rural areas is discussed on the basis of the need to protect the rural population and to construct earthquake resistant settlements.

2. Earthquake Resilient Settlements

Many people prefer cities for living due to economic and social reasons. Accordingly, cities usually become the main portals of migration and get crowded. Rapid urbanization and illegal construction numbers increase when the high demand in the construction industry is not balanced with efficient urban planning strategies. As a result, the problems which arise in these environments affect many people.

Due to its geographical location, Türkiye is under the risk of different natural hazards such as; earthquakes, floods and landslides. The disasters that have occurred in Türkiye in the last 65 years were caused by; 55% earthquakes, 21% landslides, 8% floods, 7% rockfalls and 2% avalanches according to the "Disaster Resistant City Planning and Construction" report (İSMEP, 2014).

In the "Climate and Disaster Resilient Cities Project" it is mentioned that Turkey ranks 45th among 191 high-risk countries (TC Ministry of Environment, Urbanization and Climate Change, 2022).

Different researches state that approximately 95-96% of Türkiye's surface area and 98-99% of its population is under the risk of earthquakes (Akıncıtürk, 2003; Türkoğlu, 2001). When the global seismic hazard map (ThoughtCo, 2019) in Figure 1 and the Turkey Earthquake Hazard Map (AFAD, 2023) in Figure 2 are examined, it can be observed that a very large part of its surface area is at risk.

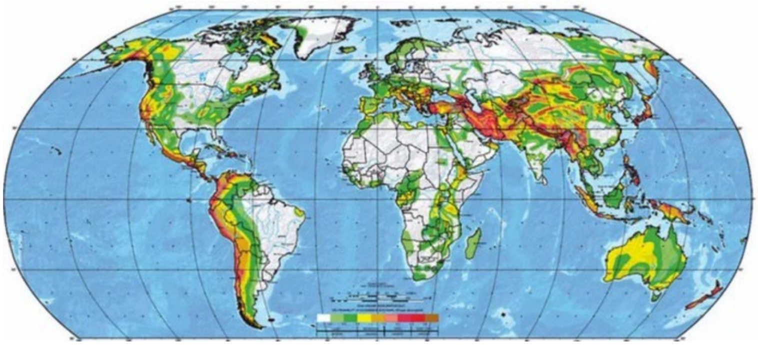

Figure 1 Seismic hazard map of the World (ThoughtCo, 2019)

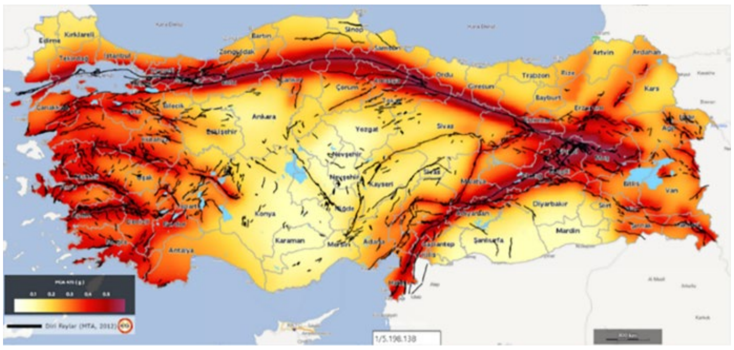

Figure 2 Seismic hazard map of Türkiye (AFAD, 2023)

Nevertheless, the regions which have high earthquake risk also have high employment potential, therefore high immigration and urbanization possibility. The regions with the highest unemployment and the highest employment rates (TUİK, 2023.03.23) can be seen in Figure 3 and Figure 4.

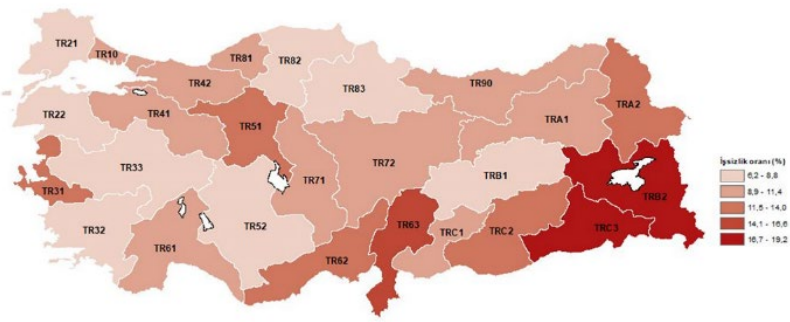

Figure 3 Unemployment rate map according to 2022 TUIK Labor Force Statistics report (TUİK, 2023.03.23)

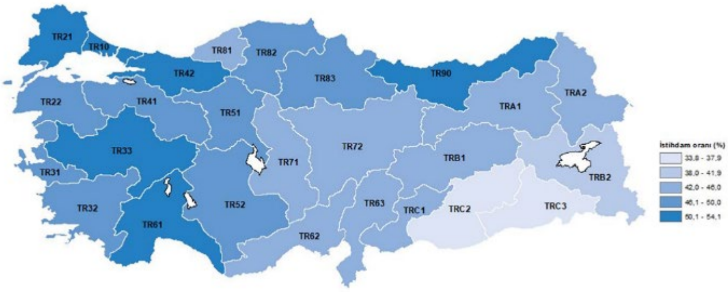

Figure 4 Employment rate map according to 2022 TUIK Labor Force Statistics report (TUİK, 2023.03.23)

Unplanned urbanization and dense housing problems mainly occur at the coastal and western regions of Türkiye as a result of employment related migration. Fatal problems will arise in these regions in the case of an earthquake, in regions where the constructions are built with low-quality materials and poor workmanship.

All practices, which aim to prevent the risks related to earthquakes and rapid urbanization, should be effectively included to urban planning strategies in order to build disaster-resilient settlements. Besides, practices which protect the urban population and prevent the depopulation of rural areas should be adopted.

2.1. Population Growth, Settlement Planning and Sustainability

Urbanization, which accelerated after the Industrial Revolution, started a rapid change in the lives of communities and caused an intense social mobility. The people of the agricultural societies began to migrate to the cities. Accordingly, the residential areas started to be constructed densely in relatively narrow regions (Çetin, 2012).

Policies which do not consider urbanization as a part of development result with; low life quality, poor development, social unsustainability, rapid and unplanned urbanization, illegal construction and vulnerable building blocks (Çetin, 2012).

Ensuring a controlled population growth in cities, integrating urban – rural settlements and providing urban planning that appropriately respond to the needs of population are the most important components of the *"sustainable city approach"*, which is the common goal of cities nowadays.

2.1.1. Population Growth

Today 55% of the world's population lives in cities and it is estimated that this rate will increase to 68% in 2050. According to the European Union statistics of 2021; 38.9% of the population lives in cities, 35.9% in medium-density cities and 25.2% in rural areas in European Union countries (Eurostat Statistics Explained, 2022).

The TUIK report which was published in 2022 (Figure 5) mentions that; 67.9% of Türkiye's population lives in dense cities, 14.8% in medium dense cities and 17.3% in rural areas. (TUİK, 2023.05.11).

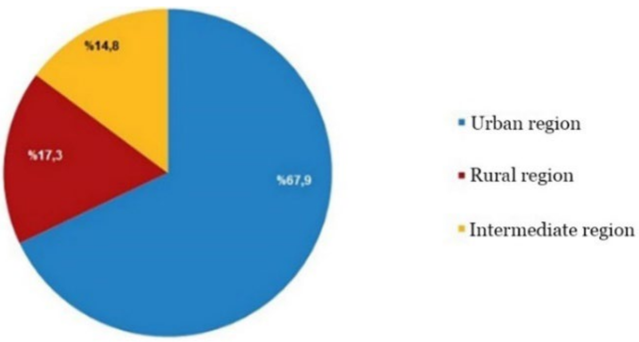

Figure 5 2022 TUİK Urban-Rural Population Statistics (TUİK, 2023.05.11)

2.1.2. Settlement Planning & Rural and Urban Sustainability

The rapid urbanization trend is trying to be reduced with sustainability approach. The Brundtland Commission Report, released in 1987, stated that poverty, rapid population growth, excessive consumption of resources and uncontrolled growth of cities are the most important problems of the world. A great amount of environmental degradation occurs during this process (Figure 6) and these problems can be solved by adopting sustainability approach.

Figure 6 Effect of rapid urbanization on the environment, India (Wired,2016)

"The CIB Agenda 21", published in 1999, examines the sustainability approach through the relationship between built environment and construction industry and evaluates it through;

- Sustainable building practices of different regions
- Problems of these regions
- Effects of construction industry on the economy, environment and society
- Boundaries and potential problems of sustainable building production
- Strengths and opportunities of traditional building techniques of different cultures
- Proposed steps regarding the society, government and construction sector (Du Plessis, 2002).

Additionally, Agenda 21 mentions that; each country has different conditions regarding the scale, priorities, local capacity, capabilities and problems. Therefore, each country should prepare a unique sustainable development plan that considers its priority during the planning process (Du Plessis, 2002).

The basic principles proposed by Agenda 21 for the construction of sustainable cities are;

- *Urbanization and development of rural areas*: The link between urban development and investment strategies and the impact of these on rural areas are not well studied. Usually, the development in rural areas remains limited as the governments only aim the development of cities. Therefore, there is a significant boundary between rural and urban areas (Figure 7). In order to prevent this difference and ensure a sustainable development model in cities, urban plans should be reviewed. Rural areas should be defined as the most important part of this model during this process.

Figure 7 Contrast between rural and urban areas, Ehningen, Germany (Kemper, 2020)

- *Sustainable housing production*: Housing production is an essential part of the urban fabric. When the sustainability of formal and informal housing constructions in cities are evaluated, it can be mentioned that, although they have many deficiencies, informal housing constructions are more sustainable than formal housing production methods. Therefore, informal housing production methods needs to be examined, improved and implemented in urban policies (Du Plessis, 2002).
- *Innovations in building materials*: Construction industry is one of the leading industries that contribute the most to carbon emissions. Therefore, sustainable improvements in this industry will have noticeable environmental outcomes. Instead of using modern building materials which are produced by using non-renewable resources and by consuming great amount of energy, environmentally compatible materials should be produced by using alternative materials. New materials and techniques should be affordable for local people with limited financial possibilities (Du Plessis, 2002).

The most important subject which needs to be mentioned in this context is the use of traditional materials which can be obtained easily and which have low environmental impact. The integration of traditional and modern construction techniques is also important. (Du Plessis, 2002).

- *Modernization of traditional construction techniques*: Traditional construction techniques are being used and improved by the local people for centuries. As these techniques are developed by using locally available materials and as these buildings are constructed without competing with the nature, they integrate with the nature even when they are abandoned. Although traditional construction systems cannot be easily integrated with the modern construction industry, efforts to modernize the traditional systems (Figure 8) can encourage more sustainable construction techniques and help to develop better urban area examples (Du Plessis, 2002).

Figure 8 A modern vernacular structure (Re-Thinking the Future, n.d.)

- *Increasing the effectiveness of administrative staff*: Changing the behavior of local authorities and improving their environmental approach is important in extending sustainable policies. Training the management staff, finding resource to develop sustainable buildings and making regulations that encourage sustainable construction techniques are important necessities (Du Plessis, 2002).

- *Creating a new model for development:* All developed and developing countries achieve economic growth through a high production-consumption model. However, the social and environmental implications of this model are enormous. This approach, which leads to a rapid environmental deterioration, also destroys the social structure and deepens the gap between rich and poor. The communities which adopt this approach and focus only on economic growth distance from spiritual values, cultural heritage and all traditional practices. Nowadays, new approaches, which offers to share the Earth's resources fairly and suggest a more reasonable consumption, gain strength (Du Plessis, 2002).

In light of this information; it can be mentioned that the earthquake risk, which is one of the most important problems of Türkiye, should be determined as the most important priority in urban planning. It is also an important necessity to take measures to protect the population in rural areas in order to prevent the population growth of cities and to ensure social and economic sustainability.

When the common features of sustainable settlement practices are evaluated, they can be briefly summarized as; they preserve traditional values, improve rural-urban linkage, draw attention to the environmental and sustainable importance of traditional building methods and aim to improve the environmental approach of administrative staff.

Türkiye's first Urbanization Council which was held to implement the main topics mentioned in Agenda 21 agreed on similar goals regarding "Sustainable Urban Development" approach;

- Improving the disaster resilience of settlements,
- Protecting natural and cultural assets,
- Preventing illegal housing,
- Providing local development (Kocaoğlu & Sert, 2018).

These goals can be achieved by determining appropriate urban and rural policies and by managing the population growth in urban areas.

3. Ensuring Rural Sustainability to Construct Earthquake-Resilient Settlements

"Rural sustainability" is defined as the social and ecological conditions required to provide the needs of local community, to strengthen urban-rural linkages and to support regional economies. Rural sustainability policies have been built in a social and political framework for many years and have been carried out with an approach mostly focused on agriculture. However, there are other features which are thought to be effective on rural sustainability. These features can be defined as follows;

3.1. Agriculture

The agriculture-focused approach emerged in opposition to two different perspectives. The first, "agro-industrial" approach, aims to provide sufficient food for expanding urban areas. This industry uses the soil, plants and animal products as resource and uses these resources in the manufacture of food and clothing. The "post-productivism" approach, on the other hand, evaluates agricultural land use with a productive, ecological, social and aesthetic perspective which contributes to the farm's income (Sonnino et.al., 2014).

These approaches, which consider the rural area as the source of agricultural production, has evolved markedly over the last few decades. The new approach which is defined as the "sustainable rural development approach", aims to combine agriculture with different practices that have the potential to improve both the relationship between farms and people, and the linkage between rural and urban areas. It focuses on improving the economic conditions of the community to maintain social sustainability, aims to create new areas for the production, distribution, processing and consumption network of agricultural products and cares about the support of community (Sonnino et.al., 2014).

3.2. Tourism

Development of tourism industry is another approach adopted to ensure the social sustainability of rural areas. Tourism activities help to prevent migration by ensuring the development of local community and support the economy. Different tourism activities can be carried out by highlighting the strong characteristics of the region.

Although mass tourism is important in terms of the economic development of countries, it causes permanent damage to the environment (Figure 9). As the buildings are designed to accommodate a great number of people, they usually cannot harmonize with the natural environment. Besides, as they are usually designed self-enclosed, they cannot blend with the cultural characteristics of the local community and can damage the social structure of the surrounding.

Figure 9 Buildings of mass tourism and the natural environment, Bodrum, Muğla (Independent Türkçe, 2019)

3.3. Entrepreneurship

The existence of local entrepreneurs who can contribute to the development of the region is also an important requirement. Local entrepreneurs who have contacts in urban area can be effective in strengthening the links between the urban and rural areas. As local entrepreneurs are equipped in terms of qualifications such as marketing and knowledge, they can bridge the urban and rural areas (Mayer et.al, 2016).

3.4. Mobility

Another important feature that ensures the social integration of the rural community and supports the economic and demographic features of rural area is mobility. Increasing the strength of mobility and accessibility to urban areas is a crucial necessity in supporting the demographic and economic structure (Camarero et.al., 2016).

Rural life is generally considered suitable for elderly people. Making rural life suitable for young individuals as well can be achieved by increasing employment in the rural area and by ensuring accessibility to the urban area.

3.5. Urban texture and cultural heritage

Preserving the originality of the rural area and protecting the urban texture are other important features which may have effect in managing the urban growth and preserving sustainability (Tutal, Topçu, 2018).

Modern construction techniques became widespread in rural areas with the acceleration of urbanization and spread of modern construction techniques. The main reason of the burst of modern construction techniques is that traditional construction techniques are not flexible in terms of installation of mechanical, electrical and plumbing systems. As everyone wants to easily access to technology and draws away from everything that does not support technological developments the traditional construction techniques were abandoned in time.

However, while low-rise adobe or half-timbered traditional structures have a low collapse and loss possibility during an earthquake, a multi-storey reinforced concrete structure is more likely to collapse and cause losses as the construction and workmanship quality of modern buildings constructed in rural areas is usually low.

Besides, modern buildings in rural areas usually lead the loss of authenticity and urban texture in terms of cultural heritage. The traditional buildings which remain idle after abandonment (Figure 10) also lead to the loss of cultural identity and arise security concerns in rural areas. When this common trend and their results are evaluated; loose of attraction, declining in employment, increase in migration and accordingly failure in social sustainability can be observed in these regions.

Figure 10 Abandoned traditional house, Birgi, İzmir (Küçük Oteller, 2018)

The traditional building techniques evolved throughout the centuries. These buildings are designed in harmony with the climatic and topographic characteristics of the region, are built by using local materials and their disaster resilience was increased within this period by using trial and error method (Özdemir, Topçu, 2022). Therefore, traditional construction techniques are considered as an important component in building earthquake resilient settlements. Researches in this field reveal that traditional structures should be modernized and their extended use should be encouraged.

Anatolia has a rich culture in terms of traditional construction techniques. A large number of building typologies have been developed as a result of the abundance of material diversity and the presence of different cultures in the region. The most important of these building types was the traditional Ottoman House. This house typology emerged in the 13th-14th centuries, widely used until the 17th century and gradually abandoned after the Industrial Revolution.

The features of Ottoman House were improved against disasters, especially against earthquakes in time and this building type provided a significant contribution to the architectural texture and cultural richness of Anatolia. It may still provide contribution to the architectural texture and cultural richness of Türkiye today.

4. Importance of Traditional Building Techniques in Creating Earthquake Resilient Settlements

Rural sustainability is an important goal in preventing the rapid increase of urban growth, solving the problems which arise due to population increase and building earthquake-resilient settlements. The use of traditional construction systems is important in ensuring rural sustainability all over the world.

Many European countries, especially Italy and United Kingdom, make great efforts for different reasons to preserve traditional construction techniques and the buildings constructed with these techniques. The main reason for the conservation efforts is that the weaknesses of these techniques against disasters were eliminated during their evolution. The most important disaster risk in Anatolia is the earthquake risk.

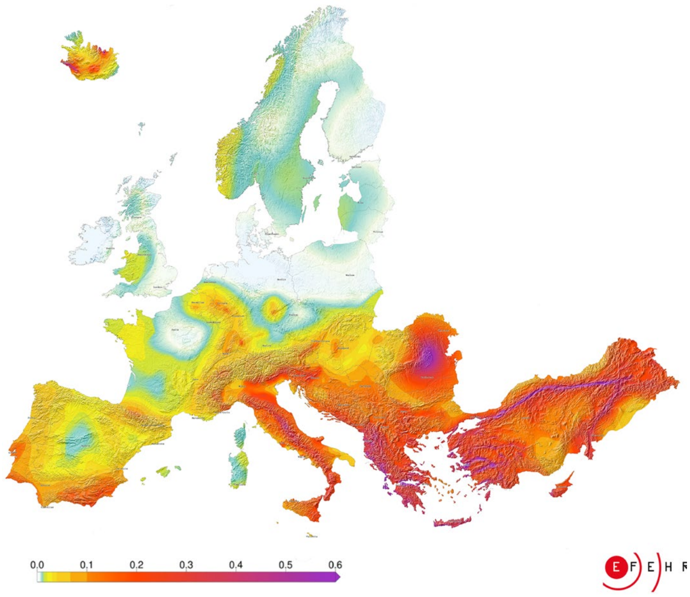

Figure 11 European seismic hazard map (EFEHR, n.d.)

Although Europe's earthquake risk is less than Türkiye, as can be seen in Figure 11, Greece, Italy and Portugal are European countries which have higher earthquake risk. Therefore, there are traditional building typologies developed and used in these countries which have high earthquake resistance.

Previous earthquakes and researches reveal that properly located and detailed traditional buildings have high earthquake resistance. They absorb seismic energy in sufficient amounts and reduce damage by providing structural integrity. Accordingly, it is an important necessity to understand the strengths and weaknesses of traditional building systems, integrate them with modern construction systems and encourage their use with the help of carefully designed master plans.

4.1. Earthquake resistant systems

Communities that experience frequent and severe earthquakes develop building techniques in order to prevent earthquake-related hazards. The pragmatic and theoretical knowledge gained over time by the communities that experience earthquake-related problems is defined as "seismic culture" (Correira et.al, 2014).

Seismic culture practices which were developed, sustained and transferred by local communities is mostly unwritten. It consists rules to be followed for land selection and settlement location. This information can be observed from the general appearance of the settlement. Traditional buildings which evolved within seismic culture are particularly designed to ensure earthquake resistance. They were built by using the most advanced techniques and equipment of the period they belong and they were perfected over time (Correira et.al, 2014).

Site selection is the most important issue in developing an earthquake resilient settlement. The destructive properties of the earthquake are related to the soil type, distance to epicenter, depth and duration of the earthquake. Active or potentially active faults around the settlement is important. Buildings should be constructed within a reasonable distance on both sides of the fault, which is defined as a buffer zone (Figure 12), to prevent construction in high-risked areas. Besides, the construction site should not be a landfill or an agricultural land in order to prevent hazards in case of an earthquake (Akıncıtürk, 2003).

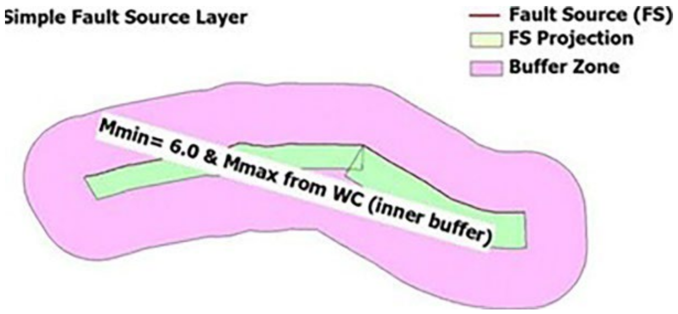

Figure 12 Fault source and buffer zone (Demircioğlu et.al., 2018)

However, the structural features of the buildings, construction and workmanship quality are also important in increasing the earthquake resistance of a building. All types of structural system can be earthquake proof with the appropriate design of these features.

4.1.1. Response of buildings to earthquakes

Earthquakes affect structures with horizontally transmitted seismic forces which moves from the ground level to upwards. This force starts a rotation out of lane and the structural elements with a heterogeneous structure try to overturn with this effect.

"Overturning" is the first type of damage that affects structures and can lead to partial or general collapse of the structure. If the connection between the walls is strong, the building presents a significant ductility during the earthquake which is defined as “box-behavior”. Buildings which have box-behavior do not overturn and the horizontal forces generated during the earthquake are transferred to the walls in the direction of the earthquake. During the earthquake, the shear forces create cracks at the mortar joints, as seen in Figure 13, and this is the second type of damage (Correira et.al, 2014).

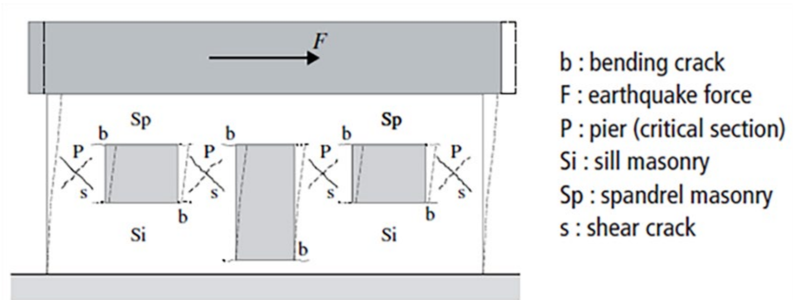

Figure 13 Deflection and cracks due to earthquake (Arya et.al., 2014)

4.1.2. Techniques to increase strength of traditional buildings against earthquakes

Box behavior must be ensured to avoid overturning and this can be achieved by producing effective joints and using horizontal connections. Walls are the fundamental elements of masonry buildings and must behave as a whole under seismic forces (Correira et.al, 2014).

As openings create discontinuities on wall surfaces and reduce the resistance of the wall, the distribution and dimension of wall openings needs to be carefully designed. Wall surface should have good workmanship with less openings in order to increase the strength of the wall and help the building to survive during the earthquake (Correira et.al, 2014).

The buildings in rural areas are not strong enough as they are usually constructed without the intervention of a qualified professional. In order to increase the earthquake resistance and absorb the seismic forces in such buildings, the flexibility of them should be increased. Instead of strong masonry walls which show less flexibility, walls including wooden ring beams which have strong floor-wall connections are more suitable (Langenbach, 2015).

When the earthquake resistant building techniques of different cultures are evaluated, some common features can be observed. These features can be briefly summarized as follows;

- Masonry walls supported by buttresses
- Form dense rectangular mesh networks in order to increase resistance
- Wooden ring beams placed within the masonry walls (Figure 14)

Figure 14 Timber ring beams in a masonry wall, Cumalıkızık, Bursa

- Using flexible binding materials such as clay or lime mortars
- Constructing strong connections between the elements to provide "box behavior"
- Rows of brick added horizontally within the masonry walls
- Lowering the center of gravity by using half-timbered systems

The use of heavy masonry walls, especially on the ground floors, and buttresses constructed to support the walls are common traditional devices used for increasing the earthquake resistance of buildings. The dense rectangular plan scheme produced with walls placed perpendicular to each other aims to provide high strength against strong dynamic loads (Correira et.al, 2014).

The most common technique which is used to lower the center of gravity is preferring heavier building materials in the ground floor and lighter materials in the upper floors. Heavy stone masonry walls are usually preferred in the ground floor to increase the earthquake resistance of the building and also in order to protect the building against the effects of water and humidity. On the other hand, thinner stone walls or light wooden-framed walls were used in the upper floors. Buttresses, staircases (Figure 15) and vaulted spaces are the other common features used for lowering the center of gravity (Correira et.al, 2014).

Figure 15 Outside staircase, *(profferlo),* Italy (Minor Sights, 2015)

One of the most common devices which is used to decrease the weight of the building is the use of wood. Wood is preferred due to its high flexibility, high deformation capacity and its high ability in the dissipation of seismic energy. Nevertheless, wooden ring beams prevent the progression of cracks by separating the wall into horizontal sections in masonry walls. Horizontal and vertical connections made with wooden materials increase the shear, bending and torsional resistance of structures. (Correira et.al, 2014).

These methods have been used for centuries. The most ancient examples of these methods which is visible in some archaeological sites show holes in stones drilled to place wooden elements in order to increase the flexibility of the walls.

4.2. Timber frames as an earthquake resistant system

Wood is used in two different ways in increasing the earthquake resistance of the buildings. The first is the use of wood as a "*ring beam*" and the second is its use as a *"wooden frame"*. It is believed that the use of ring beams dates back to 9000 years ago in Anatolia. Ring beam is known as *"hatıl"* in Anatolia and it spread to many parts of the world due to migrations and cultural influence over centuries. Ring beams are placed horizontally on masonry walls to transmit and distribute the load evenly to the ground. Two lines of wooden beams are placed to the inner and outer sides of the masonry wall and then connected to each other with wooden pieces added in the other direction (Hughes, 2000).

"Wooden frames" have been used for centuries to increase the earthquake resistance of the building. They are constructed by producing a frame with circular or rectangular wooden elements and then by filling the empty spaces defined by the frame with local abundant materials. "Frame", "masonry panels" and "masonry structure", which are the components of wooden frame systems, are not independent and they are structurally integral with each other during an earthquake. The panel size is important in the determination of the earthquake resistance of the system. There is evidence that small panels have higher earthquake resistance. Another important detail which increases the earthquake resistance of this system is the diagonal braces added to the corners of the frames to increase the lateral resistance of the building. Diagonal braces (Figure 16) are common features of Ottoman Houses (Langenbach, 2015; Correira et.al, 2014).

Figure 16 Diagonal bracings of an Ottoman House, Safranbolu, Karabük (BBC Travel, 2023)

These systems have been produced and used in earthquake prone regions of the world for centuries. Previous earthquakes reveal that, appropriately constructed and detailed structures which have evolved in this way show high earthquake resistance. Anatolia and its surroundings, especially Europe, Middle East and Asia, also produced earthquake-resistant traditional building typologies.

Masonry buildings has been built together with wood in Greece since the Minoan civilization. The system was initially built by using wood horizontally to bond and strengthen the masonry walls. Then the system evolved into a frame built both in horizontal and vertical directions to prevent the progression of cracks which occur due to the transfer of loads (Poletti et.al., 2015; Ortega et.al, 2017).

A building system called *"La Casa Baraccata"* (Figure 17) became widespread in Southern Italy after a series of devastating earthquakes occurred in Calabria in 1783. La Casa Baraccata, which was first constructed in the 14th century, was built with a wooden internal frame embedded into the rubble construction (Tobriner, 1983; Correia et.al., 2014; Poletti et.al., 2015; Scibilia, 2017).

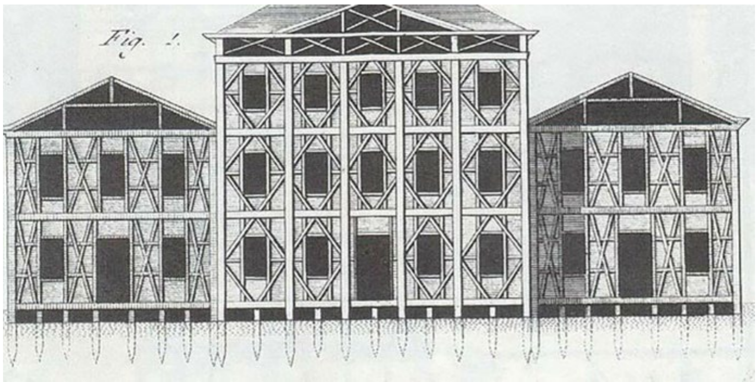

Figure 17 Typical elevation of Casa Baraccata (Niglio & Valencia-Mina, 2013)

After the Lisbon earthquake destroyed the Lisbon Downtown in 1755, a new building system called *"Pombalino"* was proposed for the reconstruction of the city. The proposed building system was a part of the urban plan which was the first known study that fully documented the effects of an earthquake and provided recommendations for urban planning (Poletti et.al., 2015).

Pombalino was designed to increase the earthquake resistance and fire safety of the building. An affordable and faster construction period was aimed by the standardization of the construction system components. The wooden frame forms a “X” with horizontal and vertical elements as in Figure 18, and the panels defined by the frame are then filled with different materials (Gülkan & Langenbach, 2004; Ferah 2009; Poletti et.al., 2015).

Figure 18 *Pombalino* wall system (ConservationTech, n.d.)

The *importance* of *Pombalino* is that this system was designed and proposed for the reconstruction of the downtown of a multi-storey city center after a devastating earthquake (Figure 19). After the 1909 Benavente (40 km north of Lisbon) earthquake which was also felt in Lisbon, very slight damages were determined in Pombalino buildings. Although the earthquake resistance of the buildings could not be fully observed at that level of damage in that period, recent experiments show that the wooden frame has high resistance to numerous shaking tests and absorbs seismic energy without losing its structural integrity (Cardoso et.al., 2003, Gülkan & Langenbach, 2004).

Figure 19 *Pombalino* buildings of Baixa Region, Lisbon, Portugal (Documentary Tube, 2022)

Traditional wooden framed buildings of India and Pakistan showed high resistance and did not collapse during the 2015 Gorkha earthquake, which took 80.000 lives and left 3 million people homeless. However, masonry and reinforced concrete structures were greatly destroyed in the same earthquake (Langenbach, 2015).

A similar condition can be mentioned about Haiti, which is also an earthquake prone country and has experienced a very strong earthquake recently. In the 2010 earthquake, which had a magnitude of 7 and took at least 200.000 people's lives, the traditional buildings maintained their structural integrity and experienced less damage. Nevertheless, most of the reinforced concrete structures in the city center collapsed. In the same year, approximately 500 people lost their lives in the Chile earthquake, which had a magnitude of 8.8. Although the Chile earthquake was larger, it was less destructive than the Haiti earthquake due to Chile's earthquake resistant urban planning strategies and construction techniques (Langenbach, 2010).

In the light of this information, it can be mentioned that, although most of the earthquake resilient traditional building techniques have been abandoned in time, these techniques perform well during the earthquakes as their weaknesses were improved during their evolution process.

As the construction process of modern buildings cannot be easily controlled in rural areas and accordingly the construction quality is often low, it is necessary to prevent the abandonment of traditional techniques in rural areas. This requirement is important not only in terms of earthquake resistance, but also in ensuring the sustainability of rural settlements.

4.3. Traditional Ottoman House as an earthquake resistant and sustainable system

The Ottoman Empire, which ruled between the 14th and early 20th century, produced many significant works that contributed to the architectural history for more than 600 years. The Ottoman residential architecture emerged from general tendencies of the nomadic communities which moved into Anatolia in the 11th century. Accordingly, the houses showed similarities with a traditional nomadic tent for a long period of time. Ottoman houses were built single-storied and consisted one or two rooms in the beginning. They evolved into traditional Ottoman House with the addition of wooden-framed upper floors in the 17th century (Tanyeli, 1996; Topçu, 2019, Güçhan, 2007). The Ottoman House were built with different plan types as can be seen in Figure 20.

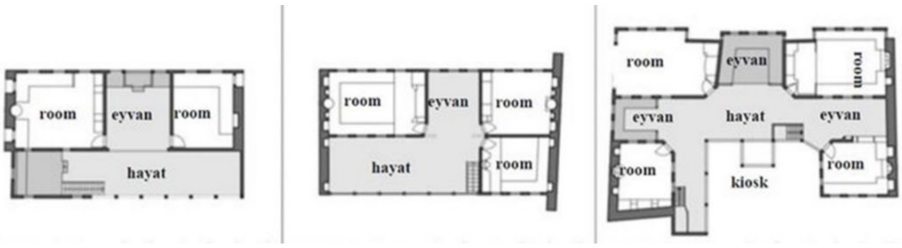

Figure 20 Different plan types of traditional Ottoman House

This system, which is built with wooden-framed upper floors on a masonry ground floor, is defined as *hımış.* The empty spaces between the frame are filled with local abundant materials such as stone, adobe, brick or lath and plaster. Lath and plaster *hımış* buildings are also quite common as they don't increase the weight of the structure and considered safer in earthquake prone regions. Figure 21 shows an example of a *hımış* building built with brick infilled wooden-frame (Güçhan, 2007; Koca, 2018).

Figure 21 *Hımış* house, Cumalıkızık, Bursa

As they are mostly built without the interference of any professional *hımış* buildings are defined as "non-engineered buildings".

4.3.1. Evaluation of traditional Ottoman House according to earthquake resistance

Non-engineered buildings are constructed by using empirical knowledge in solving the specific problems of the region in which they are located. However, buildings may confront serious problems in cases where these references are not fully or inadequately implemented. Therefore, it is a necessity to introduce and implement a set of rules in order to increase the earthquake resistance of these structures, as they are built without the support and control of professionals. *"Guidelines for Earthquake Resistant Non-Engineered Construction"* describes measures and practices to increase the earthquake resistance of non-engineered buildings (Arya et.al., 2014).

Earthquake is a natural phenomenon and the major result of an earthquake which cause damage is "ground shaking". Buildings may take hazard or collapse due to earthquake induced acceleration, velocity or displacement during an earthquake (Arya et.al., 2014).

Buildings give an unseen respond to the seismic force and this resistance is defined as "inertia force". Inertia force is directly proportional to the weight of the building (Figure 22). Therefore, the weight of the building material is important in seismic design. The lighter the material, the smaller will be the seismic force (Arya et.al., 2014).

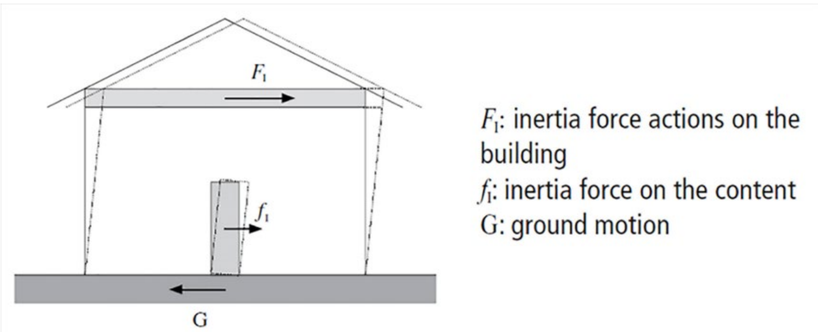

Figure 22 Inertia forces caused by the earthquake ground motion (Arya et.al, 2014)

Building elements normally only bear to vertical loads. However, horizontal bending and shearing effects on the building also increase during an earthquake due to the increase in bending tension stress. Accordingly, the tensile strength of the materials should be high to increase the earthquake resistance of the building. As the tensile strength of brick and stone is relatively low, significant cracks occur in masonry walls and this reduces the resistance to bending load (Arya et.al., 2014).

There are different factors that affect the building during an earthquake. The intensity of the earthquake, ground acceleration, duration of the shaking, distance to the center of the earthquake, etc. are factors that cannot be controlled. However, the seismic characteristics of the building site, soil type and the structural properties of the building can be controlled (Arya et.al., 2014).

The following features a can be listed as in Table 1 in the design of earthquake resistant buildings;

Table 1 Important features of earthquake resistant design in relation to soil and building properties

1	**Soil type**	Settlements placed on bedrock and hard soil is safer
		Settlements placed on soft soil is riskier
		Flat topographies are less likely to be hazardous
		Cliffs, narrow valleys and steep topographies are more likely to suffer damage
		Precautions should be taken for ground water
2	**Plan type**	Regular and symmetrical plan schemes are safer
		The seismic response of single-storey buildings with a rectangular plan is better
		Torsional effects can be observed in L or U plan schemes, these plan schemes should be separated
		Dimensions of enclosed areas should be small, interconnected walls should be added in order to build a rigid box
3	**Wall openings**	Size and number of wall openings affect the seismic resistance Larger and numerous wall openings lead to vulnerability
4	**Distribution of structural elements**	Load-bearing walls should not be interrupted.
		"Aspect ratio" of a load-bearing wall is important Walls with large aspect ratio may slide Diagonal cracks occur on walls with moderate aspect ratio Diagonal and horizontal cracks occur on walls with small aspect ratio.
		A complete wall enclosure with a roof will provide box behavior
5	**Strength properties of the building**	All structural elements should be connected to each other in order to lead the building act as a single unit during the earthquake
6	**Foundations**	Mixed foundations (different foundation types used together) have a very high risk
		The depth of foundation is important, shallow foundations have high risk as they are more affected by climatic conditions (freezing in cold regions)
		In areas with high earthquake risk, isolating the structure from the earthquake effect is a suitable solution to prevent friction between the structure and the foundation A flexible connection must be created between the structure and the foundation to ensure insulation A well-known method which is used for this purpose is to place the structure on a solid ground and support it with short poles
7	**Material selection**	Materials with high tensile, compressive and shear strength are safer
		Unit weights of the materials should not be high
		The deformation ability and bending strength of the material should be high
		Mortar should be flexible enough to allow elastic behavior
		Brittle materials such as; adobe, brick and concrete are risky as they can cause sudden collapse under high rates of loading Strengthening brittle materials with steel increases ductility
		Using ductile materials such as; steel and wood are useful
8	**Features about fire**	Fire is one of the most common problems after an earthquake and therefore, fire-resistant and non-flammable materials should be preferred to prevent fire
		Materials which prevent fire progression should be selected
9	**Workmanship**	Providing proper construction details and a careful construction process is crucial in improving the earthquake resistance of the building

Traditional timber-framed *(hımış)* buildings are considered one of the most important building types of the Ottoman Period. Hımış system emerged after a long trial and error process and the construction techniques improved during this process in order to increase the earthquake resistance. The techniques estimated to be used for this purpose can be listed as follows;

- Adding wooden ring beams at certain intervals to prevent masonry walls from collapse due to earthquake load
- Using lightweight materials, such as wood, at the upper floors in order to lower the center of gravity
- Supporting the corner studs and the studs on the bay window edges with secondary wooden elements and diagonals to increase the lateral strength of the wooden frame
- Connecting wooden elements with nails to allow small movements, instead of using wooden joints that reduce flexibility
- Building lath and plaster upper floors to lighten the wooden panels of the system (Figure 23)

Figure 23 Lath and plaster *(bağdadi)* wall

When the traditional Ottoman House is evaluated according to the earthquake resistance improvement methods which are put forward by UNESCO (Table 2);

Table 2 Evaluation of Traditional Ottoman House in relation to soil and building properties

No	Feature	Evaluation
1	**Soil type**	When the settlement pattern of the Ottoman Empire is evaluated, it can be observed that the settlements were built on bedrocks and hard soiled lands. The settlements were usually located on slightly sloping lands to benefit from heat and light.
2	**Plan type**	The traditional Ottoman House was usually rectangle or square planned. The depth of oriel windows was designed proportional with the street width and supported with angle braces and diagonals added to strengthen the masonry walls
3	**Wall opening**	As ground floor walls are more important in increasing the earthquake resistance of building, they are often built of masonry and with less openings. Wooden ring beams were placed along the masonry walls in order to transfer and evenly distribute the loads and also to prevent overturning of masonry walls during an earthquake
4	**Distribution of structural elements**	The masonry walls of the ground floor were usually built with no openings or few openings. Wooden ring beams were placed along the wall to increase the earthquake resistance. Wooden framed upper floors were connected to the masonry walls with horizontal wooden elements which surround the inner and outer surface of the masonry wall, and then the frame is completed with regularly placed wooden studs.

		Secondary wooden elements and diagonals are placed at corners, near the openings and oriel windows to increase the lateral resistance of the wooden frame. The panels were then filled with local abundant materials. The "panels" and the "wooden frame" structurally integrate with each other during an earthquake. The wooden frame absorbs the seismic energy and maintains the structural integrity of the building. The collapse of panels usually does not lead to the complete collapse of the structure. Lighter and more earthquake resistant systems can be obtained instead of using heavy infill materials such as; brick, adobe or stone. Lath and plaster technique is a light, elastic and earthquake resistant alternative rather than these infill materials. The roof is built with a wooden frame and connected to the system with nails. Wooden elements are fixed with nails, in order to increase the flexibility of the structure under seismic loads.
5	**Strength properties of the building**	In order to ensure the structural integrity of traditional Ottoman House; • wooden ring beams are added inside masonry walls, • wooden wall plates are laid on top of the masonry wall to increase the resistance of masonry walls • corner posts and studs are added to tie the upper and lower floor plates diagonals and secondary wooden elements are added to the corners to absorb lateral loads.
6	**Foundations**	Different types of foundations such as individual footings or continuous foundations were used in the construction of traditional Ottoman House. At the beginning of its evolution process usually shallow foundations were observed (Cerasi, 1998). However, the depth of the foundations increased and the building-soil integration became stronger in later periods as the builders excavate until they find a hard ground (Azezli, 2009).
7	**Material selection**	As wood is a ductile material which has the ability to undergo significant plastic deformation under stress, wooden ring beams make an important contribution in absorbing seismic energy. They are added along the masonry walls in order to reduce the risk of cracking, overturning and collapse of the wall as stone is a brittle material. Lowering the center of gravity and decreasing the weight of the building is important in increasing the earthquake resistance. Therefore, traditional wooden framed constructions such as *hımış* is very efficient in ensuring the earthquake resistance of the building. It lowers the center of gravity by using stone in the ground floor and using wooden frame in the upper floors and decreases the inertia force by keeping the weight of the building low. Clay-based and lime-based mortars are frequently preferred as binding materials, both in masonry walls and wooden panels. They are advantageous because of their high flexibility and deformation ability.
8	**Features about fire**	Since the upper floors are mainly built with wood, the fire resistance of the building is low. Wood can catch and spread fire easily. In some cases, it can cause a whole neighborhood to burn down with the help of the wind. The construction of Traditional Ottoman House was prohibited several times during the Ottoman Era to prevent this problem. However, this prohibition was not implemented due to many advantageous features of this building type. Building a masonry wall outside the wooden frame could be preferred just like the Pombalino style buildings, to avoid this problem. However, this practice both increases the weight and the inertia force of the structures. In order to increase the fire resistance of the Traditional Ottoman House, precautions such as fire retardants can be more efficient.
9	**Workmanship**	Proper construction details are one of the most basic parameters in increasing the earthquake resistance of the buildings. Therefore, trainings should be given to the builders and local authorities to increase the awareness and to control the buildings during the construction process.

When the methods which are recommended by UNESCO to increase earthquake resistance of non-engineered traditional buildings and the production methods of traditional Ottoman House are compared, it can be observed that it was designed in accordance with most of these methods.

Wood's sensitivity to various organisms and its low fire resistance are the shortcomings of the Ottoman House that need to be solved among the mentioned topics. Nowadays, wood's fire resistance and biological durability is increased by preserving wood with different chemicals.

Beside many positive features in terms of earthquake resistance, traditional Ottoman House also has the potential to support the sustainability of rural settlements by strengthening the connection between the users and their local knowledge and cultural heritage. For this reason, wooden-framed buildings have significant advantages in terms of sustainability.

4.3.2. Evaluation of traditional Ottoman House according to sustainability goals

The buildings are expected to be compatible with the natural environment, contribute to sociocultural sustainability and support the economic development of the region in building sustainable settlements.

In the European Union Project titled *"Versus, Heritage for Tomorrow: Vernacular Knowledge for Sustainable Architecture"* the characteristics of traditional buildings built in different parts of the world were evaluated in terms of sustainability.

Environmental, sociocultural and socioeconomic characteristics of the buildings were examined in this project (Figure 24).

Figure 24 Environmental, socio-cultural and socio-economical sustainable principles (Correia et.al., 2014)

Criteria related to *"environmental sustainability"* focus on minimizing human being's intervention in the environment, taking measures to reduce the negative effects of built environment and finding solutions to remove the deteriorations that have already occurred because of the built environment. In this context, some subtitles have been determined regarding environmental sustainability as;

- To respect nature
- To be appropriately situated
- To reduce pollution and waste materials
- To contribute to health quality
- To reduce natural hazards (Correia et.al., 2014).

Constructing the building in harmony with the topography, making minimal intervention in the natural environment, orienting the building in the proper direction to benefit from the environmental factors, using local materials, combining technical and empirical methods are some strategies being discussed in the context of environmental sustainability (Correia et.al., 2014).

Criteria regarding *"sociocultural sustainability"* examines the effects of built environment on social relations such as, sense of belonging, identity, personal and social development. The subcriteria which are discussed within this framework aims to support all positive social and cultural developments in society. Accordingly, these are;

- To protect cultural landscape
- To transfer construction cultures
- To enhance creativity
- To recognize intangible values
- To encourage social cohesion (Correia et.al., 2014).

Social sustainability subtitles emphasize subjects such as; understanding the value and dynamics of the settlement area, protecting biological diversity in the region, valuing collective memory, providing the support of local community and ensuring the transfer of cultural and historical values (Correia et.al., 2014).

Finally, *"socioeconomic sustainability"* criteria deal with the environmental characteristics of the construction process of traditional buildings. Here "cost" is related with "labor" as traditional building construction is not a capital-intensive industry. The subtitles related to this criterion are;

- To save resources
- To extend the building's lifetime
- To optimize construction efforts
- To promote local activities
- To support autonomy (Correia et.al., 2014).

Fair sharing of resources, encouraging shared use of spaces, constructing appropriate scaled buildings, eliminating transportation problems, constructing resistant and durable structures, preferring recycled materials and supporting passive systems are discussed under this title (Correia et.al., 2014).

"Traditional *Ottoman* House" was also evaluated within the scope of the study which examines the relationship between sustainability and architecture. According to the evaluation of these fifteen subtitles defined under three main titles; it can be mentioned that the Ottoman House meets the sustainability criteria above average (Correia et.al., 2014).

5. Conclusion

Most of the common features of earthquake-resistant buildings are found in the traditional Ottoman House. However, when the current situation of rural settlements is evaluated, it is observed that traditional Ottoman Houses are often abandoned or neglected. Due to the lack of a broad conservation and restoration culture, traditional buildings are damaged or destroyed during earthquakes. Positive results could be achieved if the construction, use and maintenance terms of traditional buildings are encouraged by governments, inspected by local authorities and maintained by the owner.

Another important requirement is to understand traditional skills and knowledge, improve this knowledge by combining it with modern materials and techniques and to make innovations.

As well as traditional knowledge and authenticity of traditional building techniques are important in improving modern construction techniques and-abilities, it is also beneficial in reducing the long-term vulnerability of local communities in terms of earthquake.

In conclusion, taking advantage of traditional building techniques, particularly traditional Ottoman House in Türkiye, to build sustainable and earthquake-resistant settlements will help to;

- Control the population growth in urban areas by preventing migration from rural areas
- Reduce financial and emotional losses related to earthquakes
- Protect the natural environment and biodiversity
- Protect historical and cultural heritage

- Ensure agricultural development
- Develop alternative tourism types by highlighting the values specific to the region in the long term.

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Resume

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