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Observations on earthquake resistance of traditional timber-framed houses in Turkey

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Abstract

The aim of this study is to establish the earthquake behaviour of traditional timber-framed houses in Turkey and their technical features to serve as a guide in their conservation. This paper first discusses the destructive effects of changing settlement patterns on the traditional building stock and explores earthquake damage on traditional Turkish buildings, analysing the 1894-İstanbul, 1970-Gediz and finally 1999-Kocaeli earthquakes. A short definition is then provided of timber-framed building methods in Anatolia, and the earthquake damages occurring in them are given. The following section briefly discusses the earthquake behaviour of timber-framed constructions in different countries. The paper concludes with the interpretation of features that increase the earthquake resistance of timber-framed buildings, which are related to the selection of land and the use of the lath and plaster technique, timber lintels, braces and nails.

Keywords: Turkey; Earthquake; Traditional houses; Timber; Timber-framed houses; Construction technique

1. Introduction

1.1. Changing settlement strategies and their implications for the urban fabric

Anatolian cities, showing typical characteristics of the pre-industrialized Ottoman cityscape, were subjected to extensive transformations due to rapid urbanization and modernization processes which took place after the establishment of the Turkish Republic in 1923. Preservation and planning activities were gradually developed and redefined to control and direct this unexpected change until the 1940s. However, it was only after 1951, when another wave of modernization due to the mechanization of agriculture in the rural areas had pushed people out of villages and into the urban areas, that preservation and planning activities became parallel processes by new preservation laws put into action and the establishment of new institutions related to such laws.

Again, efforts made for the sake of "modernizing" the cities due to this internal migration resulted in the gradual loss and replacement of the old urban fabric. New traffic arteries were opened in the traditional sectors creating new development areas along their stretches. Hence, by the end of the 1960s, the abandoned traditional sectors of the cities became squatter areas and led to loss of public interest in such areas and in related types of architecture-mainly timber-framed construction.

The insufficiency of the existing policies and economic resources to develop new land to accommodate the fast rate of urbanization had caused reconstruction of cities over the existing urban fabric. Beginning in 1973, with the legalization of the concept of "conservation area", building rights were restricted within the boundaries of the registered "urban conservation sites". This resulted in the practical freezing of construction activity and a decrease in land values at these sites and their gradual transformation into shelters for low-income groups [1].

After 1980, parallel to the neo-liberal transformations that occurred in the political system, some fundamental

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changes were brought about in the national planning activities. These changes were decision making at a local scale rather than centrally, making partial plans rather than total plans, and populist planning strategies rather than constructing strategies for the future. This strategy dealt a major blow to the efforts of establishing an integral planning understanding in a modernist approach, which was in the process of developing until that period. Tekeli [2] defines the situation in Turkey after 1980 as a period when "*city planning, as a modernity project had withdrawn from the stage*" and states that, "*the actual city plans had become a collage of partial plans instead of being a single organic entity*". In the period after 1980, when the cities once again began to have a high immigrant population and populist policies began to reign, the cities began to lose their local characteristics. Historic parts of the cities and vernacular structures of the urban areas were once again transformed into environments consisting of building masses with deficient infrastructure created by the speculative demands of various interest groups.

Parallel to these transformations taking place in the planning field, certain construction techniques, that were apparently considered "modern", began to be favoured extensively. Especially after the 1960s, the concrete frame system was accepted as the sole option and was used abundantly throughout the entire country. By using this system of construction, the cities were subjected to widespread building activity, including the newly introduced trend of constructing summerhouses in the coastal regions. As a consequence of such trends in the above-mentioned settlement strategies and related urban construction techniques, the traditional timber-framed houses, which prevailed for 300 years in Anatolia, were gradually abandoned and almost completely forgotten.

1.2. Re-thinking timber-framed construction as an alternative for the future

The earthquakes of 1999 brought into discussion the importance of the selection, production and usage of construction techniques as the buildings affected by the earthquake were mostly built with concrete frame systems. As a consequence of these discussions, the timber and steel frame-building systems, used widely in earthquake-prone areas in developed countries, were introduced into the building market and adopted mostly by higher income groups.

These developments also brought into consideration the conservation and reutilization of timber-framed houses, which form 80% of the total number of houses registered as cultural objects in Turkey. The recent and rising trust of the public in new timber-framed structures due to the consequences of earthquakes should also be oriented to the conservation of traditional buildings. This approach will make a considerable contribution towards the protection of Turkey's cultural heritage. In order to achieve this purpose, the measures developed in the timber-framed building tradition against earthquakes should be well understood.

"Traditional timber-framed houses", which form the bulk of the historic urban fabric in Turkey, were brought into these discussions due to their earthquake-resistant properties as well as their cultural value. Research carried out thus far on traditional houses in Turkey has tended to focus on the historical, architectural, local and material properties [3,4]. In Turkey, there is hardly any detailed research on their construction techniques and static properties. Unfortunately, studies on the earthquake behaviour of traditional timber-framed buildings are also not very common in Turkey. The aim of this paper is to begin filling this gap and guide restoration implementations for timber-framed buildings.

The following section aims to discuss the effects of earthquakes on traditional timber-framed buildings in reference to former earthquakes, and establish the possible uses of traditional methods developed against earthquakes. The section will also offer concrete data for the restoration of traditional houses in Turkey, especially in terms of the determination of structural interventions. Several earthquakes have occurred in Anatolia between 1894 and 1999 [5,6]. The criteria used for the selection of the examples mentioned in this study are their locality (earthquake-prone areas where the timber-framed house tradition exists) and availability of information (damage reports) on the earthquakes. The consequences of the 1894-İstanbul, 1970-Gediz and lastly 1999-Marmara (or Kocaeli) earthquakes are examined from a historical perspective with reference to case studies in regions where traditional timber-framed structures are found, and the damage types and their consequences are discussed.

The consequences of the earthquake of August, 17th 1999 in Marmara-Kocaeli were examined and assessed by the author during a site survey conducted one month after the earthquake. The basic reason for including the 1894 earthquake in this study is because in that period, houses in İstanbul were mostly of timber-framed construction and sufficient descriptive data are available [7]. Similarly, there are some damage reports, which include valuable visual documents on timber-framed houses without an assessment of their physical condition, which can be used as first-hand references on the 1970 Gediz earthquake [8,9].

In the third section of the paper, prepared on the basis of the research made by the author [1], the tradition of timber-framed houses in Anatolia is defined in terms of construction techniques, material properties and earthquake-resistant features. The fourth section deals with some supporting findings from abroad, especially from Japan. The paper concludes with a discussion on the advantages and disadvantages of utilizing traditional timber-framed construction techniques in earthquake-prone areas.

2. Earthquake and timber-framed structures from a historical perspective

Anatolia has experienced many earthquakes throughout its history [6]. Available historical sources, helpful in examining the effects of these earthquakes on timber-framed houses, are rather limited. However, resources available on the Ottoman and/or Turkish house reveal some important information on the relation between the tradition of timber-framed construction and earthquakes.

The tradition of timber-framed houses in the central, western and northern regions of Anatolia first appeared in the medieval and early Ottoman period and improved especially after the second half of the 16th century. 16th century travellers state that the entire housing fabric of İstanbul, except important administrative buildings, consisted of single-storey mud brick masonry structures [4]. Faroqhi [10] states that the same was true for Ankara and that two-storey buildings became widespread by the 17th century. Thus, it may be stated that timber-framed house construction in Anatolia is the outcome of a 300-year tradition.

Arel [11] states that the use of timber-framed construction, an Anatolian tradition, is a consequence of the earthquake of 1510 (*Kıyameti Suğra/Great Catastrophe*), giving the following information:

> "...*In spite of this, the habit of building higher ordinary city houses in masonry must have been prevented by bringing into force some legal measures: after the destruction of 109 mosques, 1070 houses and most of the fortification walls during the earthquake of 1510, 37,000 workers from Anatolia, 2,900 workers from Rumelia, 10,000 workers of İstanbul were recruited in order to reconstruct the city with timber*."

This information given by Arel provides evidence that the timber-framed construction system was preferred for its strength against earthquakes compared to other masonry systems of that period. After the earthquake of 1509, a number of earthquakes affecting İstanbul and its vicinity took place in the years 1659, 1719, 1754, 1766, 1863 and 1894 [7]. However, due to the limited number of documented evidence, it is difficult to state whether there were similar legal measures to carry on the tradition of timber-framed construction as a preventive action after these earthquakes.

On the contrary, precautionary measures against fires can be found in the official documents of *Divani Hümayun* (the Imperial Chancery of State) covering the years 1495–1882, compiled by Refik [12,13], that declare the obligation of construction in masonry, eaves with short overhangs, limitation of building heights and banning of the utilization of timber-building elements like *tahtapuş* (synonym of *sofa*, *the* main hall, a shaded semi-open circulation and entrance space), etc. These legal documents indicate that the fear of earthquakes had been forgotten by then and the masonry construction system was in greater favour compared to timber-framed systems due to the frequent fires occurring in İstanbul. However, despite these regulations and/or later laws [14,15] restricting the usage of timber-framed construction techniques, which were put into force between 1848 and 1882 aiming to realize planning activities in more occidental norms, this system continued to be used widely, even in İstanbul. Çelik [16] states this same fact by observing that the timber-framed construction technique continued in İstanbul throughout the 19th century: "*the inhabitants living in disadvantaged or suburban districts, who could not afford masonry buildings, were exempted from this constraint*".

2.1. 1894 İstanbul earthquake

Feriha Öztin's study [7] is especially important for its detailed data on the 1894 İstanbul earthquake. Öztin states the difficulty of giving exact figures for the number of human lives lost and buildings damaged due to reasons of state censure, but gives detailed information about the different types of damage observed in the buildings.

According to the assessment of Öztin [7], during the earthquake of 1894 in İstanbul, the number of damaged public buildings built in stone and/or brick masonry—which consisted of mosques, churches, hans, public baths, madrasas, hospitals, railway stations, mansions, pavilion buildings—was 387, whereas the total number of damaged houses built in mud brick/stone masonry or in the timber-framed system was 1087. Due to the lack of information on the total number of buildings existing in 1894, it is difficult to assess the significance of these figures. However, if we can assume that the percentage of public buildings in Ottoman cities of this period was 10% while the percentage of residential buildings was 90%, it becomes apparent that the damage ratio of the two groups was noticeably different.

Regarding the outcome of the information that Öztin [7] has gathered from various resources, it may be stated that:

- The destroyed/damaged houses were masonry buildings in Yeşilköy and on the Marmara Islands.
- The most damaged/destroyed sections of the houses were the parts built in masonry such as fire walls, service walls, courtyard walls, chimneys, etc.
- In most buildings, the upper storeys or the roofs had collapsed or were destroyed.

Although it is difficult to reach a definitive conclusion from these data and define the construction system in exact terms, some features of the construction technique of houses which have survived from 1894 until today may be described. The construction technique specifications of a typical Anatolian house, explained in detail in the third section, seem to be valid for İstanbul houses despite some local variations [4].

When the remarks of some witnesses of the 1894 earthquake are examined, some contradictions may be observed. For example, Dybowski [7] quotes that in Adapazarı, the earthquake turned one building in five to ruins and points out the poor quality of the timber-framed buildings in the region. On the other hand, the interpretations of D. Eginitis, the director of The Observatory of Athens who thoroughly examined the damage in the city and reported his observations to Sultan Abdülhamid II, are completely different from Dybowski's. Eginitis states that the damage varied from district to district according to the geological characteristics of the ground and explains his observations on the buildings as follows [7]:

> "…*Besides, the merit of being timber reduced the loss. It must be greeted with pleasure that the buildings in İstanbul are not entirely built of masonry as in other regions. If this was the case the loss could have been more serious. The timber-framed buildings have resisted the earthquake amazingly. While some old timber structures of a mediocre quality were still standing, some well built, nice and new masonry buildings, even the ones joined with steel, were destroyed.*
>
> *It is clearly apparent that the timber buildings have resisted the earthquake better; on the contrary, the masonry ones have rarely withstood. The buildings of second degree of resistance after the timber ones are the buildings made of brick. The walls built with brick do not fall into pieces as they are elastic and strong, but collapse when there is insufficient tying and retaining. In Prinkipo (Büyükada), the central part of a house built of stone has collapsed while the parts built of brick stayed intact. This proves that the buildings constructed with brick joined by steel ties are perfectly resistant against earthquakes*…"

The observations of Eginitis as a technical expert on the subject are very important in confirming the fact that the buildings of the 19th-century urban fabric of İstanbul, mostly of timber-framed constructions, were more resistant to earthquakes compared to the masonry buildings.

2.2. 1970 Gediz (Kütahya) earthquake

Before the 1970 Gediz earthquake, the timber-framed building tradition was still common in the region and formed the majority of the existing fabric. The newly built public buildings were usually built in concrete skeleton and/or masonry systems. According to the reports [8,9] prepared after the earthquake, 10% of the buildings affected by the earthquake in the region consisted of structures built in concrete skeleton and/or masonry system while 90% were timber-reinforced and/or timber-framed buildings. However, in these reports, the total number of buildings and their construction techniques and the relationship between the damaged buildings were not given. So the problem mentioned in the 1894 earthquake arises here again, and making interpretations by observing the ratio of construction techniques of damaged buildings becomes difficult.

For this reason, it is not possible to establish a direct relationship between the damaged buildings and the number of human lives lost. Nevertheless, it may be stated that, according to the official records [17] the earthquake occurred at 23:02 p.m., measuring 7.2 (Ms) on the Richter scale, causing serious damage to 9452 buildings, with a loss of 1086 lives and 1260 injuries, which proves that the buildings were damaged but not totally destroyed, reducing the amount of human loss. On the other hand, the resources state that the fires, which started just after the earthquake, led to an increase in human loss in the villages of Gediz, Akçaalan and Kaya [8].

In the 1970 Gediz earthquake, less damage was observed in the reinforced concrete buildings, built conforming to the regulations and at higher standards, while the ones constructed in stone, brick or mud brick masonry systems showed more serious damage [8]. In the buildings constructed with the *Hımış* (a Turkish term used to describe the timber-framed system) technique, there were either stone, brick and/or mud brick infill or timber-framed walls clad in the *bağdadi* (the local name for timber lath and plaster) technique.

When the damaged buildings were examined, the following consequences according to the characteristics of the ground and/or other physical conditions of the buildings were observed:

- The timber-framed buildings built on solid ground were neither damaged nor suffered minor damages.
- The most affected parts in the damaged buildings were the stone, brick or mud brick masonry parts, built with weak mortar—such as the exterior main walls of the ground floor, service walls and chimneys (Figs. 1–3).
- In the cases where traditional infill materials of mud brick or stone were used, loosening of infill materials could be observed. In such cases, the timber-framed elements may have been deformed, but the frames stood intact (Figs. 2–5). Only minor damage or no damage

Fig. 1. An example showing the destroyed masonry ground floor in İgdiş Village [8].

Fig. 2. A severe damage in a masonry service wall in Akçaalan [8].

Fig. 4. A building where the frame infill is hollowed out in İgdiş Village [8].

Fig. 3. A severe damage in a masonry service wall in Örencik [8].

Fig. 5. A building İgdiş Village where the frame infill is hollowed out [8].

was observed in the buildings where timber lathing was used instead of infill materials (Fig. 6).

- When buildings with severe structural deformation were examined, it was observed that the ground floors were modified to serve as a shop or the windows were enlarged. During these interventions, in most cases, the braces strengthening the frame system against lateral forces were removed as well (Figs. 7–9).
- In another case, the framed structure located at a ground level different from the adjacent building showed severe damage in its middle floor due to the hammering effect, but the building still did not collapse (Fig. 7).

2.3. 1999 Marmara (Kocaeli) earthquake

In the earthquake of 17 August 1999 with a 7.4 (Ms) force, the number of severely damaged buildings was 50,000, human loss was 15,000, and the number of

Fig. 6. An undamaged building with a timber-framed ground floor in Akçaalan [8].

Fig. 7. An example in Gediz where the damage is caused by the removal of the posts and braces; the building is subjected to the hammering effect of the adjacent building [8].

wounded people was 32,000 according to the official records [17]. Before the 1999 Kocaeli earthquake, the majority of the existing building stock in the region consisted of recent buildings constructed with reinforced concrete or prefabricated systems and this group formed 99% of the damaged buildings. The number of timber-

Fig. 8. A timber-framed building in Gediz damaged due to the weakening of the ground floor by enlargement of the openings [8].

Fig. 9. A timber-framed building damaged due to the weakening of the ground floor by enlargement of the openings [8].

framed buildings was quite limited in the urban sections of this most important industrial region of Turkey. After the earthquake, a study was conducted of the timber-framed buildings of İzmit, Adapazarı, Gölcük and Değirmendere settlements, by a group of experts from the Department of Architecture of the Middle East Technical University, including the author. The following evaluations are based on that study:

- İzmit was one of the cities affected most severely by the Marmara earthquake. Damages occurred primarily in the newly developed sections of the city, whereas the historic core of İzmit, situated on solid ground with nearly 50% of its the buildings of timber-framed

Fig. 10. The condition of a Mesjit after the earthquake in the İzmit urban historic core. The building, which was documented by H. Topçu, was already in this condition before the earthquake.

constructions, was minimally affected. A comparative study was performed considering the condition of the buildings before and after the earthquake, based mainly on the research of Topçu [18] on the traditional buildings in the area in 1995, before the earthquake. The results showed that even the buildings having poor structural conditions before the earthquake remained undamaged after the earthquake; only a few had minor damages such as cracks or plaster loss (Fig. 10). In recent buildings constructed in reinforced concrete, some cracks occurred, while none of the buildings in the historic core had collapsed. This fact must be due primarily to the solid ground characteristics where the buildings are located.

- Sırrı Paşa Konağı (a mansion), located in Sırrı Paşa Street, did not have any significant damage; only the main timber post at the outer membrane of the central space in the upper floor had broken down causing partial damage to the ceiling. The investigation conducted on the damaged parts revealed that the main post had already lost its bearing capacity due to biological deterioration. The earthquake caused the breakage of the already weakened post and other consequent damages (Fig. 11).
- During the studies conducted in Adapazarı and Değirmendere, only a few—nearly 10—remaining timber-framed buildings were examined. In three of these buildings, the stone or mud brick infill of the timber frame of the lower floors was totally hollowed out, while in others no severe damage was found except some plaster cracks and plaster loss. It was also observed that these buildings were already unoccupied and not maintained before the earthquake (Figs. 12–14).

To summarize, as researchers such as Tobriner [19] have similarly observed, timber-framed traditional houses, despite being very few in number, were the least damaged structures after the 1999 Marmara earthquake.

3. Building specifications of timber-framed Anatolian traditional houses to be taken into consideration for their future use in earthquake zones

Timber is widely used in masonry load bearing, timber-framed or hybrid systems in the traditional house constructions of Anatolia, whereas the timber log technique is quite rare. In masonry buildings, the main construction materials are stone, brick and mud brick, while timber is used only as ties or spanning elements.

The main construction system of traditional timber-framed buildings in Anatolia is the hybrid construction technique, namely *hımış* in Turkish. The main characteristic of this technique is the construction of the ground floor in masonry, and the upper floor(s) using the timber-framed technique. Houses constructed in the *hımış* technique show a great variety in mass, plan, façade, architectural elements and ornamentation, but have quite similar constructional characteristics. This similarity is certainly attributable to the travelling building masters [1].

It will be useful to define the main structural characteristics of the "*hımış*" or "timber-framed" construction technique in order to interpret the earthquake behaviour of the houses mentioned in the previous section. The main sections of a timber-framed house can be defined in terms of three main groups (Fig. 15):

1. Masonry base,
2. Timber-framed section (floor(s)), and
3. Timber roof.

The "masonry base" of the house, consisting of the ground floor—this may include a basement and a mezzanine floor—and the foundations, is generally constructed in stone or by using stone and mud brick together. In this part of the building, the binding material is usually mud mortar, but in some cases the use of lime-enriched mortar can also be found. The masonry base of the building functionally consists of two parts: the foundations and the main walls of

Fig. 11. The damage that occurred on the ceiling of Sirrı Paşa Konak in İzmit, the front façade and the damaged main post at the upper floor.

Fig. 12. A building where simple plaster defects were observed after the earthquake in Değirmendere.

the ground floor. The foundations, which are built with rubble stone in a continuous, alternating or discontinuous order, extend at least up to the ground floor level (Fig. 16).

Fig. 13. A traditional building in an earthquake zone, with no damage after the earthquake but more abandoned and deteriorated compared to its state before the earthquake.

The ground floor walls constructed on the foundations are made of stone or mud brick and they are combined with timber tie plates regularly placed every 70–100 cm. These lintels strengthen the walls against horizontal loads and earthquake forces [20]. In the earlier period buildings, this part, defined as the masonry base, is used for service spaces as kitchen, storage, etc.

The masonry base fits the shape of the lot on which the building is located, whereas the upper floor is constructed in a regular geometrical shape with the projections built within the capabilities of the timber-framed system. Before the construction of the upper floor, the timber wall plates

Fig. 14. Two buildings in the earthquake zone with defects of plaster and infill material.

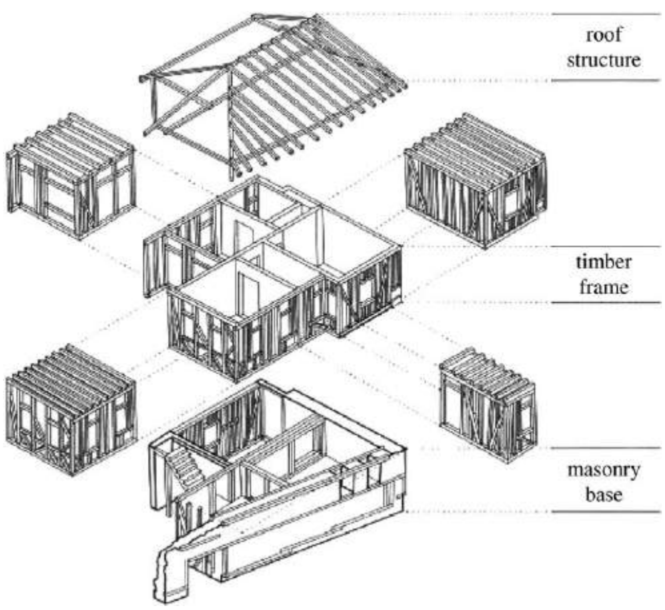

Fig. 15. Sections of a timber-framed Anatolian house, an example from Ankara [1].

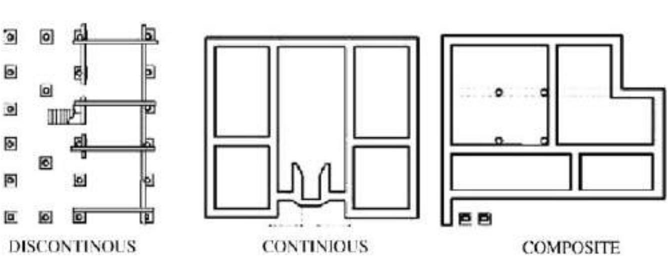

Fig. 16. Schematic drawing of foundation types in a timber-framed structure [1].

are placed on the inner and outer edges of the ground floor main walls. The free-standing posts placed in the semi-open circulation spaces known as *taşlık* are connected horizontally to the main beams, forming a base for the upper floors.

In the upper floors, the floor beams are placed on the wall plates below, forming the shape of the upper floor and the geometry of the room. The floor beams are spaced at 40–60 cm intervals, parallel to the short side of the room. The spatial dimensions are usually determined according to the size of the available materials, whereas in some larger spaces such as the *sofa*—the main circulation hall in Ottoman houses—and *taşlık* where a wide span is required, long timber beams with a relatively larger cross-section (like 15×20, 20×20 cm) are used.

If the building has a projection (*çıkma* or *cumba* in Turkish) on the upper floor, the load-bearing elements that carry the projection are constructed according to the type and extension of the projection and put in place at this stage. After the completion of the projection and the installation of the floor beams, the footplates, on which the main posts will be set, are placed at the outer edges of the walls. Subsequently, the corner posts and the main posts of the walls are placed and connected again by the wall plates on which the floor beams of the upper floor will be placed. The timber posts that will make up the main frame of the cupboards are built up at this stage similar to the inner and outer walls.

Preceding the construction of the wall frames, divisions of the wall planes are made by studs. The window posts and doorposts are mounted once their number and location are determined. Afterwards, the primary braces are placed to support the main corner posts and then the secondary posts, which divide the voids of the wall frame into equal intervals (30–40 cm) are built. All vertical elements are tied to each other with braces and tie beams, important elements in increasing the resistance of the building against lateral forces exerted by earthquakes forces [21]. In cases where the timber elements of the façade have been used for aesthetic purposes, they are arranged in a certain geometrical order together with the infill material. In addition to the use of stone, mud brick, brick or timber as infill material another widely used technique is the *bağdadi* -lath technique-. In this technique, both the interior and exterior surfaces of the walls are covered with timber laths and then plastered over. Wall materials such as stone, brick and mud brick usually cause damage to the buildings during earthquakes as they add extra load to the structure or in some cases because they have weak binding mortars. However, in the *bağdadi* technique, the timber laths increase the resistance of the building against lateral forces, and thus against earthquakes as they are light and function as additional ties and provide a certain elasticity. Various other experts shared this observation on the use of the *bağdadi* technique after the Gediz earthquake [8]. The timber weather boarding (*yalı baskısı*) of exterior façades became widespread especially after the 19th century in cities like İstanbul and Edirne. In this technique, various infills are used (lathing or brick) under the cladding. In cases where timber lathing is used under the weather boarding, this combined technique is again observed as a feature that increases the resistance of the structure against lateral forces.

In the timber-framed upper floors, one or more of the exterior walls and/or one of the inner walls, which serves as a service wall, is built in the masonry system up to the roof level. At each floor, the fireplaces and built-in cupboards are placed on this service wall. When there is no service wall in the building, the chimney walls of the fireplaces are masonry built reaching a level that is higher than the uppermost level of the roof.

During the Ottoman Period, some legal measures were taken regarding the chimneys, which were the main causes of the fires, such as enforcing the owners to build a firewall (party wall) in each house. However, these precautions seem to have failed in practice as evidenced by the building stock remaining from that period [14,15]. On the other hand, when the effects of the 1894 İstanbul and 1970 Gediz earthquakes on the buildings were examined, it could be clearly seen that the most damaged parts were the service and firewalls and the chimneys built in masonry.

During the construction process, considering the limits of the construction season, it is essential to finish the roof cover immediately after the completion of the timber-framed floors. The most common roof types used in these building are gable (*beşik*) or hipped (*kırma*) roofs. In the construction of the roof, as in the rest of the timber-framed parts, nails are used in the joints.

The timber-framed roof structure is set on the main roof girders, which are placed along the axis of the ridge purlin over the ceiling beams. The corner and king posts are placed along the full length of the ridge purlin, and tied to the ridge purlin. The ridge purlin is tied to the corners of the structure with the angle rafters determining the slope of the roof, and the opening between the ridge and the rafters is horizontally divided into equal intervals by the purlins. Laying of the rafters across the roof purlins completes the roof structure. Roof boards of 2.5–3 cm thickness are placed on the rafters and the over and under type tiles are laid down on the roof board. The roof is finished with the timber cladding of the eaves.

After the completion of the roof structure, the timber-framed wall infills, timber or brick floor coverings and timber ceilings are constructed and the outer membrane of the building is finished. The stairs within the timber-framed system are always constructed in timber. However, in some cases a few of the first steps are built of stone. The next stage of building is the manufacture and installation of architectural features such as doors, windows, shutters, timber lattices, cupboards, *aynalık* (niche for oil lamp), *sedir* (a built-in sitting platform), etc. The plastering and rendering work is done after the completion of the architectural features. The interior plasterwork follows the completion of the architectural features, whereas the rendering work may be done right after the completion of the main structure. The carving or ornamental works are added after plastering.

The timber structural elements used in these buildings usually have a cross-section of 10×10, 5×10 cm. In spaces with larger spans, elements with larger cross-sections (15×20, 20×20 cm) may be used which in any case do not exceed maximum 1 or 2 girders in a building. To join the timber elements, almost always simple nails are used; other more elaborate joints are not found in general except in some locations in Black Sea Region. In this region, certain details such as single housing (*bini*) and mortise and tenon (*lambalı geçme*) are used on the corners. Nevertheless, these cannot be considered among the elaborate timber joint details seen in northern Europe -as in United Kingdom or Norway. On the other hand, such complex joint systems are widely used in other timber elements such as doors, windows, balustrades, cupboard doors and ceilings. The rejection of the elaborate joints in structural timber-framed elements and their abundant use in architectural elements must be a conscious preference counteracting the effects of earthquakes [1].

4. Earthquake behaviour of timber-framed constructions: supporting findings from abroad

Parallel to the development of earthquake engineering as a profession, timber-framed buildings began to draw the attention of researchers in many other countries as well as in Turkey. In some developed countries such as the USA, Canada, Japan and Australia, the timber-framed technique is preferred due to its rapid construction process and low cost as well as the new technical possibility of ensuring security against fires and constructing relatively higher (3–5 storeys) buildings.

In these countries, common damages that occurred in timber buildings built before the introduction of earthquake standards were the sliding of the building on its foundations due to a weak connection of the timber frame with the foundation and collapse of the entire ground floor due to the effect of a weak first storey [22,23].

Keenan's study [24] of timber-framed buildings in several different countries states how less the effect of earthquakes is on the timber-frame buildings constructed using both traditional and modern techniques. The author points out that the reason why there was a loss of only 9 lives in a city of 85.000 people after the Anchorage–Alaska earthquake of 8.6 (in Richter) in 1964 is because the buildings were constructed conforming to the timber-framed building standards. It is also stated that in China, timber-framed buildings show a higher resistance to earthquakes compared to buildings constructed using modern techniques [25].

In Japan, an earthquake-prone country where timber-framed buildings constitute 90% of the existing housing stock, thorough research is being carried out on how to increase the earthquake resistance of buildings. As is commonly known, in a traditional Japanese house, metal ties, screws and nails are not used at all; instead the posts and beams are connected with mortise and tenon joints

[26]. The use of braces, which support posts and beams, is rather rare. As infill, the *Shinkabe* technique (bamboo trunks covered with mud plaster) is used. In another technique, devised by partially altering the traditional technique, which is called *Okabe*, the walls are clad with timber boards and plaster is applied on metal laths. The roofs are covered with traditional Japanese tiles or cement-based tiles/plates or with a metal covering which makes the roof quite heavy. The main types of damage seen in traditional Japanese houses after an earthquake can be summarized as follows [26]:

- the timber-framed houses built on soft ground are affected more by the earthquake,
- in two-storied buildings, the weak ground floors are damaged and/or completely destroyed whereas the upper floors remain intact,
- a frequent type of damage the sliding of the entire upper part as a whole where the foundations are not solid enough or the timber-framed part is not connected firmly to the foundations,
- the breaking, cracking or destruction of the mortise and tenon joints in the timber-framed elements causes bending problems and serious deformations or partial collapse of the building, and
- structural cracks and collapse of walls are the most common types of damage obtained in walls.

5. Conclusions

The consequences of the urbanization process in Turkey, which has caused the abandonment of traditional building techniques, were defined in the Introduction of the article. In addition to these facts, the disadvantages of timber-framed systems such as the restrictions of the timber techniques in the construction of high-rise buildings, inadequate resistance to fire, vulnerability to deterioration by biological organisms or common prejudices such as the destruction of forests due to timber usage in building, may be considered the main arguments against adoption of timber-framed systems in Turkey.

Contrary to the general opinion in Turkey, current research on this subject, briefly mentioned above, indicates the use of a timber-framed building system as a significant alternative towards prevention of earthquake damages. The extensive use of this technique in some developed countries such as the USA, Canada and Japan proves that this is no longer considered merely hypothetical, shows that the disadvantages of a timber-framed system can be worked upon by appropriate technologies and proves that the timber-framed building practice is actually viable, especially in earthquake-prone areas.

Following the 1999 earthquake, the timber technique was re-introduced as a construction alternative in Turkey. For example, new timber construction techniques presented by Canadian and American firms have been adopted by higher income groups, especially in İstanbul.

In addition to the above-mentioned aspects, one must also point out that the majority of listed historic buildings in Turkey are constructed in timber requiring the need for a better examination of these structures by various disciplines. When the issue is considered in terms of conservation of historical houses, this technique takes on a cultural dimension beyond a simple technical preference.

The following conclusions may be derived upon examining traditional timber-framed houses in terms of the above-mentioned research on earthquakes:

- The earthquake resistance of timber-framed buildings which are built on a soft ground without specifically designed details is very low. When we examine the locations selected for old settlements in Anatolia, we can see that the former building masters in fact took this feature into consideration and the cities were located on sound, rocky ground. The reason behind the minimal damage occurring in the houses of the İzmit urban historic core is evidence of this very same fact.
- The features that increase the earthquake resistance of the buildings are the timber lintels, braces and nails used in traditional Anatolian houses. Research conducted on traditional houses in Japan and the strengthening proposals comprise some similar details [26]. The use of nails instead of metal clamps, screws or joints in timber buildings particularly increases the flexibility of the structure [27]. Therefore, in Anatolian houses, the preference of mortice and tenon joints for architectural elements such as doors and windows, and the use of nails for the timber-framed section, may be a result of a well-considered choice. Continuation of this strategy in future interventions during the conservation and reintegration of the existing stock is very important.
- The lath and plaster technique (*bağdadi*) used in the timber-framed system is another feature that increases its resistance against lateral forces. As mentioned above, the use of stone, brick or mud brick as infill material causes damage to the buildings or the structure falls entirely during an earthquake as such materials are heavy and sometimes joined with weak mortar. In future interventions, the use of lighter infill material as timber lathing is important. Further studies should therefore be carried out to examine the potential of lighter infill materials.
- Some interventions performed for functional needs that obviously disturb the structural integrity and the balance of the building such as the enlargement of windows, removal of load-bearing elements—e.g. posts, buttresses, braces, etc.—should be strictly avoided in timber-framed buildings.

Within the framework of the conclusions derived above, it may be stated that traditional timber-framed houses in Anatolia tend to show a high performance against earthquakes due to their various characteristics beginning with the choice of location, up to the structural details. It is clear that these technical features are a result of deep-seated traditions based on many years of experience. The responsibility of professionals across various disciplines should be to carry out detailed studies on the timber houses of Anatolia and their technical advantages, and develop their technical capabilities for conservation. In many earthquake-sensible countries in the world, modern timber techniques are being used in new constructions. In Anatolia, this goal has already been achieved and should be used in the conservation of existing traditional historical timber-framed buildings.

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