Species and Deterioration of Woods Used in a Traditional Turkish House

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This study identified the wood species and evaluated the weathering and biological degradation of historical timber from a traditional Turkish house in Konuralp, Türkiye. The wood material was obtained from the floorboards, window frames, cabinets, cripple studs, ceiling boards, and joists. The species were identified as *Pinus* spp. for the cabinet, window frame, and cripple stud, *Abies* spp. for the floorboards, *Populus* spp. for the ceiling boards, and *Quercus* spp. for the joist. The macroscopic observation revealed multiple types of degradation caused by weathering, fungi, and insect attacks. The cripple studs made of pine and the floorboards made of fir had become completely unusable due to insect damage. Relatively less biological damage was observed on the cabinet made of pine wood and the ceiling boards made of poplar wood.

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INTRODUCTION

In recent years, countries with natural, historical, and cultural principles and riches have started to give more importance to these values. Türkiye is rich in terms of both the diversity and importance of historical, natural, and cultural assets. The transfer of these assets to future generations will be ensured by their protection. For this purpose, it is important to conduct the necessary maintenance and repair practices on schedule. The most important point to be considered in maintenance and repair works is that the originality of the work is preserved and that it continues to bear the traces of the period to which it belongs.

People must meet their important needs such as protection, shelter, and security, to continue their lives in natural and artificial environments (Arcan and Evci 1991). The cultural values of societies, the traditions that have been ongoing for years, have a long history that makes a society and builds its presence. The most concrete indicator of the traditional behaviors of societies is traditional housing culture, that is, home architecture. Traditional houses are one of the most beautiful forms that can display the material elements of the culture that has emerged because of the cultural assets that people have accumulated from the past to the present and their interactions with neighboring cultures (Gök and Kayserili 2013). Because of the existence of many different cultures and the characteristics of the climate, different materials are used locally in house construction. It is known that materials, such as wood, stone, and adobe, are used in the construction of houses in various regions of Anatolia.

Factors, such as climate, traditions, and customs, have been effective in the formation of the architecture of Konuralp houses, which have the characteristics of traditional Turkish houses. While it is seen that the plans of Turkish houses are shaped according to needs, it is known that Islamic culture also plays a role in the formation of plans, as well as natural conditions such as climate, topography, and geography. As in other traditional Turkish houses, it can be said that Konuralp houses are positioned in a way that does not block each other's view or the sun, and that the plan type, number of floors, and decorations are in line with the economic situation of the owner and/or the suitability of the land. There are living rooms, kitchen, toilets, or service areas on the ground floors, and living rooms and bedrooms on the upper floors. Ground floors are mostly used as living spaces (Naldan 2019). The parcel number of the house, which is located in the Konuralp neighborhood of Düzce province and is the subject of this study, is 1766, and the house is located within the boundaries of the Kocaeli Regional Board of Cultural Heritage Conservation, which was declared a second-degree protected area with the decision dated March 13th, 2013 and numbered 889. This building, which is located in the Çifte Pınarlar locality of Konuralp, was registered as a second-group cultural property with the decision of the same board dated September 30th, 2015 and numbered 2221. The building was built on a rubble stone foundation using the hımış technique. The two-story building was built with a wooden frame system, and wood was chosen as the filling material (Besni 2019). Mud brick was used as a filling material between the wood, and paint over mud plaster was applied on the interior and exterior walls (Sabuncu 2022). The most commonly used material in interior and exterior building elements is wood (Naldan 2019).

It is necessary to learn about the use of plants in history to understand some aspects of material culture and ways of life and the relationship of people with the natural environment (Melo Junior and Boeger 2015). Many studies have been conducted regarding the woods used in historical wooden structures, identifying the species, dating, and properties of historical woods in Anatolia (Akkemik and Köse 2010; Hızal Tırak and Doğu 2018; Uzun *et al.* 2018; Akkemik *et al.* 2019; Gezer and Aydoğan Selçuk 2020; Topaloğlu *et al.* 2021; Günaydın *et al.* 2023; Topaloğlu 2023) and the world (Hwang *et al.* 2009; Diadato *et al.* 2015; Madhoushi 2016; Dong *et al.* 2017; Doğu *et al.* 2017; Machado *et al.* 2019; Mertz 2021; Christopoulou *et al.* 2022; Hueto-Escobar *et al.* 2023). However, systematic information about the structure and properties of historical wood, which has been widely used in Anatolia and has an important place in architecture, is inadequate.

Due to its biological structure, wood is affected by several environmental factors (wind, rain, UV light, snow, and frost) and biological factors (mold, fungi, and insects) when used as a structural element (Palanti *et al*. 2012; Zarah and Avérous 2019; Marais *et al*. 2022). This susceptibility leads to deterioration in performance, reduced service life, decreased usage value, and other problems. Damage to the macro and/or microstructure of wood due to biological and environmental effects causes irreversible damage such as warping, wormholes, loss of strength, cracking, and loss of weight affecting its physical and mechanical properties such as dimensional stability, density, maximum water content, bending, compression, shear (Palanti *et al*. 2012; Qiao *et al*. 2016). When wood is exposed to outdoor conditions above ground, its structure deteriorates due to the effects of chemical, biological, mechanical, and light energy, known as "weathering" (Feist and Hon 1984). Initially, weathering causes changes in surface color (Arnold *et al*. 1992; William and Feist 1999), followed by the occurrence of cracks, increased roughness, and surface erosion (Feist 1990; William 2005; Özgenç *et al*. 2012). The primary factors influencing weathering are solar radiation and water (Hon and Shiraishi 2001; Teacà *et al*. 2013), although temperature, dust particles, acid rain, and air flow also contribute to surface degradation (William 2005; Reinprecht 2008). Various research studies have been conducted globally on the biotic and abiotic degradation of historical wooden buildings (Matsuo *et al*. 2009; Irbe *et al*. 2012; Macchioni *et al*. 2012; Palanti *et al* 2012; Piotrowska *et al*. 2014; Diodato *et al*. 2015; Pizzo et al. 2016; Madhoushi *et al*. 2021; Wang *et al*. 2021; Yang *et al*. 2023; Mi *et al*. 2023; Dong *et al*. 2023). However, despite the widespread prevalence of historical wooden architecture in Türkiye, the quantity of such studies is still limited.

Wooden structures and objects either become unusable or completely disappear as a result of faulty applications and destruction, both natural and human-induced. It is critical to protect the wood that has survived to the present day and to restore it close to its original state. The success of conservation work largely depends on the correct analysis of the wood material. For this reason, it is necessary to examine the wood structure in detail to determine the damage that has occurred to the wood and to identify the type of wood used in historical buildings. Especially in restoration works where it is recommended to make use of the same species, wood species identification is also important for the conservation of historic building heritage (Macchioni *et al.* 2012; Diadato *et al.* 2013; Diodato *et al.* 2015). The aim was to acquire information about the types and structures of wood by examining the wood used in the Konuralp house, which was the subject of this study, and this house is planned to be restored and is registered as a cultural property. Thus, the tree species used in the region was revealed and the species preferred by the local people was determined.

EXPERIMENTAL

Materials

The traditional Konuralp house is located in the Konuralp neighborhood of Düzce province in the Western Black sea region and is dated to the beginning of the 20th century (Naldan 2019). Konuralp is a settlement on the northeast side of the Düzce plain, at an altitude of approximately 200 m, 8 km north of the city center (Fig. 1).

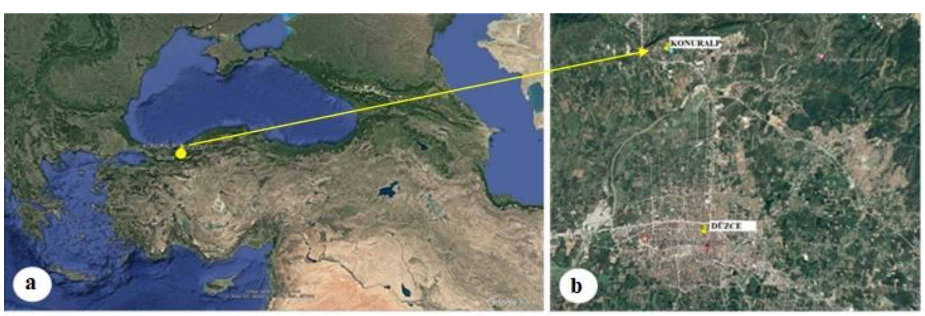

Fig. 1. a: Düzce in Türkiye; and b: Konuralp in Düzce (Google Earth 2022)

The visuals of the house with parcel number 1766 are given in Fig. 2. Because this house will be restored and the solid wooden parts will be reused to retain their originality, it was not possible to take samples from some parts of the house, and samples from some of the wooden structures of the house could not be obtained. While the surfaces of wooden material used in window frame, cabinet, and ceiling board are painted, no treatment was visible on the surface of the material used in cripple studs, floorboard, and joist. No information could be found regarding whether the wooden material used in the house was protected or not.

To protect the house and secondary destruction of cultural relics, wood samples were carefully selected from broken fragments or concealed positions. A total of five samples were collected from the floorboard, window frame, cabinet, cripple stud, and ceiling board. An *in-situ* wood element that belongs to the joist was identified and observed.

Fig. 2. Samples taken from the house in plot 1766: a: General aspects of house, b, c: Cripple studs, d: Window frame, e: Cabinet, f: Floorboard, g: Ceiling board, and h: Joist

Methods

Visual Observations

The wood species were examined to determine whether there was any evidence of weathering defects, insect activity, or decay. The macroscopic structure of wood was investigated with the naked eye and a hand lens (10x) on the small parts of wood. The existence of biological attacks was registered and the shape and diameter of the exit holes, the existence of visible internal galleries, and color changes of the wood in the case of fungi were determined.

Species Identification

Small wood samples were taken from the cabinet, window-frame, floorboard, ceiling board, and cripple stud and brought to the Düzce University Faculty of Forestry Wood Anatomy laboratory for macroscopic and microscopic examinations. No sample could be taken from the wood used in the joists, but the species could be identified by observation. These small specimens were boiled to soften them for species identification. The softened samples were sectioned with a thickness of 20 to 30 μm using a sliding microtome and stained with 1% safranin-O solution. After the stained sections were passed through a series of 50%, 70%, and 99% ethyl alcohol solutions to remove excess paint and water, they were washed 2 times with xylene to remove alcohol from the sections, and then mounted with Entellan to become a permanent preparation. Measurements and evaluations of all samples were made under a light microscope (Olympus BX51). The IAWA criteria were used in the diagnosis and evaluation of outcomes (Wheeler *et al.* 1989).

RESULTS AND DISCUSSION

Visual Observations

An apparent physical and biological deterioration was observed in the structure of all wooden elements at the macroscopic level. Based on the observations, it can be said that the causes of the defects seen in the wooden house are grouped under three headings: 1– effects of the weather, 2– rot caused by fungi, and 3– insect damage. The observations of the wooden samples chosen (floorboards, cabinet, window frame, ceiling board, cripple stud, and joist) are detailed below.

Floorboards

In the same room, it was observed that some parts of the floor were completely damaged by insects and lost, while in some of them there were wood samples that were close to solid. According to this observation, cracks (Fig. 3a1, arrow 1) and very small (0.5 to 1 mm) insect holes (Fig. 3a1, arrow 2) were observed on the wooden floor surfaces which had resulted from insect damage (Fig. 3a2). For example, there were fibrillations on the edges (Fig. 3a2/arrow 1), large and small-bore holes found in the sample (Fig. 3a2, arrow 2), and were bore holes and fecal pellets in the galleries (Fig. 3a2, arrow 3). Dark color and very small-bore holes (≤ 0.1 mm) were observed on the upper surface of the floorboard (Fig. 3b1-b2). Feist (1990) stated that light colored woods including softwoods become darker in color due to weathering conditions. The main factors that cause color changes are UV radiation, direct water contact, air moisture variations, air currents, biological agents (fungi, insects) (Kropat *et al*. 2020).

Cabinet

Paint residues on the upper surfaces, and very small-bore holes (Fig. 3c1) were observed. Circular bore holes (0.5 mm and smaller) (Fig. 3c2, arrow 1) and galleries filled with bore dust (Fig. 3c2, arrow 2) were found in the inner part of the sample. Earlywood was eroded, and latewood was evident.

Window frame

Erosion caused by weathering (sunshine and rainwater splashing) was found in window frames. Especially on the outer section of window-frames, erosion and grayish color were very intensive. The earlywood was eroded, and latewood was evident. The erosion of the wood surface is the result of chemical degradation of the wood by UV and visible light followed by a mechanical abrasion due to rain and wind (Sell and Feist 1986). The inner wood color was reddish brown, while the edge of the wood was whitish (Fig. 3d, arrow 1). It can be said that this was due to fungal damage. Fine cracks and splits were also observed (Fig. 3d, arrow 2). The cracks and splits caused by moisture and temperature changes (Feist 1990; Williams 2005; Özgenç *et al*. 2013).

Ceiling board

There were circular bore holes (1.0 to 3 mm), but they were not in large quantities (Fig. 3e, arrow 1). As stated in the literature, checks and raised grain on the surface of the ceiling board (Fig. 3e, arrow 2) are thought to have occurred due to the effect of moisture (Feist 1990; Williams 2005). There were dark colorations on the wood surface.

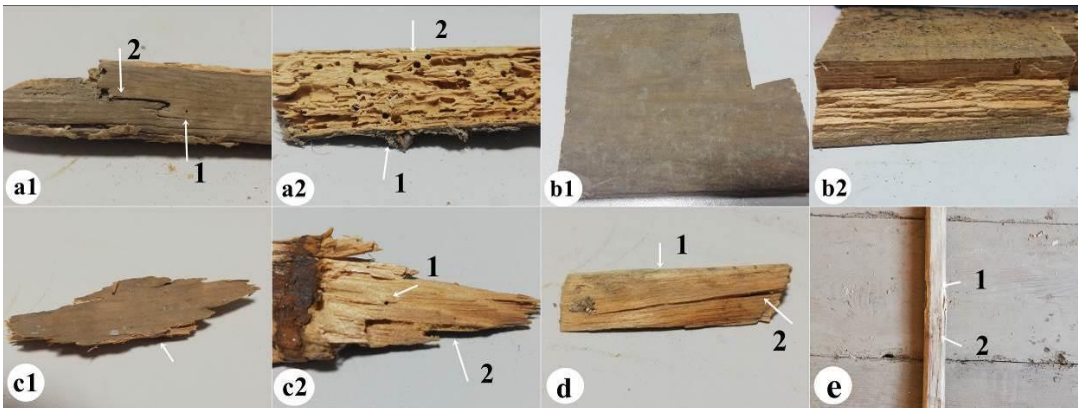

Fig. 3. Macroscopic views of floorboards, cabinet, window frame, and ceiling board. Floorboards: a1 – The wood surface in green, circular bore holes (arrow 1), cracks in wood surfaces (arrow 2); a2 – Eroded wood structure (arrow 1), larva galleries and several bore holes inside the sample (arrow 2), b1 – Upper surface of the floorboard, b2 – Small insect holes (≤ 0.1 mm) and brittle wood structure. Cabinet: c1 – Circular bore holes (≤ 0.1 mm) on the outer surface (indicate arrow), c2 – Circular bore holes (≤ 0.5 mm) (arrow 1), larva galleries on the inner surface (arrow 2). Window frame: d – White rot, 2– Fine cracks, and splits. Ceiling board: e – Small circular bore holes (arrow 1), 2 – Checks and raised grain on the surface (arrow 2)

Cripple studs

Wooden cripple studs had developed a greyish appearance and there were visible cracks and erosion in the wood surface (Fig. 4, a1). The bore holes were 2 to7 mm and large galleries with bore dust and fecal pellets were on the whole wood samples (Fig. 4a2, arrows 1-2). The inner parts of the wood samples were brownish in color and had larval galleries (Fig. 4a3, arrow 1), and there were cubic cracks (Fig. 4a3, arrow 2). All cripple studs were damaged by insects, and it was observed that the wood tissue had completely deteriorated.

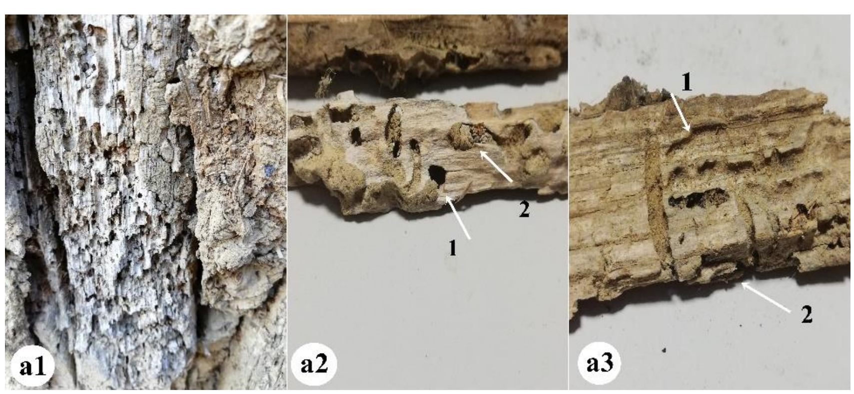

Fig. 4. Cripple studs: a1 – Visible bore holes; a2 – Light brown, intensive insects attacks, bore holes (arrow 1) and fecal pellets (arrow 2) visible on longitudinal sections; a3 – Larval galleries (arrow 1), cubic cracks (arrow 2)

Joists

An apparent physical and biological deterioration was observed in the structure of the wooden joists at the macroscopic level (Fig. 5). In general, the color of the joist surface was not uniform. The integrity of the surface was lost. Fungal mycelium on the ceiling surface (Fig. 5a) and a softened, bleached color on the surface of the joists (Fig. 5d) were observed. Those changes indicated that white-rot decay might have formed. This type of damage is always associated with high moisture content. In addition to decay, bore holes were detected both on the whole joist surface and on the decayed surface (Fig. 5b). Wide and long cracks (Fig. 5c) and large voids (Fig. 5e) were seen on the joists. It is thought that this may be due to the mechanical load and moisture content changes.

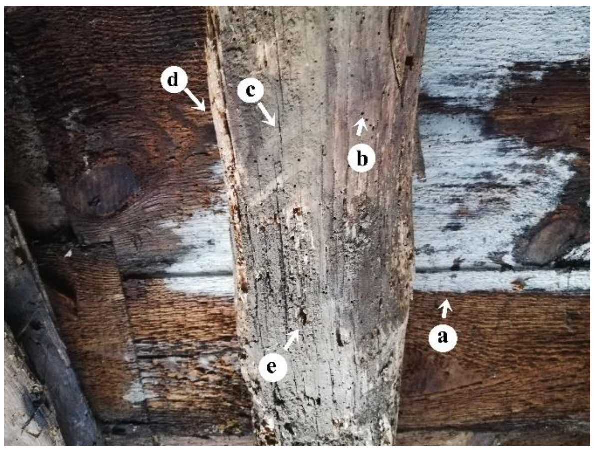

Fig. 5. Joist; a – Fungal attack, b – Bore holes of insects, c – Cracks in wood surfaces, d – Softened and bleached color, e – Large voids

Species identification

Microscopic identification of samples showed that the wooden parts of the house were made of hardwood and softwood species native to Düzce. As a result of the wood identification, the species were recognized as: *Pinus sylvestris* L., *Abies* spp., *Populus* spp., and *Quercus* spp.

Pinus spp.

Samples from the cabinet, cripple stud, and window-frame were identified as belonging to *Pinus* species (Fig. 6). Growth ring boundaries are distinct, the transition from earlywood to latewood is abrupt, resin canals are present generally in latewood, and epithelial cells of the canals are thin-walled (Fig. 6a1, c1). Wood used in cripple studs have distinct boundaries, the transition from earlywood to latewood is abrupt and gradual (Fig. 6b1). Axial parenchyma is absent. The ray heights are between 1-7 cells (Figs. 6a3, b3, and c3, yellow arrows). Rays are heterocellular and fusiform rays are present (Figs. 6a3, b3, and c3, green arrows). All rays have ray tracheids. There are 2 to 3 ray tracheids in the upper and lower parts of the rays, and the inner walls of the ray tracheids are markedly dentated. Cross-field pits are window-like types (Figs. 6a2, b2, and c2, yellow arrows). Considering the vegetation of the region, it can be thought that Scots pine and black pine species were used. Both black pine and Scots pine have window-like cross-field pits. There is only one difference that is slightly visible. The transition from earlywood to latewood is gradual in Scots pine and abrupt in black pine, in general (Schweingruber 1990; Akkemik and Yaman 2012). For these reasons, it is concluded the pine specimen defined as black pine (*Pinus nigra* J.F. Arnold) was used for the cabinet and window-frame and the Scots pine (*Pinus sylvestris* L.) was used for the cripple stud. Although this wood is of medium density and is known for its limited resistance to rot, termites, and woodworm (Vignote 2014), it was a highly preferred species in Anatolia.

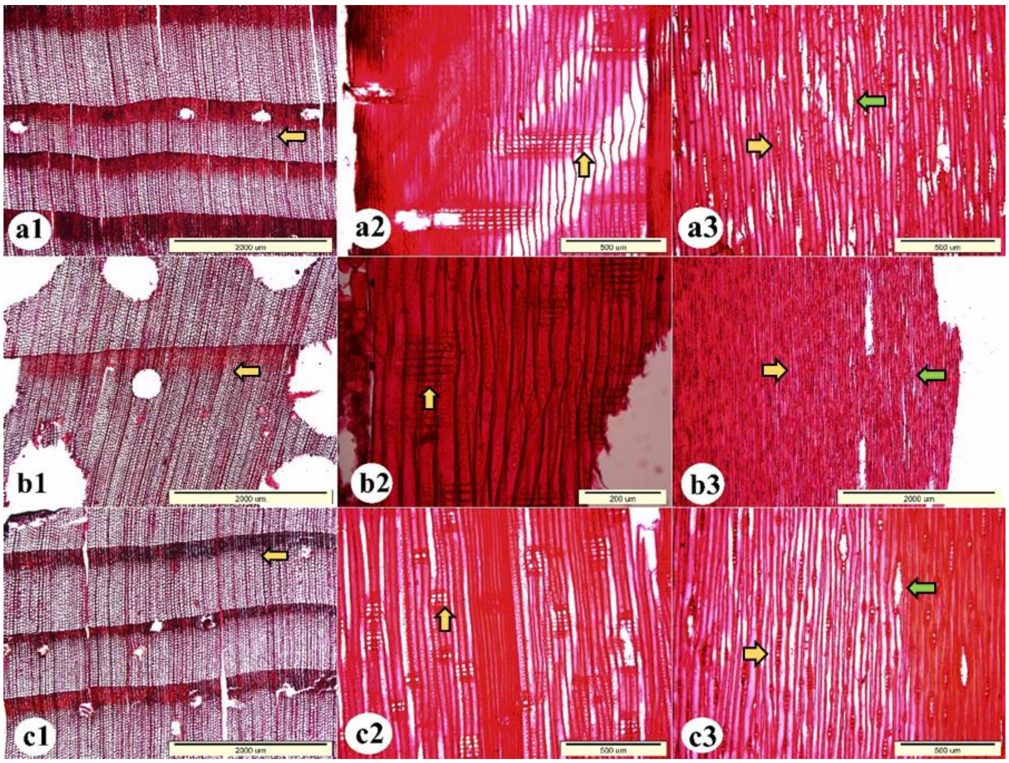

Fig. 6. Microscopic photographs of *Pinus* spp. woods. a1, a2, a3 – Cabinet, b1, b2, b3 – Cripple stud, c1,c2,c3 – Window frame

Abies spp.

Samples from the floorboard degraded by insects were identified as belonging to the *Abies* genus, belonging to the family Pinaceae, due to the distinct growth ring boundaries and gradual transition from earlywood to latewood (Fig. 7a1, arrow). There is no resin canal. In the radial section, the tangential ray cell walls show distinct nodular chains (Fig. 7a2, yellow arrow). Cross-field pits are taxodioid type (Fig. 7a2, green arrow). Average ray height is 15 to 25 cells (Fig. 7a3). Rays are homocellular (Fig. 6).

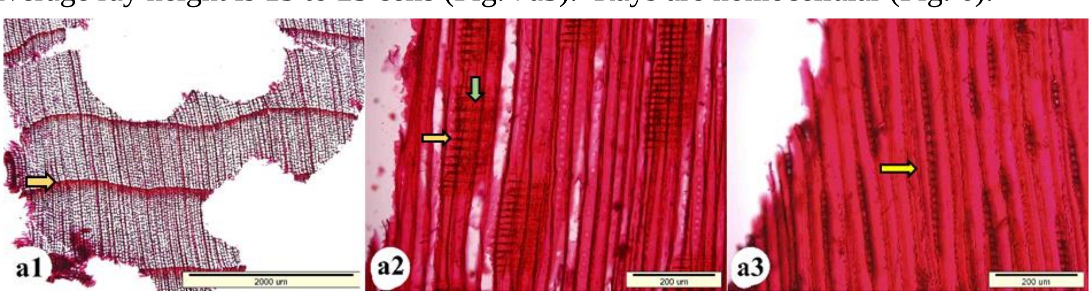

Fig. 7. Microscopic photographs of *Abies spp.* wood. a1, a2, a3 – Floorboard

Populus spp.

Samples from the ceiling board were identified as *Populus* spp. (poplar). Wood is diffuse-porous. Vessels are solitary or in radial groups or radial rows of 2 to 3 multiples (Fig. 8a1). Growth ring boundaries are less distinct. Apotracheal parenchyma is diffuse, occasionally in uniseriate, with discontinuous terminal bands. The perforation plate is simple (Fig. 8a2, green arrow). Intervessel pits are alternate and medium-sized (7 to 10 µm). There are extremely large, simple ray-vessel pits and pits are rounded (Fig. 8a2, yellow arrow). Libriform fibres are present, and fibre-tracheids are absent. Rays are uniseriate and homocellular. Ray cells are axial ovals. Average ray height is 10 to 30 (Fig. 8a3, green arrow). The vessel diameter is 30 to 60 µm.

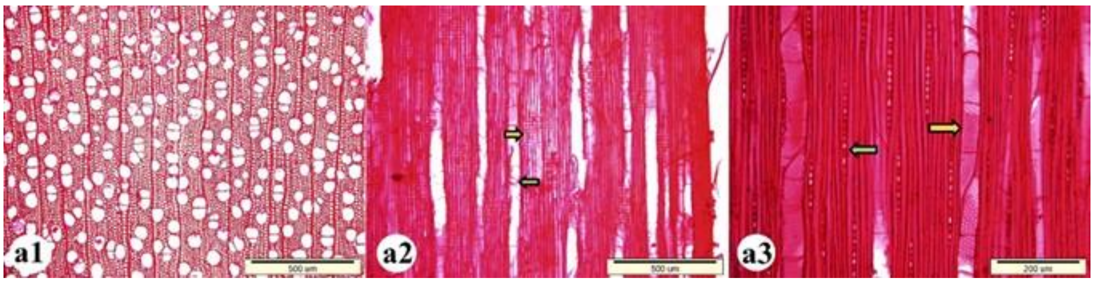

Fig. 8. Microscopic photographs of *Populus spp.* wood. a1, a2, a3 – Ceiling board

Quercus spp.

Growth rings boundaries are distinct, and it is ring-porous. Latewood vessels are arranged in diagonal and/or radial patterns (Fig. 9, arrow 1). Rays are wide and visible with the naked eye (Fig. 9, arrow 2). It can be understood from the wood material examined with these anatomical features that the wood species of the joists is *Quercus* spp. (oak wood) and belongs to the group of white oak.

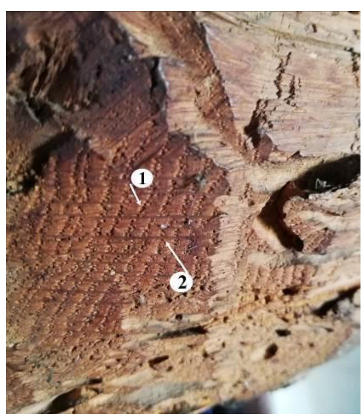

Fig. 9. Wood from the joist, 1 – Large earlywood vessels, ring-porous wood; 2 – Wide ray bands

CONCLUSIONS

1. The wood species of five different parts taken from a traditional wooden building and an *in-situ* wood element were identified. Five of them were identified with the

microscope and one of them was identified visually from 3 taxa of Türkiye origin. It has been determined that both softwood and hardwood species were used in the historical wooden house. The species were *Pinus nigra* J.F. Arnold for the window frame and cabinet; *Pinus sylvestris* L. for the cripple studs, *Abies* spp. for the floorboards; *Populus* spp. for the ceiling boards; and *Quercus* spp. for the joists. The species identification carried out suggests that the selection of tree genera for the wooden building seems to be related to the local availability.

2. Macroscopic investigation revealed that weathering, fungi, and insect attacks were seen on the wood samples from the parts of the house. The floorboards that were made of fir, and the cripple studs made of pine had become completely unusable due to biological attack. Relatively less biological damage was observed on the cabinet made of pine and the ceiling boards made of poplar. A microscopic examination of the effects of these factors will provide a better understanding of the degradation in the wood structure. In future studies, the nature of degradation will be understood more clearly by examining and presenting the change of wood cell structure through degradation.
3. It was concluded that the people living in the region used the types of wood used in architecture by knowing the characteristics of the species. For example, oak wood, which has high strength values and durability, was used in structural elements, while fir, pine, and poplar, which have lower durability, were used indoors. However, the choice of fir species for floorboards seems to be incorrect, as the material used should be resistant to moisture, mechanical strength, and biotic agents.
4. Historical wooden structures, which are part of our cultural heritage, are important and this heritage should be protected. A detailed examination of this heritage, which will be transferred to the future, will provide access to the information necessary to protect it. It is certain that the structure of wood will be investigated in detail and the restoration works to be performed in this direction will be more accurate. Conducting such studies, in which the type of historical wood is determined, and its structure is examined, jointly with the people who will conduct the restoration will increase the quality and sustainability of the restoration.

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