For The Choice of Impregnated Wood Resistant to Biological Effects in Cultural Heritage Preservation: A Methodological Approach

Habibe ÖZTÜRK[1]
habibeeoztrk@gmail.com
ORCID No: 0009-0001-6769-0486

Z. Sevgen PERKER[2*]
Bursa Uludağ University, Faculty of Architecture, Department of Architecture
zsperker@uludag.edu.tr
ORCID No: 0000-0002-6640-111X

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ABSTRACT

In order to preserve the architectural heritage and pass it on to future generations, it is essential to ensure the longevity of the building materials that make up the heritage. Wood, one of the primary building materials of the architectural heritage, deteriorates for various reasons, and biological problems are a significant part of these reasons. Different biological organisms use wood to meet their needs for food and living space. For this reason, it is essential to find solutions to biologically related problems so that the wooden material can have a long life. The most commonly used process for preserving wooden materials is impregnation. The impregnation process can be applied with different preservatives and methods for various purposes. For this reason, architects who carry out conservation applications must evaluate the negative factors the wooden material will face regarding structure and detail, focus on specific performances, and choose materials accordingly. In this context, this research aims to analyze impregnation research focusing on the biological resistance of wooden materials and to guide architects who practice preservation. Within the scope of the research, six articles on the subject in the DergiPark database were analyzed in terms of their content. As a result, the research presented a biological resistance-oriented framework that will systematize architects' impregnated wood selection processes in cultural heritage protection.

KEYWORDS

Architecture, Biological Resistance, Building Material, Impregnation, Wood

INTRODUCTION

Wood has provided exceptional examples of architecture in all geographies. Traditional wooden structures, produced in harmony with each geographical context's unique environmental, social, and cultural conditions, have become the most critical parts of the universal cultural heritage. Every architectural structure exists with materials and can continue by protecting the building materials. Preserving wooden materials is essential in transferring wooden structures, which constitute an important part of the universal cultural heritage, to future generations.

It is also known that wood, which has been preferred as a building material throughout history due to its superior physical and mechanical properties, has deteriorated for various reasons (Perker, 2004), (Perker & Akıncıtürk, 2006). Biological problems are important among the causes of deterioration in wooden materials. As it is known, wood is an organic material. Depending on its organic structure, wood material can be damaged for reasons such as creating a suitable living space for biological organisms and meeting the food requirements of some organisms.

Although the relevant literature varies in terms of the way the subject is addressed, international academic resources can be generally classified under the following headings in terms of the topics covered:

- Studies examining the natural strength of wood and biological degradation processes and examining the behavior of organisms such as bacteria, fungi, insects, termites, and sea creatures together with the degradation mechanisms of wood materials (Cragg, 2003), (Daniel, 2003), (Distel, 2003), (Goodell, 2003), (Halliwel, 2003), (Little et al., 2012), (Martín & López,

[*] **Corresponding author**

2023), (Messner et al., 2003), (Reading et al., 2003), (Schmutzer et al., 2008), (Shelton & Grace, 2003), (Zhu et al., 2022),

- Studies on developing methods in wood preservation (Leightley, 2003), (Nicholas & Crawford, 2003), (Preston, 2003), (Repič et al., 2022),
- Studies to develop an environmentally friendly approach to wood preservation (Calovi et al., 2024), (Green & Schultz, 2003),
- Studies focusing on the biological strength of wood composites (Gardner et al., 2003), (Tascioglu & Tsunoda, 2010), (Tawfik et al., 2020),
- Studies on wooden structures and biological risks (Udele et al., 2021), (Wang et al., 2018),
- Studies to increase the biological resistance of wood, especially the impregnation process (Belchinskaya et al.2021), (Can et al., 2023), (Cooksona et al., 2009), (Kjellowa & Henriksen, 2009), (Lee et al., 2022).

Impregnation is one of the most common applications for protecting wooden materials against various damaging factors. The impregnation process, known as an in-depth protection application, is carried out to ensure the wooden material's long life against various factors that may damage it, also varies (Bozkurt et al., 1993). The diversity of wood species, impregnation materials, and methods makes it difficult for the architect to choose the impregnated wood material. On the other hand, wooden material and structural elements of buildings, joinery, and coatings. It can be used in various elements, but the place of use of the material also changes the expected performance. This makes it necessary to approach material selection by focusing on specific performances.

In the recent international literature focusing on the impregnation process of wood to increase its biological resistance, it can be seen that different impregnation materials have been tested on various types of wood. In a study conducted on using spent engine oil as an impregnation component in increasing the biological strength of birch wood, it was found that spent engine oil significantly increased the dimensional stability and water resistance of the wood. In the same study, it was stated that spent engine oil significantly increased the resistance of wood, especially against brown rot (Poria placenta fungi) (Belchinskaya et al., 2021). In another study, the biological properties and hygroscopic and thermal performances of Oriental spruce (Picea orientalis L.) impregnated with phase change material (PCM) were evaluated. As a result of the study, it was revealed that PCMs are resistant to wood-destroying fungi (Can et al., 2023). In the study conducted on P. radiata sapwood (outer wood of Radiata pine) and heartwood of E. Obliqua (inner wood), it was determined that permethrin dissolved in supercritical carbon dioxide (CO_2) was effective against termites as an impregnation agent (Cooksona et al., 2009). Another study on small wood samples concluded that impregnating wood with biocides using supercritical CO_2 is an effective method. Experiments conducted within the scope of the study showed that supercritical CO_2 can quickly penetrate the wood structure and not damage the impregnated samples (Kjellowa & Henriksen, 2009). In a study focusing on the concentration of pyroligneous acid in protecting wood against biological attacks, different concentrations of pyroligneous acid obtained from Rubberwood and pyroligneous acid obtained from oil palm trunk were sufficient against mold growth. The same results have been observed to be effective against fungi and termites (Lee et al., 2022).

There are different studies on wood impregnation in the scientific literature based in Türkiye. Much research on the biological resistance-oriented impregnation process consists of experimental studies. However, in the relevant literature, no current research has been found that focuses directly on the issue of biological resistance in the impregnation of wood materials and covers the studies on the subject collectively, and in this sense, can provide a guide for the architect's choice of impregnated wood. In this context, the aim of this research is to present a guiding scheme that will help the architect select impregnated wood materials by analyzing current experimental research in DergiPark focusing on biological resistance in the impregnation of wood materials.

BIOLOGICAL FACTORS AFFECTING WOOD

Wood creates an excellent food and living space for many living creatures thanks to its organic structure. These creatures damage the structural integrity of wood, causing it to rot and deteriorate (Thomasson et al., 2006). As a result of invasions, significant damage occurs to wooden materials, and the material's durability decreases. Protection practices are of great importance to minimize the effects of biological pests on wooden materials and extend the material's life. Biological factors that cause wood deterioration: It can be examined under four headings: bacteria, fungi, insects, termites, and marine borers.

BACTERIA

Bacteria are known as the smallest organisms in the plant kingdom and can generally survive in aerobic or anaerobic conditions, depending on the environmental conditions. Bacteria, which typically develop optimally in the 20-30 °C temperature range and 80-100% relative humidity, penetrate the material when the untreated wood is wet. This creates a brown and damp appearance in the wood. The fermentation process of bacteria also leads to a sour odor in the wood.

Bacteria that damage wood have a corrosive effect and cause dark stains on the surface of wooden materials. A certain amount of free water must be in the wood for bacteria to multiply. This situation also creates a suitable environment for the development and proliferation of fungi. It is important to implement appropriate moisture control and protection practices to control and prevent the effects of bacteria on wooden materials (Bozkurt & Erdin, 2011), (Günay, 2002).

FUNGI

Fungi are vegetative organisms with many species. Unlike other green plants, these creatures cannot produce their nutrients because they do not have chlorophyll in their structures. All fungal species that damage wood need a food source such as wood raw material, an appropriate temperature and humidity level, and oxygen to continue their development (Bozkurt & Erdin, 2011), (Günay, 2002). When any of these requirements are missing, fungi either die or remain in a particular form, failing to develop until they find more favorable conditions. Fungi that damage wooden materials: Color can generally be classified as color-giving fungi and rot-causing fungi (Fig. 1).

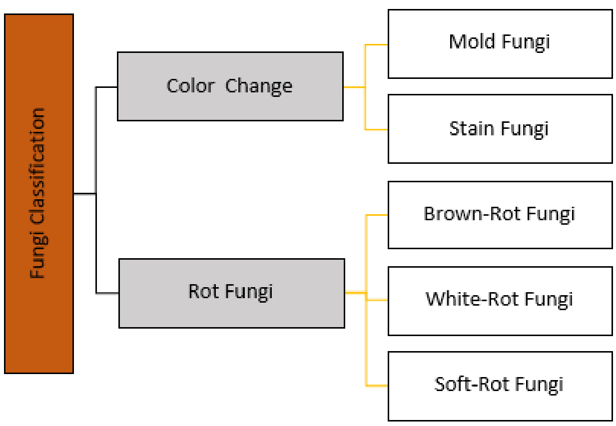

Figure 1. *Classification of fungi that damage wood materials.*
(Figure 1 was prepared by the authors using (Bozkurt, 2008), (Bozkurt & Erdin, 2011), (Günay, 2002), (Örs & Keskin, 2001)).

Fungi that damage wood are generally divided into two main categories: those that cause discoloration and those that cause rot. Fungi that give color to wood act by consuming the protoplasm in the cell cavity (Örs & Keskin, 2001). These fungi are divided into two categories: mold and stain fungi.

Mold fungi generally feed only on the substances inside the cell without affecting the cellulose and lignin found in the cell wall. They feed especially on carbohydrates found in the sap ray parenchyma cells and, therefore, do not affect the physical properties and resistance of the wood. However, the black or green mold layer can damage the aesthetic appearance of the wood and make bonding operations difficult (Fig. 2). During the drying process of wood, mold fungi die, and the resulting superficial discolorations can be removed after the wood has completely dried (Bozkurt, 2008).

Stain fungi feed on carbohydrates such as starch and sugar in wood cells. Since they do not damage the cell wall, they do not reduce the strength and durability of the wood, but they change its permeability and visual properties. The color change is not superficial, like molds, but can also spread to the inner parts of the wood. If the wood surface gets water, these fungi develop and give the wood a gray-blue color (Fig. 3). For this reason, these mushrooms are also called blue-stain mushrooms (Günay, 2002). The amount of moisture and temperature are important factors for developing stain fungi. Although it varies depending on the species, the most suitable humidity amount is generally between 30-40%, and temperature requirements vary between 18-20-25 °C (Bozkurt, 2008).

Figure 2. *Mold fungi (Is It Really Mold or Just Staining? CONNER Industries, 2024).*

Figure 3. *Stain fungi (Aslan & Usta, 2009).*

Fungi that cause rot in wood initiate the decay process by damaging the compounds that form the cell wall of the wood (Örs & Keskin, 2001). According to their effects on wood tissue, rot-causing fungi are divided into three types: brown rot, white rot, and soft rot fungi (Thomasson et al., 2006).

Brown-rot fungi destroy the cellulose in the cell wall; therefore, the remaining lignin causes the wood to turn brown (Fig. 4). Due to these fungi, the wood cracks longitudinally and transversely, and cube-shaped pieces that can be crushed with fingers are formed (KUDEB, 2009). Brown rot causes an approximately 70% decrease in the resistance and weight of wood (Bozkurt, 2008).

White-rot fungi degrade all components of wood cell walls, especially lignin and hemicellulose; however, cellulose is generally not attacked (Fig. 5). For this reason, the remaining cellulose provides a white color to the wood (Sundararaj, 2022). White rot fungi do not cause transverse cracks, abnormal narrowing, or collapse like brown rot fungi.

Soft-rot fungi affect the material by destroying the cellulose and hemicellulose layers (Fig. 6). These fungi usually occur in very humid places in direct contact with soil and water. It is seen that the resulting rot preserves the original form of the material, but surface discoloration, softening, and pitting occur. Fine cracks appear on the rotten surfaces as the material dries, and crumbling occurs (Örs & Keskin, 2001).

Figure 4. *Brown-rot fungi (Sundararaj, 2022).*

Figure 5. *White-rot fungi (Sundararaj, 2022).*

Figure 6. *Soft-rot fungi (Sundararaj, 2022).*

INSECTS AND TERMITES

Insects can damage wood for sheltering, feeding, or laying eggs (Milton, 1995). These creatures consume outer wood to open gallery spaces and lay eggs in these tunnels. Although the larvae are not visible from the outside, they consume the interior of the wood and cause mechanical weakness (Bozkurt & Erdin, 2011). The optimum humidity for these harmful insects to survive is generally between 8-10%, and the temperature is between 20-30ºC (Kartal, 2016).

Among the insect species that most destroy wooden structures are the house goat beetle (Hylotrupes bajulus) (Fig. 7), (Fig. 8) the common furniture beetle (Anobium punctatum), the variegated gnawing beetle (Xestobium rufovillosum) and the parquet beetle (Lyctus linearis) (KUDEB, 2009).

Figure 7. *Adult and worm state (Yıldız, 2011).*

Figure 8. *Destruction of wood by the sama insect (Yıldız, 2011).*

Termites, another important wood pest worldwide, cannot generally be detected from the external surface but can be noticed by the gallery spaces they open when a wooden section is taken. Therefore, termites are one of the organisms that cause the most severe damage to wooden materials. Termites destroy the material by consuming the cellulose of the wood (Fig. 9), (Fig. 10).

Figure 9. *Image of termites (Arango et al., 2021).*

Figure 10. *Termite damage on pine (Arango et al., 2021).*

MARINE BORERS

Wooden building elements, especially structures such as bridges and piers in the sea, can be destroyed by some creatures living in the sea. The magnitude of the damage caused varies depending on many factors, such as temperature, salinity of the water, symbiosis with fungi, and wood type. Among marine borers, mollusks (sea worms - Teredo sp., Bankia sp.), crustaceans (Limnoria sp., Sphaeroma sp.), and pholads (Martezia sp.) can be given as examples (Bozkurt & Erdin, 2011), (Milton, 1995) (Fig. 11), (Fig. 12).

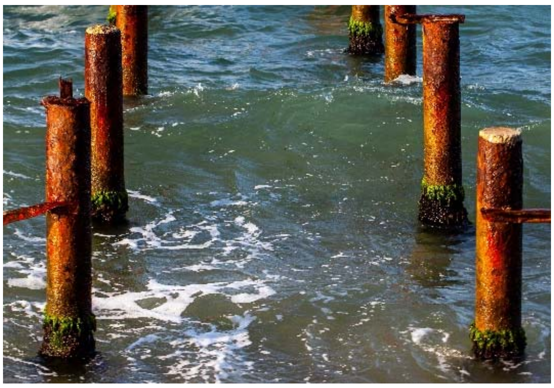

Figure 11. *Damage on wood in marine (Transportation place Dock near the Sea Free Photo, 2024).*

Figure 12. *Damage on wood in marine (Wooden bricole, wooden mooring poles in the water, Venice, Italy, 2019 Free Photo, 2024).*

METHOD

The database used for data collection within the scope of the research is DergiPark. First, the database was searched with the keyword "impregnation." The article list obtained as a result of the search was examined in detail. From the list, studies published in the Turkish language, focusing on the biological resistance of impregnation of wooden materials and containing experimental content, were determined. Thus, the six studies obtained constituted the data set of this research (Table 1).

Table 1. *Table Information about the articles in the dataset.*

Title of Journal	Authors (Year)
Düzce University Faculty of Forestry Journal of Forestry	Şen & Hafızoğlu (2008) Şen & Yalçın (2009)
Journal of Bartin Faculty of Forestry	Can & Sivrikaya (2017)
Turkish Journal of Forestry	Dizman Tomak, Günaydın & Arpacı (2021)
Turkish Journal of Forestry Research	Kılınç, Temiz, & Köse Demirel (2022)
Artvin Coruh University Journal of Forestry Faculty	Altay & Özdemir (2023)

It is the systematic analysis of the data set obtained due to the scanning in terms of content. In this context, a table containing the citation information of the articles that make up the data set was created. Then, the contents in the articles, the tree/wood type, impregnation material, and impregnation method, were analyzed and evaluated in terms of the effect of impregnation on the biological resistance of the wooden material.

RESULTS

All of the studies included in the research are publications in academic journals on "Forestry" between 2008 and 2023. Wooden material can be protected against damage caused by biological pests by impregnation. When the studies on the effect of impregnation on the biological resistance of wooden materials were examined, it was seen that the wood type used in all studies was natural wood. The tree/wood species used in the studies include softwood such as Scots pine, red pine, and oriental spruce; hardwood include oriental beech, alder, and poplar (Table 2).

Table 2. *Wood species used in the articles.*
(Table 2 was prepared by the authors using (Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009), (Can & Sivrikaya, 2017), (Dizman Tomak, Günaydın & Arpacı, 2021), (Kılınç, Temiz, & Köse Demirel, 2022), (Altay & Özdemir, 2023)).

WOOD SPECIES			ARTICLES					
			1	2	3	4	5	6
NATURAL WOOD	SOFTWOOD	Scotch Pine	■	■		■	■	
		Picea Orientalis	■					
	HARDWOOD	Oriental Beech	■					■
		Poplar			■			
		Alder	■				■	

In the studies covered within the scope of the research, it was determined that natural preservatives and water-borne preservatives were used. Natural preservatives include thuja, sumac, acorn extract, and pine extract. Water-borne preservatives include alkaline copper quaternary, copper-chrome-arsenic (CCA), copper-chrome-borate (CCB), geothermal water (İzmir-Seferihisar-Doğanbey hot spring area), copper azole (CuA), zinc chloride ($ZnCl_2$), nano cerium oxide (CeO_2), nano zinc oxide (ZnO), copper II sulfate ($CuSO_4$), copper azole (Tanalith-E), boric acid (BA), borax (Bx) and ammonium sulfate (AS) (Table 3), (Table 4).

Table 3. *Water-borne preservatives used in articles.*
(Table 4 was prepared by the authors using (Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009), (Can & Sivrikaya, 2017), (Dizman Tomak, Günaydın & Arpacı, 2021), (Kılınç, Temiz, & Köse Demirel, 2022), (Altay & Özdemir, 2023)).

WATER-BORNE PRESERVATIVES	ARTICLES					
	1	2	3	4	5	6
Alkaline Copper Quaternary					■	
Ammonium Sulfate						■
Borax						■
Boric Acid						■
Copper Azole		■	■		■	
Copper II Sulfate				■		
Copper-Chrome-Arsenic	■	■				
Copper-Chrome-Borate		■				
Nano Cerium Oxide				■		
Zinc Chloride				■		
Nano Zinc Oxide				■		

Table 4. *Natural preservatives used in articles.*
(Table 3 was prepared by the authors using(Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009), (Can & Sivrikaya, 2017), (Dizman Tomak, Günaydın & Arpacı, 2021), (Kılınç, Temiz, & Köse Demirel, 2022), (Altay & Özdemir, 2023)).

NATURAL PRESERVATIVES	ARTICLES					
	1	2	3	4	5	6
Pine Extract	■					
Sumac Extract	■					
Thuja Extract	■					
Acorn Extract	■					

In the studies covered within the scope of the research, it was determined that only pressure-applied methods were used as an impregnation method for the biological resistance of wooden materials. Among the methods where pressure is applied, it is seen that full cell and vacuum methods are preferred (Table 5).

Table 5. *Impregnation methods used in articles.*
(Table 5 was prepared by the authors using (Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009), (Can & Sivrikaya, 2017), (Dizman Tomak, Günaydın & Arpacı, 2021), (Kılınç, Temiz, & Köse Demirel, 2022), (Altay & Özdemir, 2023)).

IMPREGNATION METHODS		ARTICLES					
		1	2	3	4	5	6
NON-PRESSURE	Brushing or Spraying						
	Dipping						
	Hot-Cold Bath						
	Soaking						
PRESSURE	Full Cell Process	■	■				
	Vacuum process			■	■	■	■

In the studies, the effect of the impregnation materials and methods used on the density and permeability of the wood was taken into account to evaluate biological resistance. In order to reveal the effect of biological destruction, the weight losses of wooden materials were examined. Situations where weight loss is low are considered situations where the effect of the impregnation on biological durability is high. In the studies discussed within the scope of the research, it is seen that the copper-chrome-borate (CCA) substance, which contributes to the reduction of weight losses, has a positive effect on the biological resistance of wood (Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009). Although the preservative named Tanalith-E has a positive effect on reducing weight loss in poplar and alder species, the same substance had a negative effect on increasing weight loss in Scots pine (Can & Sivrikaya, 2017), (Kılınç et al., 2022), (Şen & Yalçın, 2009). It has been determined that borate compounds contribute positively to the biological resistance of wood materials by reducing weight loss, whereas ammonium silicate has an opposite, negative effect (Altay & Özdemir, 2023). It has been observed that zinc chloride is among the substances that contribute positively to biological resistance by reducing weight loss (Dizman Tomak et al., 2021).

Another way to evaluate whether impregnation is effective on wooden material is to evaluate permeability values. Value changes in the permeability of the material differ according to washing conditions. Accordingly, as the amount of washing increases, the permeability, in other words, the impregnation efficiency, decreases. Thus, the resistance of the material against biological effects decreases. In the studies covered within the scope of the research, the resistance to washing of zinc chloride, which has a positive effect on the biological resistance of wood, was also interpreted as positive (Dizman Tomak et al., 2022), (Öztürk, 2024).

As a result of analyzing the experimental studies included in the research, a scheme was created that holistically reveals the positive contribution of impregnation to the biological resistance of wooden materials. The diagram includes research results that positively contribute to the biological resistance of wooden materials (Fig. 13).

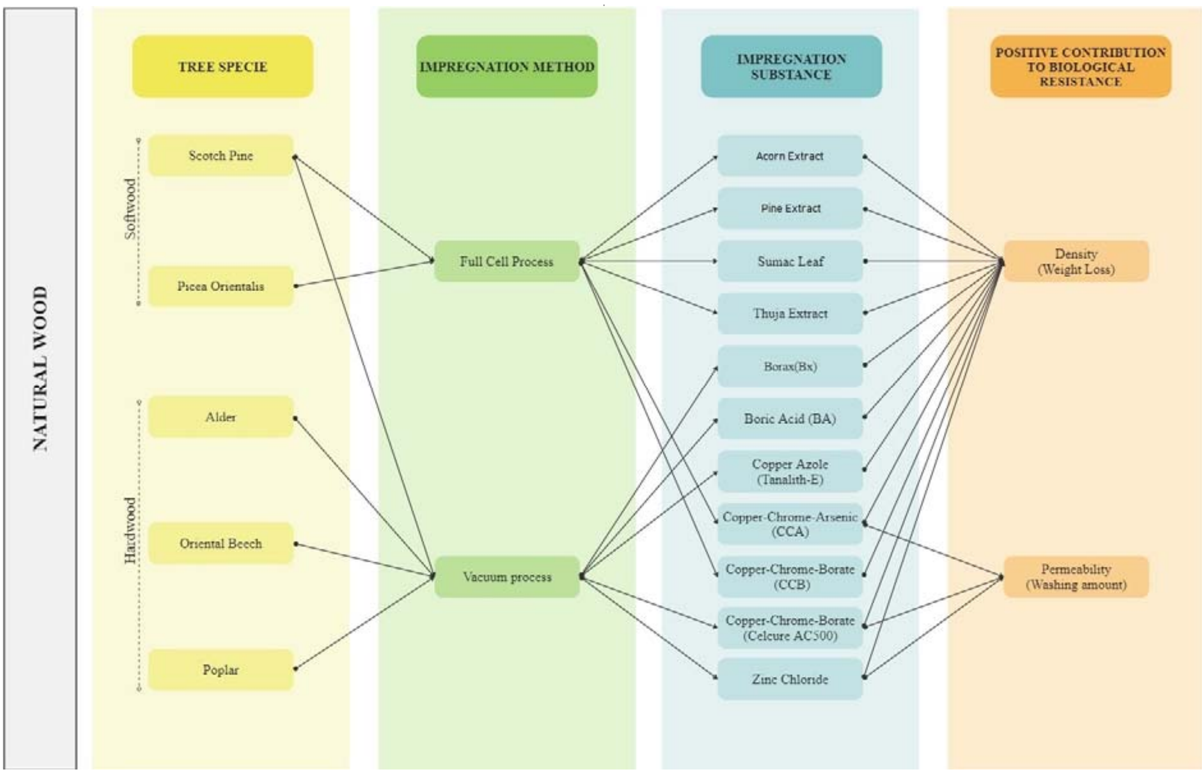

Figure 13. *Scheme for the positive contribution of impregnation to the biological strength of wooden materials (Figure 2 was prepared by the authors using (Şen & Hafızoğlu, 2008), (Şen & Yalçın, 2009), (Can & Sivrikaya, 2017), (Dizman Tomak, Günaydın & Arpacı, 2021), (Kılınç, Temiz, & Köse Demirel, 2022), (Altay & Özdemir, 2023), (Öztürk, 2024)).*

CONCLUSION

Within the scope of the research, six articles written in Turkish were obtained from the DergiPark database and focuses on the effect of impregnation on the biological resistance of wooden materials. The tree/wood type, impregnation material, impregnation method, and the impregnation process's effect on the wooden material's biological resistance were systematically analyzed. As a result of the analyses, various classifications were reached according to the effects of the impregnation process on the wood.

In studies focusing on the effect of impregnation on the biological resistance of wooden materials, It has been observed that natural wood types are preferred, only natural and water-borne preservatives are used as impregnation materials, and the filled cell method and vacuum methods, which are pressure applied methods, are used as impregnation methods.

Literature has been researched on tree species such as Scotch Pine, Picea Orientalis, Alder, Oriental Beech, and Poplar. As impregnation materials that give positive results, acorn extract, pine extract, thuja extract, sumac extract, boric acid (BA), borax (Bx), copper azole (Tanalith-E), copper-chrome-arsenic (CCA), It has been determined that substances such as copper-chrome-borate (CCB) and zinc chloride (ZnCl2) stand out. Although an early study focused on wood extracts as impregnation materials, it is understood that recent studies have focused on chemical-containing impregnations. When the results are compared with recent international studies focusing on the impregnation process, it is seen that similar tree species (Picea Orientalis) are used in a limited number of international studies. It has been determined that international studies have been conducted on different tree species, such as birch wood, P. Radiata, and E. Obliqua. Differences in tree species are considered natural in the context of prioritizing local and regional species. However, while recent studies in DergiPark mostly focus on chemical-containing impregnation materials, recent international studies show that substances such as spent engine oil, phase change materials, supercritical carbon dioxide, and pyroligneous acid obtained from trees are used as impregnation materials. Considering today's environmental problems, environmentally friendly protection practices are of great importance, especially to increase the biological durability of an environmentally friendly material such as wood. In this context, it is thought that new research on the usability of waste oils or plant-derived substances as impregnation materials will contribute to the relevant literature.

As a result of the research, a scheme was created that holistically reveals the positive contribution of impregnation to the biological strength of wooden materials, based on articles in DergiPark. It is believed that the created scheme is a guide to help the architect rationally select the impregnated wooden material to be used in applications to preserve the architectural heritage.

CONFLICT OF INTEREST

The Authors declare that there is not any conflict of interest about this paper.

REFERENCES

Altay, Ç., & Özdemir, E. (2023). Yanmayı geciktirici maddelerle muamele edilen ve epoksi ile poliürea reçineleriyle kaplanan Doğu kayını odununun çürüklük direnci. *Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi*, 24(1), 106-112. https://doi.org/10.17474/artvinofd.1194306

Arango, R., Lebow, S. T., & Glaeser, J. A. (2021). Wood handbook, Wood as an engineering material. Chapter 14. Biodeterioration of Wood.

Aslan, S., Usta, İ. (2009). Ağaç Malzemede Mavi Renk Oluşumu ve Mavileşmenin Ahşabın Kullanımına Etkileri. *Yapı Dünyası Dergisi*, 2009, 164-165.

Bozkurt, A., Göker, Y., & Erdin, N. (1993) Emprenye tekniği. İstanbul Üniversitesi Orman Fakültesi Yayınları.

Bozkurt A., Y., & Erdin, N., (2011). Ağaç Teknolojisi. İstanbul Üniversitesi Yayınları Erişim adresi: http://nek.istanbul.edu.tr:4444/ekos/KITAP/2012-02062.pdf

Bozkurt, Ö. (2008). Tarihi yapıların restorasyonunda ahşabın biyolojik bozulmalarına karşı yerinde emprenye tekniklerinin uygulanabilirliği. Doktora Tezi, Trakya Üniversitesi Fen Bilimleri Enstitüsü, Mimarlık Anabilim Dalı, Edirne.

Belchinskaya, L., Zhuzhukin, K. V. , Ishchenko, T., & Platonov, A. (2021). Impregnation of Wood with Waste Engine Oil to Increase Water- and Bio-Resistance. *Forests*, 12, 1762.

Calovi, M., Zanardi, A., & Rossi, S. (2024). Recent Advances in Bio-Based Wood Protective Systems: A Comprehensive Review. *Applied Sciences*, 14, 736.

Can, A., Lee, S. H., Antov, P., & Ghani, M. A. A. (2023). Phase-Change-Material-Impregnated Wood for Potential Energy-Saving Building Materials. *Forests*, 14, 514.

Can, A., & Sivrikaya, H. (2017). Mantar Tahribatına Uğramış Titrek Kavak Odununun FT-IR Yöntemiyle Kimyasal Analizi. *Bartın Orman Fakültesi Dergisi*, 19(1), 139-147. https://doi.org/10.24011/barofd.299364

Cooksona, L. J. , Qader b A., Creffielda, J.W., & Scown, , D.K. (2009). Treatment of timber with permethrin in supercritical carbon dioxide to control termites. *The Journal of Supercritical Fluids*, 49, 203–208.

Cragg, S. M. (2003). Marine Wood Boring Arthropods: Ecology, Functional Anatomy, and Control Measures. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 272-286). American Chemical Society.

Daniel, G. (2003). Microview of Wood under Degradation by Bacteria and Fungi. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 34-72). American Chemical Society.

Distel, D. L. (2003). The Biology of Marine Wood Boring Bivalves and Their Bacterial Endosymbionts. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 253-271). American Chemical Society.

Dizman Tomak, E., Günaydın, A., & Arpacı, S. S. (2021). Bakır, çinko ve seryum içeren kimyasal maddeler ile odunun antifungal özelliklerinin iyileştirilmesi. *Turkish Journal of Forestry*, 22(1), 56-61. https://doi.org/10.18182/tjf.801815

Gardner, D. J., Tascioglu, C., & Wålinder, M. E. P. (2003). Wood Composite Protection. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 399-419). American Chemical Society.

Goodell, B. (2003). Brown-Rot Fungal Degradation of Wood: Our Evolving View. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 97-118). American Chemical Society.

Green, F., & Schultz, T. P. (2003). New Environmentally-Benign Concepts in Wood Protection: The Combination of Organic Biocides and Non-Biocidal Additives. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 378-389). American Chemical Society.

Günay, R. (2002). Geleneksel ahşap yapılar sorunları ve çözüm yolları. İstanbul: Birsen Yayınevi.

Halliwel, B. (2003). Free Radical Chemistry as Related to Degradative Mechanisms. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 10-15). American Chemical Society.

Is It Really Mold or Just Staining? CONNER Industries. Conner Industries Retrieved January 23, 2024, from https://www.connerindustries.com/is-it-really-mold-or-just-staining/

Kartal, S. N. (2016). Tarihi ahşap yapılarda biyotik/abiyotik bozunmalar ve koruma/bakım Önlemleri. *Restorasyon ve Konservasyon Çalışmaları Dergisi*, (16), 51-58.

Kılınç, S., Temiz, A., & Köse Demirel, G. (2022). Tanalith E ve Celcure AC 500 ile emprenye edilerek hazırlanan kızılağaç kamelyalarının biyolojik dayanımı ve yıkanma mekanizması. *Ormancılık Araştırma Dergisi*, 9 (Özel Sayı), 363-368. https://doi.org/10.17568/ogmoad.1095156

Kjellowa, A. W., & Henriksen, O. (2009). Supercritical wood impregnation. *The Journal of Supercritical Fluids*, 50, 297–304.

KUDEB. (2009). Kudeb ahşap eğitim atölyesi geleneksel ahşap yapı uygulamaları. İstanbul: İ.B.B. Kudeb Yayınları. Erişim adresi: https://kudeb.ibb.istanbul/wp content/uploads/2020/01/Geleneksel-Ahsap-yapi-Uygulamalari-Kitabi.pdf

Lee, C. L, Chin, K. L., Khoo, P. S., Hafizuddin, M. S., & H'ng, P. S. (2022). Production and Potential Application of Pyroligneous Acids from Rubberwood and Oil Palm Trunk as Wood Preservatives through Vacuum-Pressure Impregnation Treatment. *Polymers*, 14, 3863.

Leightley, L. E. (2003). Protection of Wood Using Combinations of Biocides. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 390-398). American Chemical Society.

Little, N. S., Blount, N. A., Londo, A. J., Kitchens, S. C., Schultz, T. P., McConnell, T. E., & Riggins, J. J. (2012). Preference of Formosan Subterranean Termites for Blue-Stained Southern Yellow Pine Sapwood. *Journal Of Economic Entomology,* 105 (5), 1640-1644.

Martín, J. A., & López, R. (2023). Biological Deterioration and Natural Durability of Wood in Europe. *Forests*, 14, 283.

Messner, K., Fackler, K., Lamaipis, P., Gindl, W., Srebotnik, E., & Watanabe, T. (2003). Overview of White-Rot Research: Where We are Today. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 73-81). American Chemical Society.

Milton, F. T. (1995). The preservation of wood. Minnesota Extension Service.

Nicholas, D. D., & Crawford, D. (2003). Concepts in the Development of New Accelerated Test Methods for Wood Decay. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 288-312). American Chemical Society.

Örs, Y., & Keskin, H. (2001). Ağaç Malzeme Bilgisi. Ankara: Atlas Yayınevi.

Öztürk, H. (2024). Ahşap emprenyesi üzerine yapılan çalışmaların analizi. Yüksek Lisans Tezi. Bursa Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Mimarlık Anabilim Dalı, Bursa.

Perker, Z. S. (2004). Geleneksel Ahşap Yapılarımızda Kullanım Sürecinde Oluşan Yapı Elemanı Bozulmalarının Cumalıkızık Örneğinde İncelenmesi. Yüksek Lisans Tezi. Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Mimarlık Anabilim Dalı, Bursa.

Perker, Z. S., & Akıncıtürk, N. (2006). Cumalıkızık'da Ahşap Yapı Elemanı Bozulmaları. *Uludağ Üniversitesi Mühendislik Fakültesi Dergisi*, 11(2). https://doi.org/10.17482/uujfe.61527

Preston, A. F. (2003). Can Understanding the Mechanisms of Biodegradation Help Preservative Development? In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 372-377). American Chemical Society.

Reading, N. S., Welch, K. D., & Aust, S. D. (2003). Free Radical Reactions of Wood-Degrading Fungi. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 16-31). American Chemical Society.

Repič, R., Pondelak, A., Kržišnik, D., Humar, M., & Škapin, A. S. (2022). Combining mineralisation and thermal modification to improve the fungal durability of selected wood species. *Journal of Cleaner Production*, 351, 1-9.

Schmutzer, M., Schwanninger, M., Fackler, K., Messner, K., & Gradinger, C. (2008). Comparison of methods to evaluate the potential of fungal growth on decay of spruce wood after short-time treatment. *International Biodeterioration & Biodegradation,* 61 (4), 319-324.

Shelton, T. G., & Grace, J. K. (2003). Termite Physiology in Relation to Wood Degradation and Termite Control. In B. Goodell, D. D. Nicholas, T. P. Schultz (Eds.), *Wood Deterioration and Preservation Advances in Our Changing World-ACS Symposium Series 845* (pp. 242-252). American Chemical Society.

Sundararaj, R. (Ed.). (2022). Science of Wood Degradation and Its Protection. Springer Singapore.

Şen, S., & Hafızoğlu, H. (2008). Bazı Bitkisel Ekstraktların Toprakla Temasta Odun Koruyucu Etkinliklerinin Belirlenmesi. Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi, 4(1-2), 69-82.

Şen, S., & Yalçın, M. (2009). Çeşitli Koruyucu Maddeler ile Emprenye Edilmiş Sarıçam (Pinus sylvestris L.) Odununda Deniz Şartlarında Oluşan Ağırlık Kayıplarının İncelenmesi. *Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi*, 5(2), 1-10.

Tascioglu, C., & Tsunoda, K. (2010). Biological performance of copper azole-treated wood and wood-based composites. Holzforschung, 64 (3), 399-406.

Tawfik, M. E., Ghanem, S. M., Eskander, S. B., Abd El-Nasser, N. H., & Motawe, F. H. (2020). Biological Performance of Hard Wood Composite formulated from Rice Straw and Polystyrene Foam Wastes. *KGK Kautschuk Gummi Kunststoffe,* 73(10), 49-56.

Thomasson, G. L., Capizzi, J., Dost, F., Morrell, J., & Miller, D. (2006). Wood preservation and wood products treatment: training manual. Erişim adresi: https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8403_1.pdf

Transportation place Dock near the Sea Free Photo. Vecteezy. Retrieved May 14, 2024. https://www.vecteezy.com/photo/3109641-transportation-place-dock-near-the-sea.

Udele, K. E., Morrell, J. J., & Sinha, A. (2021). Biological Durability of Cross-Laminated Timber- The State of Things. *Forest Products Journal*, 71 (2), 124-132.

Wang, J. Y., Stirling, R., Morris, P. I., Taylor, A., Lloyd, J., Kirker, G., Lebow, S., Mankowski, M. E., Barnes, H. M., & Morrell, J. J. (2018). Durability Of Mass Timber Structures: A Review Of The Biological Risks. *Wood and Fiber Science*, 50 (Special Issue), 110-127.

Wooden bricole, wooden mooring poles in the water, Venice, Italy, 2019 Free Photo, Vecteezy. https://www.vecteezy.com/photo/2840616-wooden-bricole-wooden-mooring-poles-in-the-water-venice-italy-2019. Retrieved January 23, 2024.

Yıldız, Ü. C. (2011). Dış mekanda ahşap kullanımı. KTÜ Orman Fakültesi, Orman Endüstri Mühendisliği, Ders Notu.

Zhu, Y., Li, W., Meng, D. S., Li, X. J., & Goodell, B. (2022). Non-enzymatic modification of the crystalline structure and chemistry of Masson pine in brown-rot decay. *Carbohydrate Polymers*, 286, 119242.