Düzce University
Journal of Science & Technology

Research Article

A Physical Properties-Focused Analysis for the Selection of Impregnated Wood in Architecture

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DOI: 10.29130/dubited.1431384

ABSTRACT

Wood, one of the building material of the architectural tradition and the future, is subject to deterioration due to various factors. The most commonly used process for the protection of wooden materials is impregnation. The diversity of wood species and impregnation materials and methods complicates building material selection processes for architects. The diversity of building elements requires focusing on the different performances of the material in the building material selection process. In this context, this research aims to provide a guiding framework that focuses on the effect of impregnation on the physical properties of wooden materials. Within the scope of the research, 35 Turkey-based, experimental research articles on the subject in the Dergipark database were analyzed in terms of wood type, impregnation material, impregnation method, and the effect of impregnation on the physical properties of the wood material. As a result of the research, a physical property-oriented framework has been reached that will rationalize the impregnated wood building material selection processes for architects who are decision-makers in the architectural design and building repair stages.

Keywords: *Architecture, Wood, Impregnation, Material, Physical Properties*

Mimaride Emprenyeli Ahşap Seçimi İçin Fiziksel Özellik Odaklı Bir Analiz

Öz

Mimarlık geleneğinin ve geleceğin başlıca yapı malzemelerinden biri olan ahşap, çeşitli etkenler karşısında bozulmaya uğramaktadır. Ahşap malzemenin korunması konusunda yaygın olarak uygulanan işlem emprenyedir. Ağaç türlerinin yanı sıra emprenye madde ve yöntemlerinin çeşitliliği, mimarlar için yapı malzemesi seçim süreçlerini karmaşık hale getirmektedir. Ahşap yapı elemanlarının çeşitliliği ise yapı malzemesi seçim sürecinde malzemenin farklı performanslarına odaklanılmasını gerektirmektedir. Bu bağlamda bu araştırmanın amacı; emprenyenin ahşap malzemenin fiziksel özelliklerine etkisine odaklanan, rehber niteliğinde bir çerçeve sunmaktır. Araştırma kapsamında, Dergipark veritabanında yer alan, konuyla ilgili 35 adet Türkiye merkezli, deneysel içerikli araştırma makalesi ağaç türü, emprenye maddesi, emprenye yöntemi ve emprenyenin ahşap malzemenin fiziksel özelliklerine etkisi bakımından analiz edilmiştir. Araştırma sonucunda, mimari tasarım ve yapı onarım aşamalarında karar verici konumda olan mimarlar için, emprenyeli ahşap yapı malzemesi seçim süreçlerini rasyonel hale getirecek, fiziksel özellik odaklı bir çerçeveye ulaşılmıştır.

Anahtar Kelimeler: *Mimarlık, Ahşap, Emprenye, Malzeme, Fiziksel Özellikler*

Received: 04/02/2024, Revised: 10/03/2024, Accepted: 24/08/2024

I. INTRODUCTION

Material is fundamental to realizing the architectural design and maintaining an existing structure. Material selection processes are carried out by architects as decision-makers, both during the design of a new building and the maintenance, repair, or renovation of an existing building. They are multi-dimensional, multi-parameter, complex processes. Aesthetic concerns, technical performances, environment-product interactions, costs, and socio-cultural requirements are considered in the architect's selection of building materials. There may be many parameters [1]. It is of great importance for architects to systematize and rationalize the complex material selection process.

In today's architectural environment, many material alternatives come to the fore for the architect. However, the responsible architecture approach, especially regarding the environment and human health, necessitates the selection of environmentally friendly materials. Wooden material, which has provided important examples of traditional architecture throughout history and is considered one of the primary materials of today's sustainable architecture, stands out among material alternatives due to its superior aspects, especially its positive environmental interaction.

Despite its superior properties, wooden material can also deteriorate due to physical, chemical, biological, and human-induced reasons [2-3]. The preservation of the universal architectural heritage produced with wooden materials and the widespread use of wood as an ecological building material choice in contemporary buildings are closely related to minimizing material problems. The most commonly used process for the protection of wooden materials is impregnation. There are various studies on the impregnation process in the literature. However, the mentioned studies are: It is seen that it varies in terms of wood species, impregnation materials, impregnation methods, and the properties desired to be imparted by impregnation. The diversity of building elements produced with wooden materials, and on the other hand, the variety of impregnation processes, which is a wood material protection application, cause the architect's choice of building element design, maintenance, repair, and renewal to become more complicated. Therefore, it is significant to create rational selection aids that can be useful for the architect in choosing impregnated wood materials. In addition, the diversity of building elements in which wooden materials can be used requires focusing on the different performances of the material in the material selection process.

There are various experimental studies on the impregnation of wood materials in Turkey-based literature. However, in the relevant literature, holistic research that focuses on the specific performance of the impregnated wood material to be used in building element design and provides a guide that can help architects in material selection in this sense has yet to be found. In this context, this research aims to analyze Turkey-based experimental research focusing on the effect of impregnation on the physical properties of wooden materials; the aim is to present a guiding scheme that will help the architect rationally choose the impregnated wooden material to be used in the design, maintenance, repair or renewal of building elements.

II. PHYSICAL PROPERTIES OF WOOD

Wood's Physical properties are examined under the headings of moisture, density, thermal properties, electrical properties, acoustic properties, visual properties, and permeability.

A. MOISTURE

Wood is a material that can absorb and release moisture in its environment thanks to its hygroscopic feature [4]. The moisture content of wood material varies depending on the type of tree, its age, growing environment, the part of the wood from which it was taken, and the cutting season. Water is present in tree cells in three different forms:

- Structural water is included in wood's chemical structure and is not affected by drying processes.
- The absorption of water occurs due to the tendency of the cellulose in the cells to attract water. This type of water can cause the wood to swell.
- It is water that is found free between and within cells.

The physical properties of wood change depending on the moisture level. When dry wood is placed in a humid environment, it absorbs moisture, expands in size, and increases volume [5-6].

The moisture content in the wood is a factor that determines the quality of impregnation. Therefore, the wood material must be dried to a suitable moisture before impregnation. Effective impregnation penetration cannot be achieved in newly cut trees due to their high humidity and low void volume.

B. DENSITY

The specific gravity of wood varies depending on the type of tree, which part of the tree it is taken from, and the moisture content it contains. While the water content in freshly cut wood is generally between 35-50%, this rate drops to 10-20% in dried wood. Therefore, the specific gravity of freshly cut wood has a different value than dried wood. Additionally, there is a directly proportional relationship between the specific gravity of the wooden material and the mechanical properties of the material. The mechanical properties of wood material with high specific gravity are also expected to be strong [2].

C. THERMAL PROPERTIES

Wood has low heat permeability because it contains air due to the heat impermeability of its essential component, cellulose, and its porous structure. However, the thermal conductivity of wood may vary depending on the moisture in the wood, its type, and fiber direction. Wood expands when exposed to heat and contracts when cooled. However, these expansion and contraction rates are small [5, 7].

D. ELECTRICAL PROPERTIES

The dried wood material cannot conduct electricity. However, as the moisture level of the wood increases, its electrical conductivity also increases, and a change in electrical conductivity occurs depending on the fiber direction of the wood [6]. Wooden can be an effective insulation material when impregnated or glued with paraffin or synthetic resins and when it does not contain moisture [7-8].

E. ACOUSTIC PROPERTIES

Air gaps in the internal structure of wood provide wood with the ability to absorb sound. Thus, it can provide good insulation against sound. The propagation speed of sound waves in wood varies depending on the tree type, fiber orientation, annual ring structure, void ratio, surface roughness, humidity, temperature, density, and frequency of sound waves. As the moisture content in wood material increases, the material shows a heterogeneous feature, which reduces the speed of sound propagation [7].

F. VISUAL PROPERTIES

Elements such as color, texture, shine, and smell reflect the physical properties of wood. Wooden material can have various color tones due to the extractive substances it contains. Even in wooden materials from the same tree species, different color tones can be observed. This is due to the different densities within the same tree and the different reflections of light. Whether the wooden material has a glossy or matte appearance is related to the material's ability to reflect light. In addition, extractive substances found in the structure of wood material, especially substances such as essential oils, resin, and tannin, can contribute to the identification of the tree species by creating the unique smell of the material [2].

G. PERMEABILITY

Permeability is an important factor determining the degree of impregnability of wood. It is a term that generally describes the rate at which liquids pass through a porous surface under pressure [9]. If a material allows liquid flow easily under pressure, it is understood to have high permeability. The type of wood material, sapwood or heartwood, causes significant differences in permeability [10].

III. METHOD

The research material consists of academic articles with experimental content based in Turkey and published in Turkish. In order to obtain the material to be studied within the scope of the research, in the first stage, a search was done on the "Dergipark" database with the keyword "impregnation." The articles encountered as a result of the scanning were examined in detail, and 35 articles focusing on the effect of impregnation on the physical properties of wooden materials were identified. The mentioned articles constituted the study material of this research.

The contents of the articles covered within the scope of the research: The tree/wood type, impregnation material, and impregnation method were analyzed and evaluated in terms of impregnation's effect on the wood's physical properties.

IV. RESULTS

In this section, the effects of the impregnation process on the physical properties of wood were examined in the studies covered within the scope of the research, and various parameters were discussed to evaluate these effects. The mentioned parameters include the type of tree/wood being impregnated, impregnation materials, impregnation methods, and the effects of impregnation on the physical properties of the wooden material.

In this context, samples of two different types of wood were used in the studies examined. Among the natural and engineered wooden materials used, applications of different wood species have also been identified. As seen in Table 1, examples of softwood species in the studies include spruce, Picea Orientalis, Scots pine, black pine, red pine, fir, Uludağ fir, cedar, and hybrid. Among the hardwood species, beech, oriental beech, alder, heaven tree, black poplar, poplar, eucalyptus, iroko, oak, Quercus Petraea, Anatolian walnut, and ash were used.

Table 1. *Wood species used in the articles*

WOOD SPECIES			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
NATURAL WOOD	SOFTWOOD	Scotch Pine		X	X	X			X				X				X	X			X	X				X			X		X					X	
		Black Pine									X						X		X	X			X	X													
		Red Pine	X									X							X	X			X					X							X		
		Uludağ Fir											X									X									X						
		Spruce		X	X	X																											X				
		Picea Orientalis										X						X														X					
		Hybrid															X																				
	HARDWOOD	Oriental Beech										X	X					X			X										X	X					
		Oak (Quercus Robur)																								X				X							
		Quercus Petraea																				X									X						X
		Ash																									X										
		Walnut																																			X
		Poplar															X																				
		Eucalyptus					X								X																						
		Beech		X	X	X																				X				X			X				
		Alder		X	X	X																															
		Heaven Tree						X																													
		Iroko															X																				
ENGINEERED WOOD	SOFTWOOD	Red Pine												X		X																					
		Scotch Pine								X																								X			
		Anatolian Black Pine												X		X																					
		Cedar of Lebanon												X		X																					
	HARDWOOD	Alder																																X			
		Poplar														X																					
		Black Poplar												X																							
		Oriental Beech								X																											

Studies have shown that various impregnation substances that affect the physical properties of wood are used. The impregnation materials used in studies on this effect are classified into four categories: natural, oil-borne, water-borne, and organic solvent preservatives.

Accordingly, colophon (pine resin), linseed oil, tea plant extract, pine tannin, acorn, and waste sunflower oil were identified as examples of natural impregnation materials (Table 2). Boron oil, base oil, paraffin and alkyd resin were among the oil-impregnation materials used in a few studies (Table 3). In the water-soluble impregnation materials category, boric acid (BA), borax (Bx), sodium perborate, polyethylene glycol (PEG-400), Vacsol, Vacsol-Aqua, Immersol-WR, copper-chrom-boron (Tanalith-CBC), Phosphoric acid (FA), ammonium sulfate (AS), diammonium phosphate (DAP), zinc chloride, copper-chrom-boron (Wolmanit-CB), sodium borate, Alkaline Copper Quat (Celcure AC500), Micronized Copper Quat (MCQ), geothermal water (Afyonkarahisar, Ömer-Gecek- Gazlıgöl), (Kütahya, Eynal-Çitgöl-Naşa), (Aydın, Alangüllü-Çamköy-Germencik), (Konya, Ilgın), (Afyonkarahisar-Denizli-Kütahya), Imersol aqua, Timber care aqua, copper azole (Tanalith-E), monoammonium phosphate (MAP), nano titanium dioxide, nano boron nitride, zinc borate and alkyl ketene dimer (AKD) were used (Table 4). As organic solvent impregnation agent, styrene (St), methylmethacrylate (MMA), isocyanate (ISO), ProtimWR230, barite (Baso4), and organosilicon compounds (Dow Corning 1-6184; Z-6341, 2-9034, IE 6683, Z70) (Table 5).

Table 2. *Natural preservatives used in articles*

NATURAL PRESERVATIVES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Acorns																							X												
Colophon (Pine Resin)		X												X																					
Linseed Oil			X																																
Pine Tannin																							X												
Tea Plant Extract															X																				
Waste Sunflower Oil																															X				

Table 3. *Oil-borne preservatives used in articles*

OIL-BORNE PRESERVATIVES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Alkyd Resin														■																					
Paraffin	■			■			■																	■											
Paraffin Wax			■																																
Vaseline																								■											
Base Oil																								■											
Boron Oil											■																								

Table 4. *Water-borne preservatives used in articles*

WATER-BORNE PRESERVATIVES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Alkyl Ketene Dimer																																		■	
Alkaline Copper Quaternary																■																			
Ammonium Sulfate							■	■					■	■													■					■			
Borax					■	■	■					■	■	■													■								
Boric Acid	■				■	■	■					■	■	■													■							■	
Copper Azole																									■				■						
Copper-Chrome-Borate						■	■		■			■	■	■																					
Diammonium Phosphate							■																												
Geothermal Water																	■	■				■				■							■		
Immersol Aqua																							■												
Immersol-WR 2000						■							■																						
Micronized Copper Quaternary																■																			
Monoammonium Phosphate																																■			
Nano Boron Nitride																												■							
Nano Titanium Dioxide																												■							
Phosphoric Acid						■																													
Polyethylene Glycol	■				■	■	■						■																						
Sodium Borate										■																									
Sodium Perborate	■				■																														
Timber Care Aqua																							■												
Vacsol						■	■																												
Vacsol-Aqua																				■															
Vacsol-WR													■																						
Zinc Borate																																■			
Zinc Chloride								■																			■								

Table 5*. Organic solvent preservatives used in articles*

ORGANIC SOLVENT PRESERVATIVES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Isocyanate	■				■	■	■																												
Methyl Methacrylate	■				■	■	■						■																						
Organosilicon Compounds																														■					
ProtimWR230									■																										
Styrene	■				■	■	■						■																						■
White Spirit			■																																
Barite																			■																

In these studies, it was determined that two impregnation methods were used to determine the effect of impregnation on the physical properties of wood. These are methods where non-pressure is applied and methods where pressure is applied. Table 6 shows that brushing/spraying, dipping, soaking, and hot-cold bath methods were used among the methods that do non-pressure. It has been observed that the filled cell and vacuum methods are used among the methods where pressure is applied.

Table 6. Impregnation methods used in articles

IMPREGNATION METHODS		ARTICLES																																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
NON-PRESSURE	Brushing or Spraying												■		■																	■				
	Dipping		■	■	■					■		■						■	■		■		■	■	■			■		■		■	■			■
	Hot-Cold Bath																										■					■				
	Soaking																					■												■		
PRESSURE	Full Cell Process											■					■												■		■				■	
	Vacuum process	■				■	■	■	■		■			■		■				■						■		■								

Accordingly, the effects of the wood species, impregnation material, and method used in these studies, where impregnation affects the physical properties of wood, are given in Table 7.

Table 7. Matrix showing the effect of impregnation on the physical properties of wood

PHYSICAL PROPERTIES	ARTICLES																																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Moisture	■		■		■	■	■					■	■	■			■				■		■	■				■			■		■	■	■
Density						■					■	■		■				■	■			■	■		■	■				■	■				
Thermal Properties								■																			■					■			
Electrical Properties																																			
Acoustic Properties																																			
Visual Properties		■		■					■	■						■				■									■						
Permeability							■						■		■		■	■	■			■			■										

Effects that cause wood to change due to moisture are the effects of wood's resistance to water intake and swelling and contraction values. In the studies examined, it was determined that boric acid and borax, which are water-borne impregnation materials, showed good resistance to water [11-13]. In addition, it is seen that water resistance is increased by mixing boric acid with alkyl ketene dimer (AKD), which has poor water resistance properties when used alone [14]. It has been determined that paraffin and petroleum jelly, which are oil-borne impregnation materials, have good water resistance [15]. Linseed oil and colophon, which are natural impregnation materials, have properties that increase water resistance in wooden materials [16-17]. It has been determined that organic solvent impregnation materials defined as "water repellents" increase the water resistance of wood materials [18]. It has been determined that the substances that increase the water resistance of wood by affecting its swelling and shrinkage movements are boron nitride and geothermal water taken from Kütahya-Eynal and Denizli [19-21]. On the other hand, styrene material negatively affects the swelling and shrinkage values of wood, reducing the material's dimensional stability and causing a decrease in water resistance [22].

As the amount of boron-containing substances used in the impregnation process increases, the density of the wood material also increases [23]. Since the mechanical properties of wood material with high density are expected to be strong, the mentioned increase is positive for wood material.

Ammonium sulfate has a positive change in the thermal properties of artificial wood material obtained from Scots pine and oriental beech, and impregnation substances such as monoammonium phosphate, zinc borate, and boric acid in artificial wood material obtained from Scots pine appears to cause [24-25].

When the color change and surface roughness values from the visual characteristics of the wooden material were examined, it was determined that paraffin had an improved effect on the visual properties of the material despite the odor, and Wolmanit-CB and MCQ substances increased the color change resistance [26-28]. It has been found that sodium borate and Vacsol negatively affect the visual properties by increasing the surface roughness [29-30].

In some of the studies examined, it is seen that some mechanical properties of the wood material and its physical properties are discussed due to the multiple parameters in the impregnation. Among the mechanical properties considered, Features such as modulus of elasticity, compressive strength, bending strength, and dynamic bending strength are included.

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 physical properties of wood material (Figure 1). The diagram includes research results that positively contribute to the physical properties of wooden materials [31].

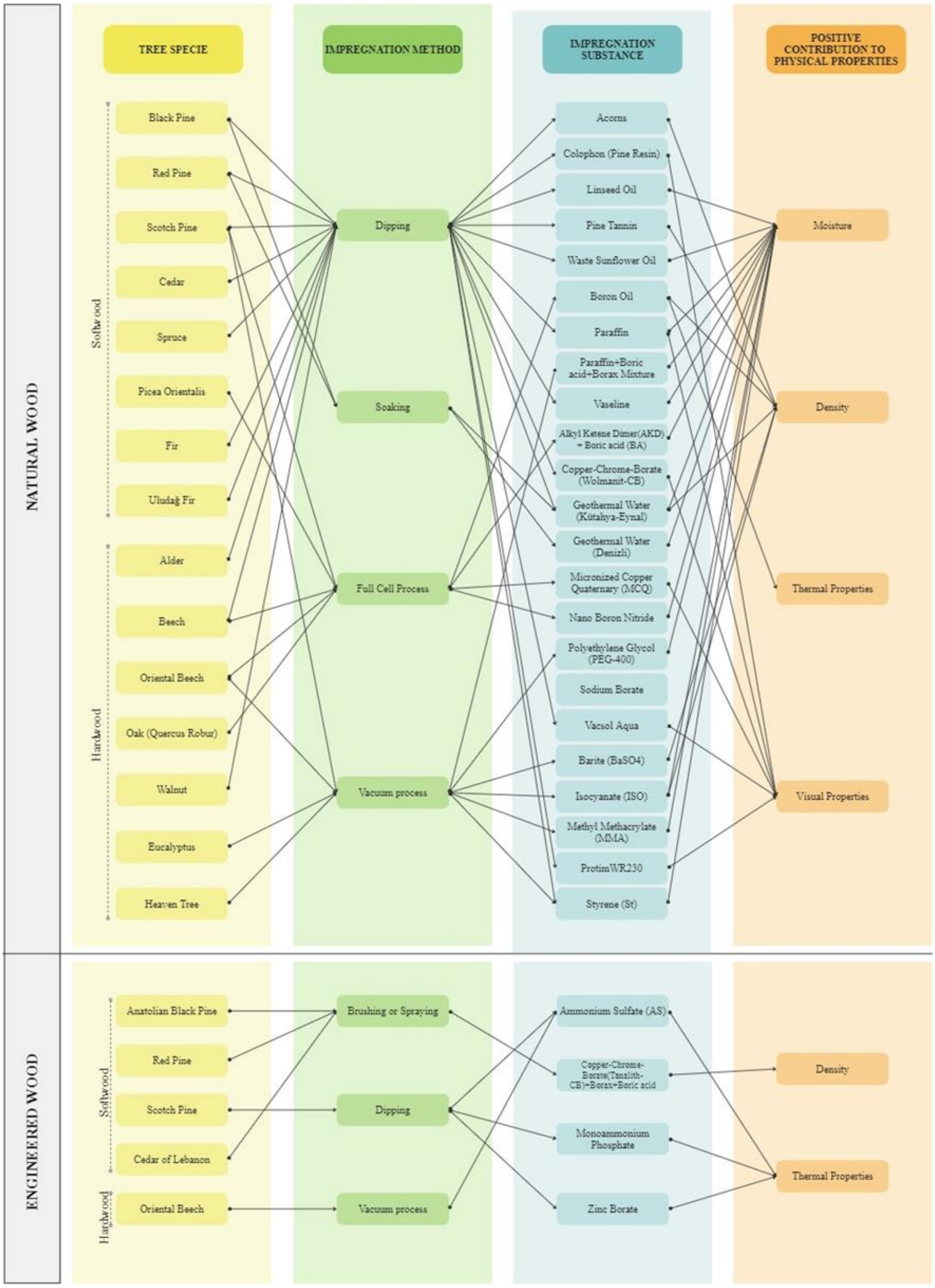

Figure 1. *Scheme for the positive contribution of impregnation to the physical properties of wooden materials*

V. CONCLUSION

Today's architectural environment has to bear the responsibility of producing ecological solutions with high energy efficiency that reduce environmental pollution and carbon footprint in the face of various environmental problems, especially climate change. Wood, one of the primary materials of the architectural tradition in world history, has a significant potential for producing responsible architectural products in the face of today's environmental problems. The popularization of wood as a building material that offers ecological solutions depends on the efficient use of existing raw material resources and the long life of the wood used. For this reason, it is significant to improve the behavior of wooden materials against various factors.

Within the scope of the research, thirty-five articles written in Turkish were obtained from the Dergipark database, which includes academic articles in Turkey and focuses on the effect of impregnation on the physical properties of wooden materials. The tree/wood type, impregnation material, impregnation method, and the impregnation process's effect on the wooden material's physical properties were systematically analyzed.

In studies focusing on the effect of impregnation on the physical properties of wooden materials, Both natural and engineered samples as tree/wood type, It has been observed that natural, oil-borne, water-borne, and organic solvent preservatives are used as impregnation materials, and both non-pressure and pressure applied methods are used as impregnation methods. Within the scope of the research, it is understood that linseed oil and colophon (pine resin), which are natural preservatives, paraffin and vaseline, which are oil-borne preservatives, and boric acid and borax, which are water-borne preservatives, come to the fore in increasing the water resistance of the material. It has been noted that boron-containing impregnation materials have a positive effect on the density of wood, ammonium sulfate, mono ammonium phosphate, zinc borate, and boric acid have a positive effect on the thermal properties of wood, and preservatives such as Wolmanit-CB and micronized copper quat have a positive effect on color change resistance.

As a result of the research, a scheme was created that holistically reveals the positive contribution of impregnation to the physical properties of wooden materials. It is believed that the created scheme is a guide that will contribute to the architect going through a systematic process focused on physical performance in selecting impregnated wood materials.

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