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Woodworks of Chinese-Ancient Roof Structures and the Impact of Wood Adhesives on Wood Protection

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Conflicts of Interest
There are no conflicts to declare.

ABSTRACT

Chinese-ancient buildings have attracted so much attention in recent years for being well planned and designed. Scholars have been fascinated by how wooden-structures have been resistant to rainfall throughout the years. These structures have passed the test of time and are still standing strong. That is because ancient builders invented waterproof methods that helped to make the wooden structure resilient to water. The purpose of this paper is to survey the intriguing use of waterproof methods on Chinese-ancient wooden structures and the strengthening techniques used to protect them from damages caused by exposure to water, not to mention other abrasive forces, which destroy the wooden structures quickly. This paper, adopted the General Administration of Quality Supervision, Inspection, and Quarantine of China's (GT/T 1934-2009) method of determining water absorption level and the wood preservation method used in a study by Lebow (2010) to investigate the impact of wood adhesives on wood protection.

Keywords: Chinese-ancient wooden structure; waterproof methods; water absorption; strengthening techniques

Introduction

Ancient buildings in China have an unshakable position in the history of ancient architecture, and the protection of ancient-buildings has always been of great concern. According to Steinhardt (2004), various waterproof mechanisms preserved the ancient-wooden structures. Again, R. Baronasa, F. Ivanauskasa et al.

(2001) proved that these waterproof methods have been effective and aided in wood preservation. This innovation has gone a long way to influence the works of other architectural scholars in Western Europe. In the 17th century, Europe also adopted waterproof methods in their roofing systems (Hodge 1960, Klein 1998, Niu and Sternberg 2006). Research on the structural performance of ancient-buildings began in 1970, and up-to-date results have shown that to improve the moisture-proof conditions of Chinese-ancient wooden structure, more effort is needed to maintain as well as retrofit. Wood protection can be possible when different techniques are adopted to prevent the material from decay leading to less structural damages. Lebow (2010), Sonmez， and Budakci (2010) have all conducted studies on preservation techniques to provide long-term protection of the wooden product. The preservation techniques appear not only inspired by Polyurethane resin-based coats (pure engineering approach). It has proved to be an alternative when it comes to wood waterproofing materials.

Research Framework

The research framework presents the two general types of wood preservation in a pictorial view adopted from Lebow (2010).

1. The first process is the pressure processe, where the wood is saturated in closed vessels under pressures substantially above atmospheric.
2. The second process, the non-pressure process vary in both procedures and equipment used.

Additionally, Figure1 is a representation of the steps in the pressure-treating process (Lebow 2010):

1. Immerse a piece of untreated wood into a cylinder.
2. Secondly, a vacuum is applied, which pulls air out of the wood.
3. Also, the wood is then immersed in a solution while it is still under vacuum.
4. Again, ally pressure to force the preservative into the wood.
5. Furthermore, pump out the preservative, and pull out the final vacuum. This process is to ensure the removal of excess preservatives.
6. Lastly, pump out the excess preservative and detach the wood from the cylinder.

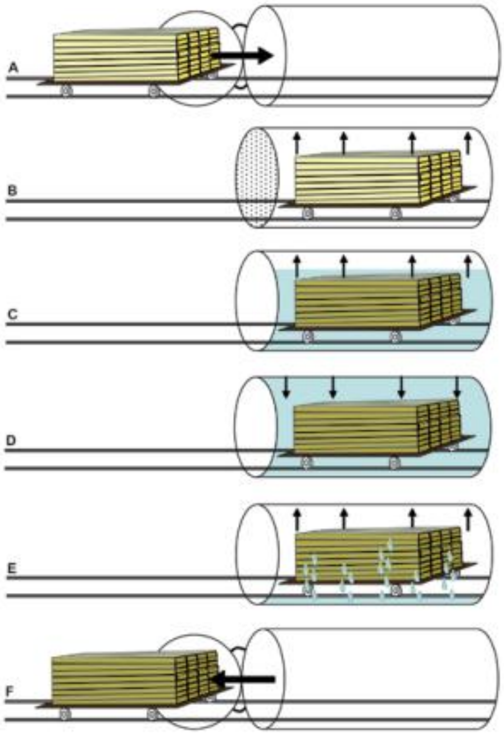

Figure 1: A representation of the application of preservative processes. Source - (Lebow 2010)

Literature review

Characteristics of ancient Chinese Architecture wooden structure

Ancient Chinese architecture has a long history of achievements. After the end of the primitive society, Chinese-ancient architecture mainly consisted of wood structure, supplemented by brick, tile, and stone. The wooden frame structure was the structural model in ancient Chinese architecture, creating various planes and appearances suitable for this structure. Traditionally, Chinese-ancient wooden building structures, grouped into three categories: Log-cabin-type, through-type frame, and beam-lifted frame as seen in(Li, Tang, et al. 2017, Que, Li et al. 2017), as seen in figure 2.

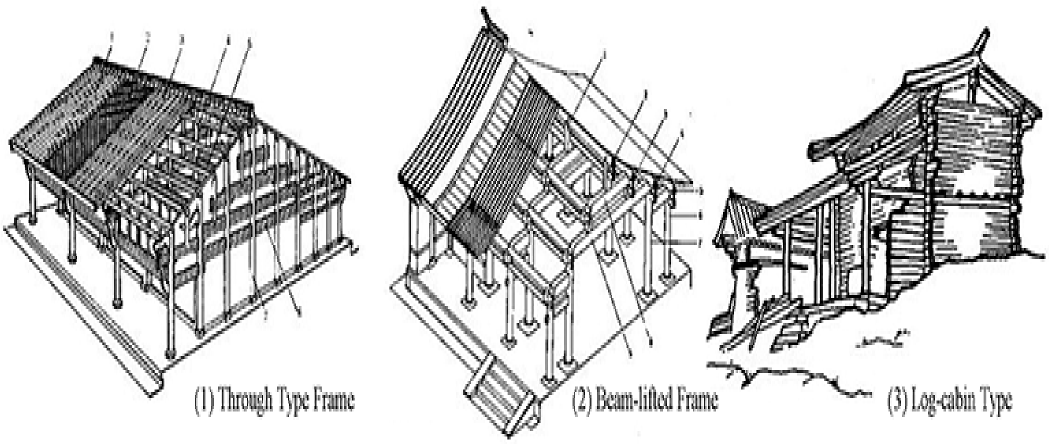

Figure 2: Types of traditional Chinese wooden structures. Source - (Li, Tang, et al. 2017)

The beam-lifted frame

This type of beam was mainly for ancient palaces and temples in the Northern part of China. It has several layers of beams erected with depth on a horizontal paving layer of the column top or net. The beams in this structure have short layers, where columns or wood blocks are erected in the middle of the top-beam to form a triangular roof truss. Purlins are assembled between adjacent roof trusses at both ends of beams and small columns in the middle of the top beams. The rafters are arranged between purlins to form a unique framework of houses with double sloping roofs(Li, Tang, et al. 2017).

Log-cabin-type is a building structure without columns and genders. This structure comprises of round wood or rectangular or hexagonal wood, which is a stacked-layer in parallel. The corners receive the ends of the timber. The timber is then crossed and occluded to form the four walls of the structure. Then, low columns are erected on the left and right sides to support the purlin. This structure needs a lot of wood, so it is limited in absolute scale(Li, Tang, et al. 2017).

The through-type frame has its columns connected in series along-side the cross beams. These columns are connected in series with the "Dou fang" along the direction of the purlin. The beam head aligns with the column together with the sandalwood bar is also positioned on the beam head, whiles the short beam is supported by the low-column. The total number of beams can reach 3-5 when stacked in that way. The beam head is placed on the bucket arc when the bucket arc is on the column. In contrast, the though bucket-type timber frame has small materials and strong integrity, with closely arranged columns, only used when the indoor space scale is not in a spacious place.

The earliest Chinese wooden architectures in Shanxi:

The history of the earliest wooden structures trace back to the third year of Jian Zhong in the Tang dynasty in Wutai Mountain of the Shanxi province, the location of the Nanchan temple one of the earliest ancient buildings. It was founded in 782A.D. of the Tang Dynasty, more than 1200 years ago (Steinhardt 2004).

Figure 3: Nanchan temple, source - (Li, Tang, et al. 2017)

"Foguang" temple (located in Wutai Mountain, Tang Dynasty- 857AD). "Foguang" temple is the second earliest existing wooden structure of the Tang Dynasty in China. The full name of Foguang temple is Foguang Zhenrong temple, located in Foguang Mountain, 30 kilometers northeast of Wutai County, Shanxi Province (ChinaDaily 2018).

Figure 4: Foguang Mountain, source - (Li, Tang, et al. 2017)

Yingxian Wooden Pagoda, also known as Buddha Temple Sakyamuni, this ancient wooden structure was built in the second year of the Qing Dynasty (1056 AD) and completed in the sixth year of the Ming Dynasty (1195 AD). It is the tallest and oldest existing wooden tower building in China. The pagoda stands on a 4 m (13 ft) stone platform, has a 10 m (33 ft) tall steeple, and reaches a total height of 67.31 m

(220.83 ft) tall; it is the oldest existent fully wooden pagoda still standing in China. (Steinhardt 1994, ChinaDaily 2018)

Figure 5: Yingxian Wooden Pagoda, source - (ChinaDaily 2018)

Distribution of wooden buildings before Yuan Dynasty in Shanxi Province

With the historical weathering, most of the existing wooden buildings in China are concentrated in Shanxi, especially in southern Shanxi, and only sporadically distributed in other provinces. According to the investigation results of Shanxi's cultural relics in recent years, 120 ancient wooden buildings before the Song, Liao, and Jin Dynasties are available in Shanxi Province, with an over 160 in China, accounting for 75% of the total amount. However, there were about 440 ancient wooden structural buildings in China before the Yuan dynasty, of which 350 were located in Shanxi, accounting for nearly 80% of the whole country (Wang 2021).

Data and categories of Shanxi ancient architecture

Protecting units: there are 13227 cultural relics' protection units at all levels in Shanxi Province, 452 national key cultural relics, including 369 ancient buildings; 487 provincial cultural relic's protection, including 229 ancient-buildings dived into four regions:

1. Northern region: Xinzhou, Datong, Shuozhou;
2. Central region: Taiyuan, Luliang, Jinzhong and Yangquan;
3. Southeast region: Changzhi and Jincheng;

4. Southern Region: Linfen and Yuncheng;

Table 1: Number of ancient wooden structures according to dynasties. (Source -Social education home of Shanxi Museum)

Dynasty	North	Central section	Southeast	South	Total	Accounting for % of the whole country	Whole country
Tang Dynasty	2			1	3	100	3
Wu Dynasty		1	3		4	80	5
Song Dynasty	1	8	23	2	34	70.83	48
Liao Dynasty	3				3	37.5	8
Jin Dynasty	17	18	73	5	113	88.98	127
Yuan Dynasty	6	64	157	112	339	87.15	389
Total	29	91	256	120	496	85.55	580

The factors of Shanxi ancient architecture being well preserved

The ancient-structures in Shanxi were preserved/protected because of the location of Shanxi. It is a province characterized by a dry climate, few natural disasters, and the use of local material provides rich resources of building materials such as mud, wood, and stone. The province experiences good climate conditions with fewer natural disasters has led to the sustainability of these structures.

Additionally, the inclusive culture during the Jin Dynasty, the ideology, and the practice of inheriting and protecting cultural heritage also helped preserve these monuments(Wang 2021).

The structure and preservation of ancient Chinese wooden structure

Different roofs are combined and interspersed with each other to form different varies of building roof forms. The roof styles of Chinese-ancient buildings are rich and varied(Li, Tang, et al. 2017), as seen in figure 3, but they are always inseparable from several basic styles such Hip roof style, Flush gable roof. The hip roof style is characterized by a normal ridge and four vertical ridges, forming two roof slopes. From the appearance, the hip-roof-style has double slopes, and the gables on both sides are flush with the roof or slightly higher than the building roof.

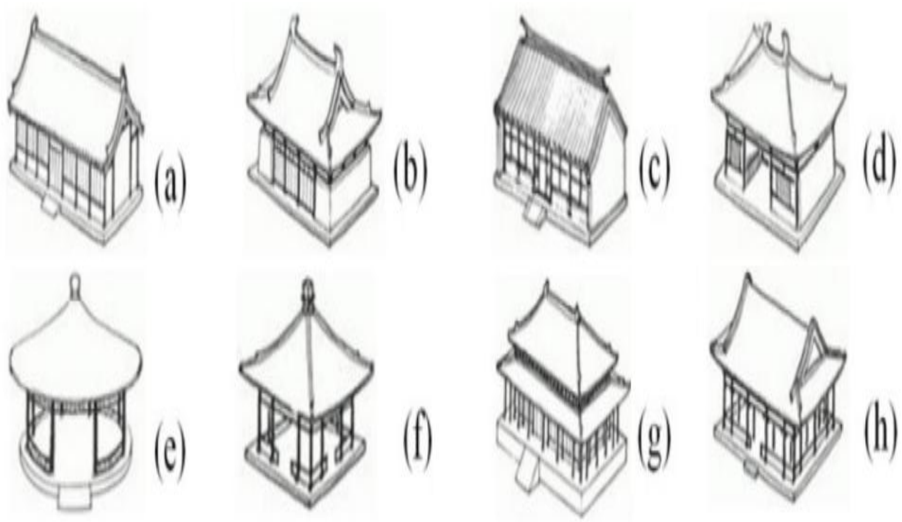

Figure 6: Examples of common ancient Chinese architecture roof styles.

(**a**) flush gable roof; (**b**) overhanging gable roof; (c)Hip roof; ((**d**) gable-hip roof; (**e**) pyramidal pavilion roof; (**f**) round pavilion roof; (**g**) double-eave hip roof; (**h**) round gable-hip roof; Source - (Li, Tang et al. 2017)

Historical evolution of Hip roof style

Throughout the centuries, the roof of a building has been of great importance and significance. The key focus when building the roofing in ancient China was the shape the building roof would have. The roofing of a house had a link to a ritual system, and they were a symbol of power and status. In the Neolithic age, before the roof system began, places for shelter were in the shape of huts, tents, and caves. During the Yin and the Shang Dynasty, roofs in the straight slope roof form and then to the sloping top. The Hip-roof style appeared relatively late, inferring there was no such roofing structure in the Song Dynasty. In the Ming, Qing, and later dynasties, the Hip roof style was a low-grade roofing style and absent in the royal buildings and some large-scale temple buildings. However, because of its relatively low-grade, drum tiles a.nd glazed tiles could not be used. With the wide use of brick, stone, and green tiles to build houses in the Ming and Qing Dynasties, the Hip-roof-style was the frequently used roof. (Li, Tang et al. 2017)

Influence of Moisture in Deterioration of wood

Moisture works as a catalyst for different types or forms of deterioration by serving as the crucial component of weathering (including freeze-thaw action), mold, decay, as well as insect attack. Moisture stains are not necessarily an indication of damage to the wood but a record of the wood being exposed to water repeatedly throughout its life or for an extended period (Lebow and Anthony 2012). The wood loses its properties when moisture content remains at over 20% over a long period. The relative humidity of the surrounding air is typically around 80-90% or more. Additionally, wood loses its properties within some months when atmospheric relative humidity more than 80%. The 70% atmospheric relative humidity is a probable critical value. Eventually, when the atmospheric relative humidity exceeds 90%, the wood begins to show signs of deterioration. (R. Baronasa, F. Ivanauskasa et al. 2001, Sonmez， and Budakci 2010, Wang 2015)

The criterion to make the wood retain its properties and its form

There are several methods used to ensure that wood maintains its properties. These methods range from structural wood preservation measures to many different chemical preservatives/processes that generally increase the resistance and the durability of the wood and preventing it from being destroyed. Another way to protect the wood is by applying varnish to the wood gives the wood that extra sheen and help prevent moisture from seeping into the grains. Like the water sealant, this will keep the natural look of the wood. (Lebow 2010).

Historically, many buildings with Dou Gong have been able to withstand strong earthquakes. They invented various methods for the protection and reinforcement to strengthen wood structures without large displacements and deformation. In the construction of large roofs such as the veranda and the double-eave hip, several components must be available to increase the roof's long-lastingness and the whole framework. The huge roofing with its self-weight on the column network also improves the stability of the framework. For example, the use of mortise and tenon: this kind of component connection without nails makes the traditional Chinese wooden structure become a flexible structure beyond the contemporary building bent, frame or rigid frame, which can not only bear a large load, but also allow certain deformation, absorb seismic energy through deformation under seismic load, and reduce the seismic response of the structure. The column rising and side-foot technique deployed to reduce the pressure at the center of gravity of the building and make the center of gravity of the whole structure incline inward hence enhancing the stability. (R. Baronasa, F. Ivanauskasa et al. 2001, Wang 2015)

According to the current Chinese standard code for seismic design of buildings (GB 50011), the seismic capacity of an ancient-wooden structure calculated using the formula; $\mathbf{F_{ek}=0.72\alpha_1 G_{eg}}$;

Where α_1 the influence coefficient corresponding to the "basic" natural vibration period T of the structure

Geg The equivalent total gravity load of the structure is 1.15ge of the building with the sloping roof; 1.06 for the flat roof building; 0.85 for the multi-story-ancient building. Ge is the value of the total gravity load of the building.

Figure 7: Mechanical reinforcement-Iron reinforcement is part of the original structure. Firstly, a beam is bound to a rafter joint. Secondly, one connection tooth and two metal plates are introduced to the first process to assist in maintaining its position in the joint.

Figure 8: Chemical reinforcement: applying varnish to give the wood that extra sheen and help prevent moisture from seeping into the grains. Source- (David, Moretti, et al. 2020)

Stabilizing the structure against the effects of rainfall

The wood structure is the main structure of the building and is an important historical and cultural asset. Once the building roof is damaged, it is not renewable, causing irreparable loss of historical and cultural heritage.

However, since the ancient buildings are old buildings, the wood structure is prone to decay in a humid environment, and rainfall is one of the catalysts that affect the building structure will deteriorate in varying degrees, such as beam-column deformation. With ancient buildings, it is necessary to strengthen and protect the wooden building structure of an ancient-building. The decay reduces the cross-section area tension, compression, bending, and shear of the beam, column components and reduces the bearing capacity, which is very unfavorable for the whole wood structure (Steinhardt 2004, Que, Li et al. 2017).

Wood adhesion in wood structures

Adhesives have been vital in the wood industry since their introduction in Europe and America in the 17th and 18th centuries. In the early 19th century, commercial casein appeared in Europe, and its commercial production gradually developed. At the end of the 19th century and the beginning of the 20th century, synthetic resins entered the field of adhesives(Ülker 2016). In the 1930s, the wood industry began to use phenol-formaldehyde and urea-formaldehyde resin adhesives, which led to profound changes in the manufacturing process. In the 1970s, Japanese wood adhesives accounted for 75% of the total production of adhesives.

In 1978, urea-formaldehyde and phenolic resins were present in 37% of the total production of thermosetting resins in wood industries in the United States. Water-based adhesives, to which water dispersed adhesives also belong (e.g., polyvinyl acetate (PVAc) adhesives, may reach an adhesion optimum when the water has penetrated the wood substrate(Boehme and Hora 2009, Ülker 2016). They are safe, non-toxic, non-combustible, easily cleanable, without pollution, cure at room temperature, colorless, transparent, and thick after curing to give a high adhesion strength to bonded wood elements (Sonmez， and Budakci 2010).

Characteristics of materials and agent in this study

Epoxy resin

The first synthesized Epoxy resin was in the year 1936 (N 2020). It's a kind of high molecular polymer with the molecular formula of (c11h12o3) n and its density of 1.2 g / cm3, which is the general name of a kind of polymer containing more than two epoxy groups in the molecule(May 2018). It is the condensation product of epichlorohydrin and bisphenol A or polyol. However, a ring-opening created by many compounds containing active hydrogen, curing and crosslinking to form a network till it becomes a thermosetting resin.

Subsequently, bisphenol (an epoxy resin) has the most resin output, complete varieties, and high-quality newly modified variety of resins. According to US2444333 (1948) and Saba, Jawaid et al. (2015), the modified epoxy resins used extensively in the fabrication of natural fiber-reinforcement composites and different industrial products are the preferred choice because of their superior mechanical, thermal, and electrical properties(Clayton 1987).

Polyvinyl alcohol

Poly (vinyl alcohol) (PVOH, PVA) is an organic compound, it has idealized chemical formula [C2H4O] n, and its appearance is a white flake, flocculent or powdery solid, tasteless. (Manfred, Hallensleben et al. 2000)(Manfred, Hallensleben et al. 2000)(Manfred, Hallensleben et al. 2000). This adhesive has the advantages of high bonding strength, fast curing, simple manufacturing, excellent performance, low cost, source of raw materials, etc., since it does not contain any toxic and harmful substances. Its performance indicators are comparable to the "three aldehyde glue" and far superior to polyvinyl acetate emulsion and modified and modified PVA wood adhesive.

Note that the invention does not contain any aldehydes, phenols, and organic volatiles, so the environmental protection is incomparable to that of the "three aldehyde glue" adhesive(Manfred, Hallensleben, et al. 2000).

Phenolic aldehydes

Phenolic aldehyde is the foaming product of phenol and formaldehyde. Formaldehyde is harmful to the human body, and nearly 20% of the raw material in phenolic resin is formaldehyde. So many manufacturers use a lot of glue to bond them together.

In different countries, such as Australia and Canada, phenolic factories are not allowed to exist because of environmental protection. Phenol formaldehyde is the foaming product of phenol and formaldehyde. Phenolic resin has no harmful substances after foaming and curing. Phenolic resins, a component for making exterior plywood known as weather and boil proof (WBP) plywood because phenolic resins have no melting point but only decompose at the temperature of 220 °C (428 °F) and above Manfred, Hallensleben et al. (2000).

Materials and methods

This paper adopted the General Administration of Quality Supervision, Inspection and Quarantine of China’s (GT/T 1934-2009) method of determining water absorption level and the wood preservation method use in a study by Lebow (2010) to investigate the impact of wood adhesives on wood protection. Hence to determine the best coat for protecting Chinese-ancient wooden structures from rainfall damages, this paper adopted the water absorption test method to observe the relation between water intake of the material before and after coating using wood samples from Hip roof structure (David, Moretti, et al. 2020).

Figure 9: Samples without treatment and after application of resins: 1) Sample without treatment; 2) With a layer of coated material;

Experimental reagents and raw materials

Table 2: Instrument used in the experiment:

Instrument name	Model type	Brand	Manufacturer
Oven-Dry Mass	202	KeWei	Beijing KeWei Co.Ltd
Brush	2271	Tianjin	Yuntengfei Co. Ltd
Digital Weighing machine	YPHX.-15Ex	Yingpeng®	Sichuan “Gongye Fangbaodianzi Zhuocheng” factory
Flask/Glassware 250 mL	BA0020250A	BoRo	BoRo Co, Ltd

Analysis and results

Water absorption test

The water absorption test method used observed the relation between water intake of the material before and after coating. For this purpose, at regular time intervals, ranging from 6hours at the beginning to 12 hours during the last stages of the process, the samples were rapidly removed from the test tubes and superficially dried. After, a digital scale weighs the sample to determine the moisture intake. Additional water was introduced into the container (with the wood samples in it). The wood sample was left for 12 to 24hours to complete immersion to determine the water absorption. The immersion process repeated until the moisture content attained a range of 109-115% (d.b). According to the General Administration of Quality Supervision (2009), the formula for determining the water absorption level of wood, the formula for calculating the water content of wood (David, Moretti, et al. 2020)(W) is:

$$W = (GQ-GH) / GH \times 100$$

The calculated value is called the absolute moisture content and the moisture content (W, %).

Expressed mathematically: W -- absolute moisture content of wood, measure scale (%);

GQ – weight of wood with moisture (g);

GH-- oven dry weight of the wood (g);

Specimen procedure

The study used wood samples from a Hip roof structure for further analyses. For comparison purposes, waterproof coating samples received three coats. Under normal conditions, wood and its products have a certain amount of moisture contained in them. Before the evaluation, the wood samples were placed in an Electric constant temperature drying oven at 60oC for no less than 4hrs as illustrated in *figure* 10 above. The value for the oven dry weight is recorded. After removing each sample from the oven, the specimen cools at room temperature of 20 to 25oC.

The difference between values obtained from two successive recorded values of weight should not exceed 0.5%. If it exceeds, return the samples to the oven for an additional 4hrs. The specimen shaped into the cubic shape of approximate dimensions L × W ×T = 20mm × 20mm × 20mm. The study conducted at least three experiments for each wood sample and the results for further analysis. Since there are changes in moisture content when exposed to air, it is necessary to weigh the sample immediately after cutting off the test piece or taking it out of the oven.

Test 1: Estimating the water absorption before coating- The moisture content of wood is the ratio of the weight of moisture absorbed in a specified time to the total dry wood mass. After drying, cooling, and weighing, the specimen was immediately placed into Glassware containing distilled water and pressed into the Glassware. The sample was immersed in water for 6hrs and measured to attain the first time (m) and then weigh for 1,2, 3, and 8 days and nights. When measuring each time, surface-dry the specimen with a cotton-fabric, and determine the mass. The distilled water in the container should be kept clean.

The weight of Sample 01 (S001) had the following characteristics:
Mass of the oven dry weight = 2.6g.
The absorption levels were according to the periods in Table 3 below.
Table 3: The table shows that the moisture content of wood based on the experiment conducted.

Name of sample	Oven dry weight	Weight of wood sample after 6hours of immersion into water	Weight of wood sample after 2days of immersion into water	Weight of wood sample after 4days of immersion into water	Weight of wood sample after 8days of immersion into water
Sample 01(S001)	2.6g	4.7g	4.9g	5.1g	6.7g

Absorption after immersion without coating in 6 h, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 2.1 / 2.6x100% = 80.77% (1);

Absorption after immersion without coating in 2 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 2.3 / 2.6x100% = 88.46% (2);

Absorption after immersion without coating in 4 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 2.5 / 2.6x100% = 96.15% (3);

Absorption after immersion without coating in 8 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 4.1 / 2.6x100% = 157.69% (4);

Test 2: Water absorbing after coating

Preparing the surface

The experimental environment played a huge role in the quality of the finished coat. It was evident that an environment with little or no dust gives better results.
To create a clear coat that is void of bubbles, blisters, and other damages is vital to prepare the surface thoroughly. Note that the suitable place to conduct this experiment is a workplace with a temperature of

18°C. It would be a big mistake to apply "cold" epoxy onto a heated wood surface as this would cause the air in the wood fiber to expand.

Procedures of Consolidation and Protection

The coated samples were untouched for almost a month at room temperature. However, the polymer materials used in this experiment needed 15 days to a month to dry. The dry process depends on the type of reagent used and environmental conditions.

The maximum time between the applications of the subsequent coat was approximately 6hrs. During these hours, polymerization occurs. The application of resins on the samples was by brushing. The color seen on the wood sample in fig.4 is because of the Phenolic aldehyde found in resin. Afterward, the water absorption test occurred two days after the resin application to the coated samples.

The weight of Sample 02 (S002) had the following characteristics:

Mass of the oven dry weight of the wood = 3.1g.

Table 4: The table shows that the moisture content of wood based on the source data

Name of sample	Oven dry weight of the wood	Weight of coated wood sample after 6hours of immersion into water	Weight of coated wood sample after 2days of immersion into water	Weight of coated wood sample after 4days of immersion into water	Weight of coated wood sample after 8days of immersion into water
Sample 02(S002)	3.1g	3.4g	3.7g	4.9g	7.2g

Absorption immersion after coating in 6hrs, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 0.3 / 3.1x100% = 9.68% (1);

Absorption after immersion after coating in 2 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 0.6 / 3.1x100% = 19.35% (2);

Absorption after immersion after coating in 4 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 1.8 / 3.1x100% = 58, 06% (3);

Absorption after immersion after coating in 8 days, % (W %) = (weight of wood with moisture - oven dry weight of the wood) / (oven dry weight of the wood) X100% = 4.1 / 3.1x100% = 132.26% (4);

Discussions and results

The study identified a big difference in percentages when comparing the water absorption level of the samples. The rate of the water absorption of the uncoated sample for the first 6hrs after immersion was an over-the-top percentage of 80.77%. When there is a presence of moisture in the wood sample, there is deformation. Thus, it is necessary to waterproof this material to avoid damages. Coated with water-based polyurethane, the spacemen showed lower water absorption. The "coated" wood sample after 6hrs in the water had a 9% mass increase after immersion.

Furthermore, the wood begins to suffer damage if its moisture content remains at over 20% for long periods.

Conclusion

Based on the results of many precious historical architectural studies, wood treatment plays a significant part in water penetration levels in wood; however, this does not prevent the total water penetration but leads to a reduction in the water absorption ratio. Water can enter the wood through the cell walls (the chamber-like wall structure, with holes). Therefore, the wood reminds wet after a long time of soaking (but this is a slow process). To summarize, laboratory experiments have recorded that different techniques seem to fall into two categories – mechanical and chemical. Hence, it is evident that the most effective chemical technique is the application of polyurethane on wooden surfaces because it reduces moisture absorption. However, to urge a decent finish, a minimum of three coats are applied to the wood. The process could take at least a few days to complete (Lebow and Anthony 2012).

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