Species and Mechanical Strengths of Wood Members in a Historical Timber Building in Gorgan (North of Iran)

Mehrab Madhoushi

This research introduces one of the most important historic constructions in Gorgan, namely, the *House of Bagheri*, placing an emphasis on wooden materials, noting that a considerable amount of solid wood was utilized as a structural element of this building. First, anatomical identification of species of wood was performed by the microscopic identification. The mechanical properties of selected old structural members were determined and compared with standard values, as well as visually inspected by an expert carpenter. The results indicated that several domestic hardwoods and one imported softwood had been used, and that old members (~ %36) showed acceptable mechanical strength despite their decayed appearance. The results implied that the visual inspections were very conservative and not reliable for restoration operations.

Keywords: Gorgan; Historic building; Mechanical strength; Wood species

Contact information: Associate Professor, Department of Wood Engineering and Technology, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan 49189-43464, Golestan, Iran. Tel: +98-17-32427050, Fax: +98-17-32427176; Email: mmadhoushi@hotmail.com, madhoushi@gau.ac.ir

INTRODUCTION

Gorgan, with the geographical coordinates of 36°50' N and 54°29' E (UN, 2004), is located in Golestan province in the northern part of Iran (Fig. 1) where the climate is mostly Mediterranean (the average rainfall is 432.1 mm, and the relative humidity is between 62.5% and 74%) (IRIMO 2015). It is considered to be a heritage city because of its history and historic buildings, some of which contain solid wood structural elements. Interestingly, despite withstanding several heavy earthquakes since the 1900s, the building is now in almost acceptable condition.

Fig. 1. A map of Iran and the location of Gorgan

Today, the concept and definition of the term "heritage" (Vecco 2010), and the repair and restoration of historic buildings is a major challenge in societies (Lourenco *et al.* 2006; Tuan and Navrud 2008). Therefore, the conservation and repair of these buildings, mostly timber constructions, are important. Researchers have considered the unique response of timber structural members under seismic loading (Ceccotti *et al.* 2006; Tampone and Messeri 2006; Şahin Güçhan 2007). In general, it can be said that "timber frame buildings are well known as an efficient seismic resistant structure and they are used worldwide", as a result of their efficient seismic performance and low cost (Poletti *et al.* 2015). It is believed that the main reason for this tolerance is the particular geometry and configurations of timber connections that were employed in historic buildings (D'Ayala and Tsai 2008; Madhoushi 2011; Pang *et al.* 2011; Wu *et al.* 2014). The configuration of such buildings and their behavior can be used as a guide for future restoration or rural development (Bağbancı 2013), as other types of building materials are used in construction nowadays, even in rural areas (Öztank 2010). Apart from traditional wooden techniques, woodframe, industrialized post-and-beam and log-homes, prefabricated housing in CLT, and others are some typologies which are popular in many European countries and in North America.

Previous studies conducted on wooden historical buildings have shown that moisture and fungal decay are likely the main sources of harm (Ronca and Gubana 1998; Pasanen *et al.* 2000), although the wood species employed for timber members could extensively influence biological (and also structural) damage (Pang *et al.* 2011). In addition, it has been shown that in Gorgan, as for other heritage timber constructions, insect and weather damage, as well as fungal decay, are the main sources of degradation (Madhoushi and Eimanian 2008).

This paper introduces species some of the architectural and structural features, faults and repair, mechanical strengths, and residual strengths of structural wood members of one of the most important historic buildings in Gorgan, namely, the *House of Bagheri*, which is a tourist site and has been designated as a cultural heritage structure (Madhoushi and Eimanian 2008). The house was built approximately 150 years ago in the *Qajar* dynasty. It has a built floor area of 3000 m^2 (Madhoushi and Eimanian 2010) and is now under repair and some parts are used as governmental office.

MATERIALS AND METHODS

Visual Inspection

A visual study of the architectural and structural features, existing faults in structures, and the reasons behind those was conducted. Therefore, extensive inspections of the building were carried out, and numerous high-quality digital images were captured, followed by the drawing of building plans. The adopted repair methods are explained and some comments on these methods are considered.

Species Identification

The *House of Bagheri* is under repair, and a contractor and an experienced carpenter defined numerous structural features of the buildings as decayed elements, and considered that these should be substituted by new members. Of the structural members considered for restoration, 64 accessible structural elements were removed from several parts of the structure (Table 1). These were the most important loading structural elements, that is, rafters, columns, beams, and door frames. The items to be used in the evaluation were selected as being representative of the entire building.

These samples were divided into two types: a small section and a large section (Fig. 2), of which the small section was taken for identification of wooden species in the laboratory. The samples were inspected at a macroscopic level; however, due to extensive decay and weathering, and also for greater insurance, anatomical identification was conducted at a microscopic level after laboratory preparation. First, a cross-sectional surface of each sample was smoothed with a sharp knife. Small and thin sections were then cut with a microtome from the cross section, and along the grain from radial and tangential surfaces, with dimensions of 10 x 10 x 10 mm^3, and prepared in a chemical solution for viewing under the microscope (Parsapajouh 1988).

Table 1. Structural Members and Numbers of Samples

Sample code	Structural member	Number of samples
R1	Rafter (1)	14
R2	Rafter (2)	11
C1	Column (1)	7
C2	Column (1)	6
B1	Beam (1)	5
B2	Beam (1)	5
D1	Door frame (1)	5
D2	Door frame (2)	3
Ba1	Balcony (1)	4
Ba2	Balcony (2)	4

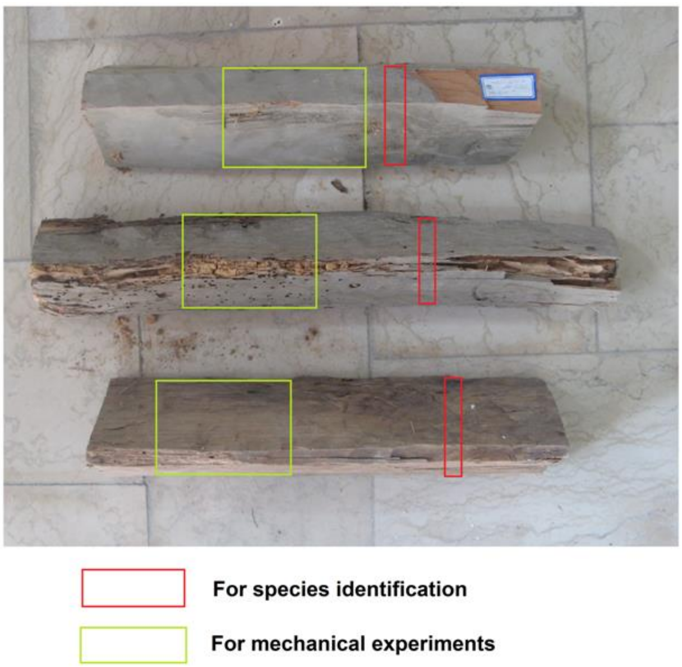

Fig. 2. An example of removed structural members and selection of parts for species identification and mechanical experiments

Mechanical Strength

Following the previous steps, static laboratory experiments were conducted on the samples in the larger section to measure their mechanical properties (Fig. 2), including flexure (Fig. 3a) and compressive strength parallel to grain (Fig. 3b), according to ISO:13061-3 (2014) and ISO:3787 (1976) standards, respectively. The results obtained were compared with a standard amount of samples from Parsapajouh (1988), and their residual strengths were determined. The laboratory results and a visual inspection of the condition of samples were used for their categorization.

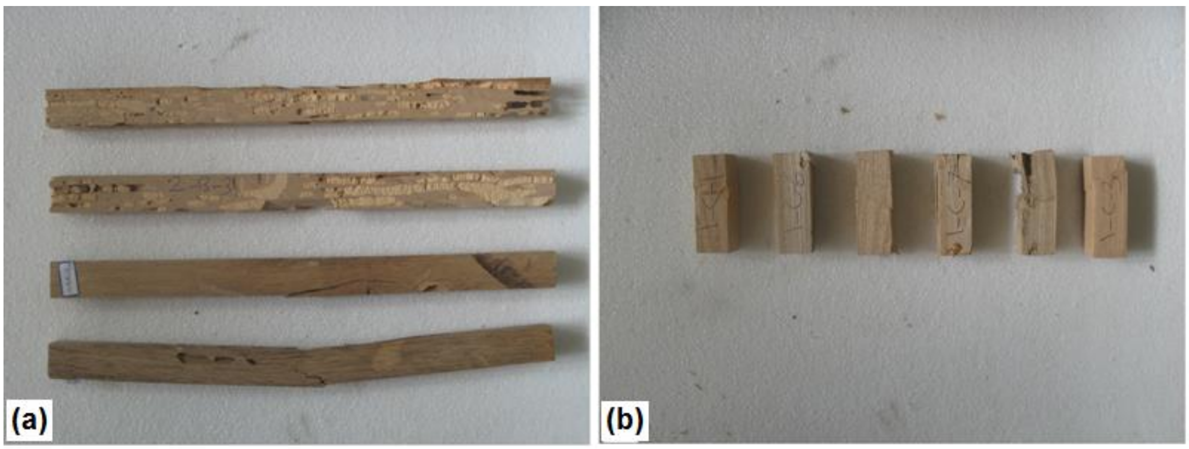

Fig. 3. Samples for (a) three-point bending with dimensions of 20 x 20 x 300 mm^3, and (b) compressive strength tests with dimensions of 20 x 20 x 60 mm^3

RESULTS AND DISCUSSION

Architectural and Structural Characteristics

Solid wood was extensively utilized for structural members, including beams, columns, rafters, roofs, and floors, in association with other traditional materials, that is, brick and cob (a mixture of clay and straw). Doors and windows were completely wooden and are well preserved.

The *House of Bagheri* is a collection of several main buildings in addition to compounds and yards (Fig. 4). A small pool is located in a central area of each yard, around which the buildings have been constructed. These buildings have almost identical architectural characteristics, and the plans of the primary constructions are shown in Fig. 5. Although there is a one-story building in this complex, it is mainly known as a two-story structure, with a few steps between floors.

The influence of Islamic art can be observed in this building, via the dome-shaped window designs (Fig. 6a). As a result of these particular designs, air circulates easily, providing good ventilation, which in turn reduces the level of damp inside the buildings (Madhoushi and Eimanian 2008). In addition, the sunlight can reach most parts of these structures, which are rectangular in shape and were constructed of materials that were essentially brick and cob in the shear walls (Fig. 6b) and solid wood in the principal structural elements (Fig. 6c and Fig. 6d)

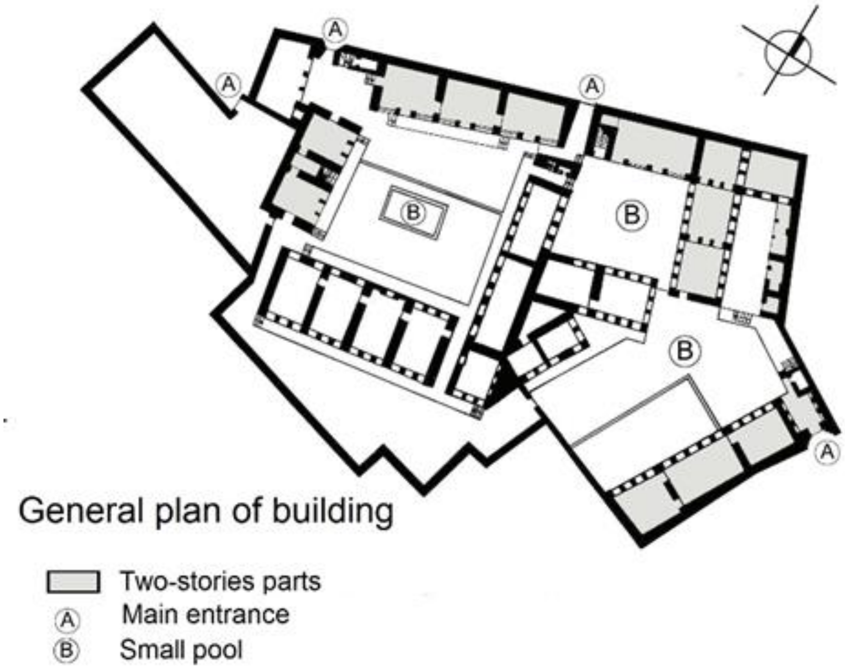

Fig. 4. General plan of the *House of Bagheri*

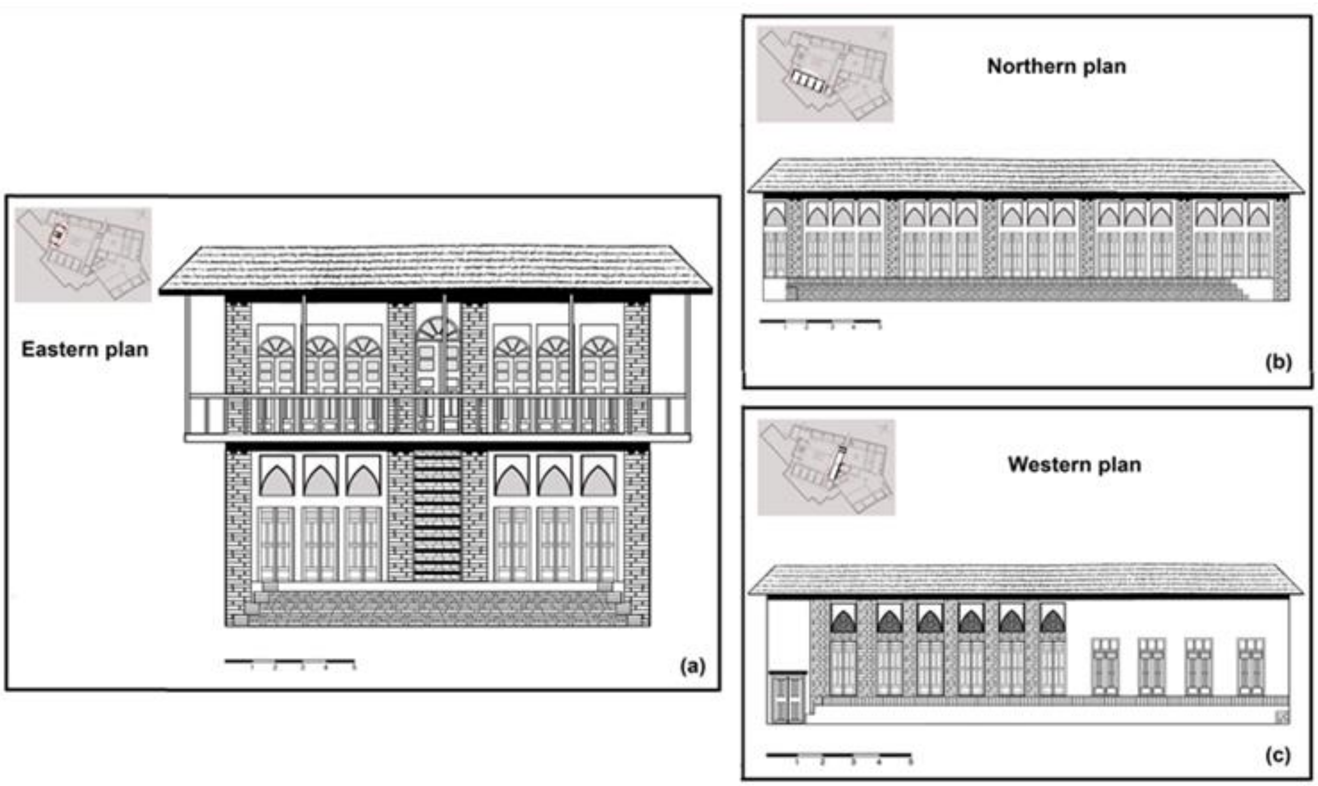

Fig. 5. (a) Eastern, (b) Northern, and (c) Western plans of the *House of Bagheri*

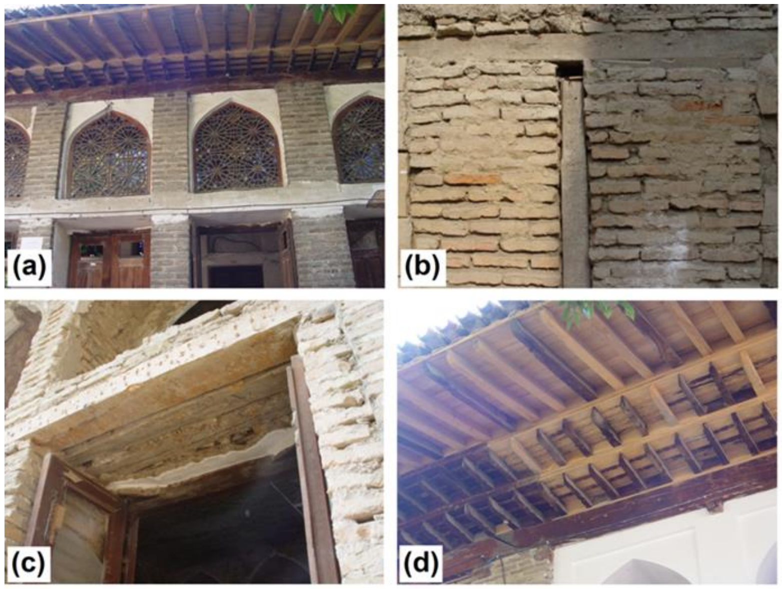

Fig. 6. (a) Islamic art as the dome-shaped window designs. The main construction materials used in the *House of Bagheri*, (b) brick and cob, (b) solid wood up the door, and (d) solid wood as the main beam and rafters

Faults and Repairs

Although investigations have been carried out on entire structures and other materials, only the main faults, and the reasons for these faults, as relating to timber members are reported in the current research. The primary faults can be considered in three groups as follows: 1. Corrosion by weathering; 2. Decay as a result of fungal attack; and 3. Internal holes made by insects. These faults (or defects) are fairly common in the northern part of Iran because of the climate; however, their distribution depends on area and species. Therefore, further studies on the types of faults existing in each building, as well as the reasons for these, are necessary. It should be noted that faults resulting from dimensional variation related to swelling and shrinkage of wood were also found, but their effects were not assessed in the present study.

Corrosion caused by weathering (sunshine and rainwater splashing) was found in opening frames and balconies. In some parts, this was very intensive and was combined with fungal decay; the wooden elements showed significant deterioration and could not be used again (Fig. 7a). In other areas, the weathering was only a surface phenomenon (Fig. 7b), and the elements were almost at full strength, meaning that they could be used again after surface intervention. Unfortunately, this important technical issue had been ignored and new members had been utilized in large volumes. From the historical point of view, and the repair protocol, adoption of this method for restoration and repair of buildings is controversial.

With regard to the fungal and insect attack, the defects were spread across the buildings. The fungal growth and decay were mainly found on rafters and internal beams exposed to moisture flows. Decay, like weathering, depends on level of severity, and two conditions were noted: one resulting in color change, and the other, which was very intensive, resulting in strength loss. The blur was seen in an area with inadequate sun exposure and ventilation, such as internal beams (Fig. 7c). It should be noted that the substitution was lacking in a few areas where the elements were on the inside of walls.

Moisture-related problems and water penetration still remain in some of the replaced parts, leading to new stains and fungal decay (Fig. 7d). Internal holes due to insects were also found in some parts, especially where hardwood had been used. It was obvious that the insects no longer live in the wooden members; however, their effect on mechanical properties was very considerable. Although the affected members were renewed, they had not been considered in some areas, and were ignored during restoration.

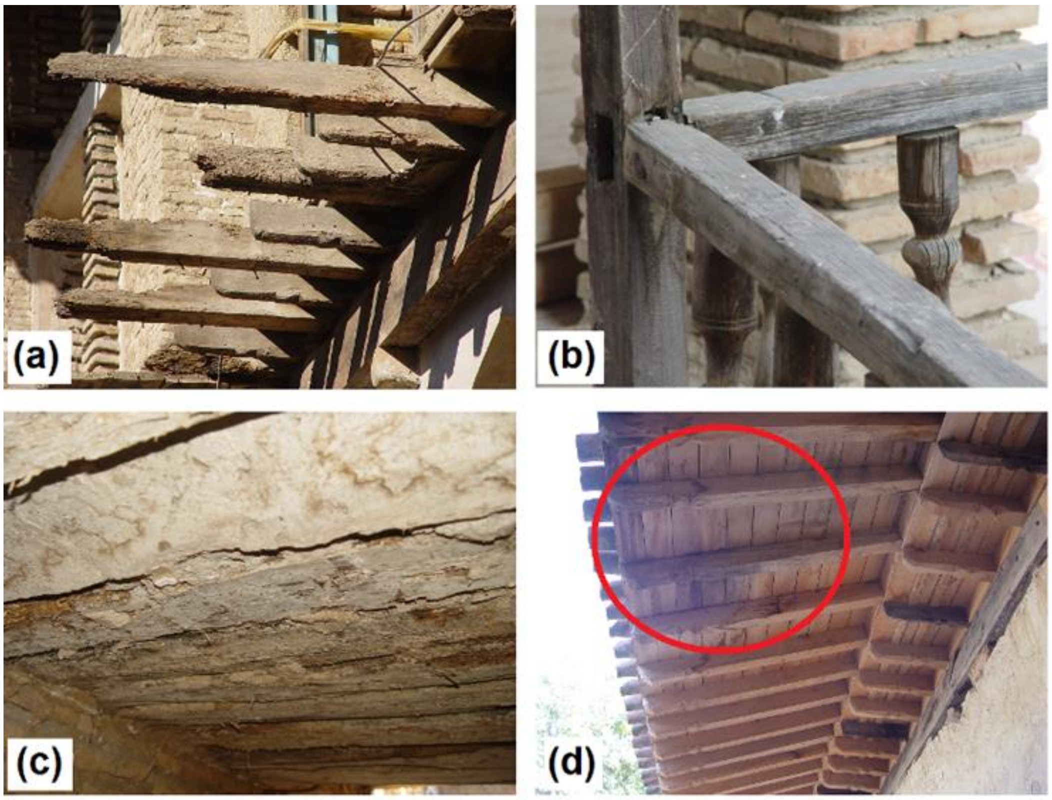

Fig. 7. (a) Intensive weathering, (b) surface weathering, (c) intensive decay, and (d) moisture-related problems in new substituted members existing in the *House of Bagheri*

Wood Species

Macroscopic and microscopic investigations on wood anatomy identification allowed the categorization of the wood members used in the buildings in two main groups: domestic wood and imported wood. Domestic wood contains hardwoods provided from the northern (*hyrcanian*) forests of *Iran,* while imported wood was softwood, which had most likely been imported from *Russia*.

The domestic species were identified as: elm (*Ulmus glabra*), lime tree (*Tilia begonifolia*), oak (*Quercus castaneifolia*), sugar maple (*Acer insign*), and the imported wood was identified as scots pine (*Pinus sylvestris*). Fig. 8 shows microscopic photos of these species in three sections. Field inspections revealed that oak and elm, known as diffuse-porous species, were more often used than the other species (Table 2). It should be noted that structural elements created from scots pine have primarily been influenced by weathering, whereas those from hardwood have been mostly affected by fungal decay and insect attack, due to their large vessels.

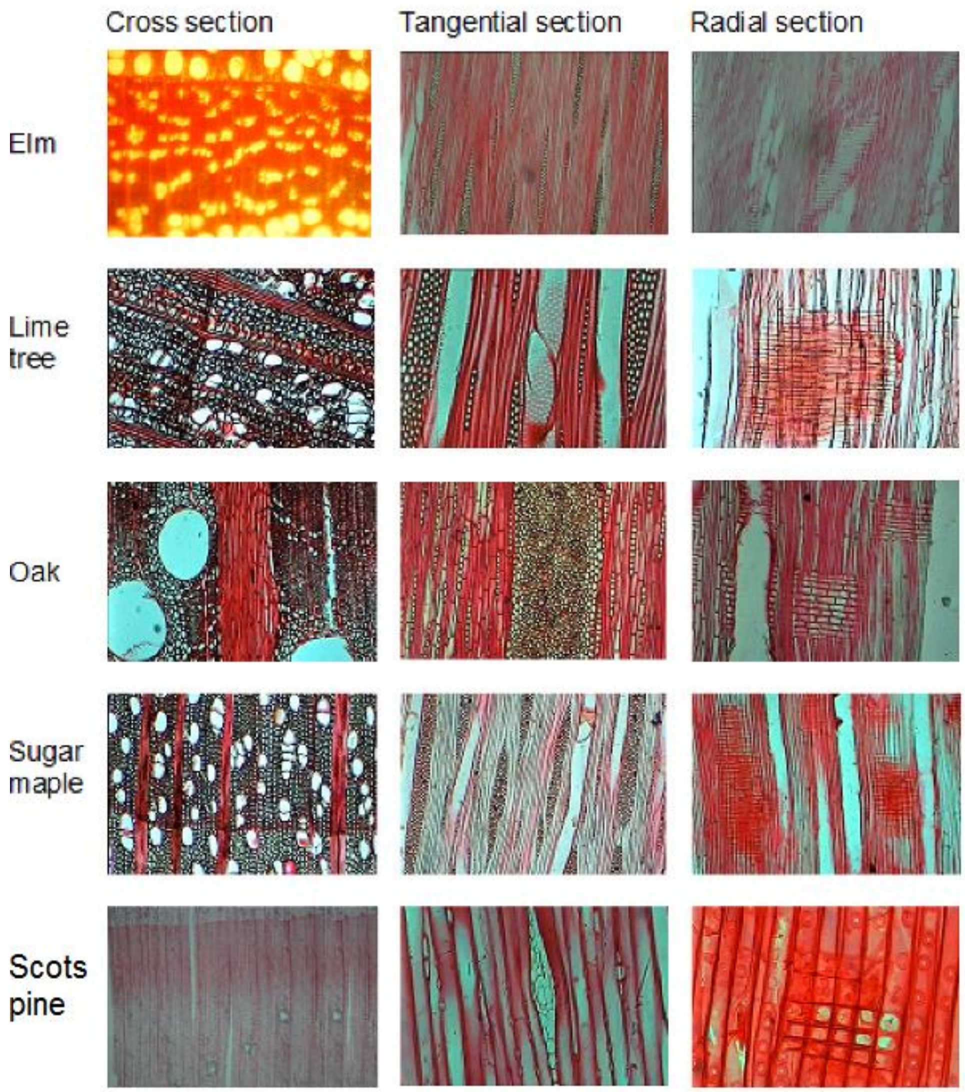

Fig. 8. Microscopic photos (x80) of wood samples collected from the *House of Bagheri*

Table 2. Identified Wood Species of Structural Members

Sample code *	Species
R1	Acer
R2	Oak
C1	Lime tree
C2	Oak
B1	Oak
B2	Oak
D1	Elm
D2	Elm
Ba1	Scots pine
Ba2	Scots pine

* Please refer to Table 1.

Mechanical Properties

Table 3 shows the average amount of determined mechanical properties of the old members. The results of the laboratory experiments regarding old members and their standard values given by the literature, enabled calculation of the residual strengths of samples (Table 4). Strength conditions of samples were categorized as four types: Very Good (V), Good (G), Fair (F), Poor (P), and were considered to be (I) from visual inspections made by an expert carpenter, and (II) on the basis of the laboratory results. For condition (II), categorization was conducted according to the percentage of the range of the residual strengths, as: V: 100-90, G: 90-80, F: 80-65, and P: less than 65.

Significant differences between the two conditions (I) and (II) were also found (Table 4). It can be observed that the ~ 36% of old members possessed acceptable mechanical strength, and could be designated as condition G.

Table 3. The Mechanical Properties of Old Wood Members

Code	Conditions		Laboratory results (MPa)			Standard amount of clear wood (MPa)[a]			Residual strength (%)		
	(I)*	(II)**	MOR[b]	MOE[c]	σ_c[d]	MOR	MOE	σ_c	MOR	MOE	σ_c
R1	F	P	71.12	6591.33	34.5	135	11000	60	52.68	59.92	57.50
R2	G	G	84.73	9801.518	57	107	12200	68	79.19	80.34	83.82
C1	V	G	90.16	6029.63	41.2	105	7250	50	85.87	83.17	82.40
C2	P	P	59.38	6882.07	29.3	107	12200	50	55.50	56.41	58.60
B1	F	P	67.53	6266.83	24.7	107	12200	50	63.11	51.37	49.40
B2	P	P	46.73	6833.41	22	107	12200	50	43.67	56.01	44.00
D1	F	G	68.77	9099.37	46.2	88	10800	55	78.15	84.25	84.00
D2	P	P	12.67	2124.28	16.47	88	10800	55	14.40	19.67	29.95
Ba1	G	F	73.22	8329.22	40.92	99	11770	54	73.96	70.77	75.78
Ba2	G	F	73.64	9107.85	41.89	99	11770	54	74.38	77.38	77.57

* Visual inspection by an expert carpenter
** Based on laboratory results
[a] from Parsapajouh (1988)
[b] Modulus of rupture
[c] Modulus of elasticity
[d] Compressive strength

The results implied that the visual inspections were very conservative (~11% V and ~ 22% P) and not reliable, and samples were considered in all four types with larger amounts for F condition. However, a comparison between conditions (I) and (II) revealed that the members might be kept for reuse because they were still structurally sound, despite their appearance. Therefore, selection of samples for restoration operations based only on visual inspection cannot lead to acceptable conservation of heritage buildings.

With regard to condition (II), it should be noted that a higher strength can be seen in aged wood samples in traditional buildings (Yokoyama *et al.* 2009). Moreover, nondestructive evaluation can be a viable alternative for a more systematic approach/procedure in assessing the timber in selection of structural members for restoration or repair.

Table 4. The Percentage of Four Categories Conditions of Samples in Two Evaluation Methods

	Very good	Good	Fair	Poor
Visual inspection	10.93	29.69	37.5	21.87
Laboratory result	-	35.93	12.5	51.56

CONCLUSIONS

1. The *House of Bagheri*, a historic construction in Gorgan, shows some damage to its timber members, and repair and restoration of the buildings is required.
2. The main faults found in the building are the result of corrosion, fungal decay, and insect attack.
3. Domestic (hardwoods) and imported (softwood) wood species were used in the construction of the building.
4. Some structural elements possessed acceptable strength, despite their decayed appearance.
5. Some current repair methods (in Iran), including traditional methods and employing only the experience of carpenters, should be modified and it is important that scientific methods should be used.

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