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# A METHODOLOGICAL ANALYSIS FOCUSED ON COMBUSTION PROPERTIES FOR THE USE OF IMPREGNATED WOOD IN ARCHITECTURE

MİMARİDE EMPRENYELİ AHŞAP MALZEME KULLANIMI İÇİN YANMA DAVRANIŞINA ODAKLI YÖNTEMSEL BİR ANALİZ

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**ABSTRACT**

Wood has superior properties, enabling it to be used in architecture throughout history. On the other hand, wood is one of the primary materials of sustainable architecture. However, wood can be damaged at various levels depending on the type and magnitude of the negative factor it encounters. It is necessary to ensure for wood to be resistant to adverse factors and to have a long life in terms of efficient use of raw material resources. Fire, which results from out-of-control burning, has caused damage or loss of some architectural structures throughout history. In order to increase the fire performance of architectural structures where wood is used as a material, structural solutions such as taking construction measures, providing sufficient cross-sections, and designing heat-resistant element combination details can be produced. However, it is also essential to take precautions on a material scale. In this context, this study aims to analyze experimental research focusing on the combustion properties of wood and to provide a guiding holistic diagram that can help architects select impregnated wood focusing on combustion performance.

**Keywords:** Architecture, Building Material, Combustion, Impregnation, Wood.

**ÖZET**

Ahşap, tarih boyunca mimarlık ürünlerinde yer almış, üstün özellikleri olan bir malzemedir. Diğer yandan ahşap, sürdürülebilir mimarlığın başlıca malzemelerinden biridir. Bununla birlikte ahşap, karşılaştığı olumsuz etkenin türü ve etki büyüklüğüne göre, çeşitli düzeylerde zarar görebilmektedir. Ahşabın olumsuz etkenler karşısında dayanım gösterebilmesi ve hammadde kaynaklarının verimli kullanımı açısından uzun ömürlü olmasının sağlanması gerekmektedir. Kontrolden çıkan yanma olayının bir sonucu olan yangın, tarih boyunca birtakım mimari yapıların zarar görmesine veya yitirilmesine neden olmuştur. Malzeme olarak ahşabın kullanıldığı mimari yapıların, yangın karşısındaki performanslarının yükseltilmesi amacıyla; konstrüksiyon önlemleri alma, yeterli kesit sağlama, ısıya dayanıklı eleman birleşim detayları tasarlama gibi yapısal çözümler üretilebilmektedir. Bununla birlikte, malzeme ölçeğinde de önlem alınması önem taşımaktadır. Bu bağlamda bu çalışmanın amacı, konuyla ilgili deneysel araştırmaları analiz ederek, ahşabın yanma özelliklerinin olumlu yönde geliştirilmesini sağlayan emprenye uygulamalarını bütüncül olarak ortaya koymak ve böylelikle mimarların, emprenyeli ahşabın yanma performansı odaklı seçimlerine yardımcı olabilecek, rehber niteliğinde bir diyagram sunmaktır.

**Anahtar Kelimeler:** Mimarlık, Yapı Malzemesi, Yanma, Emprenye, Ahşap.

## 1. INTRODUCTION

Throughout the ages, wood has enabled the production of architectural products that reflect the cultural traces of human life. An essential part of the universal cultural heritage consists of structures produced using wood. It is an important responsibility to transfer these structures to future generations. On the other hand, wood, which is the primary material of architectural products compatible with the climate and healthy for humans and the environment in every geography where it is used, is also of great importance for the future of sustainable architecture.

Wood has superior properties, enabling it to participate in the building tradition throughout history. However, wood may deteriorate due to some negative factors (Perker, 2004; Perker & Akıncıtürk, 2006). It is possible for wood to be resistant to adverse factors and to have a long life in terms of efficient use of raw material resources. Although various applications improve the wood against negative factors, impregnation is the most common (Bozkurt et al., 1993). Impregnation, which means deep protection of wood using various substances, can be applied for different purposes.

Wood is used as a building material. Parts of the building, such as walls, floors, stairs, roofs, carriers, joinery, and coating, can be involved in various tasks. Since the function of each building element is different, the performances expected from each element also vary. On the other hand, the type of wood produced for each building element using wood, the shape, and dimensions of the element are also different. All of these cause the behavior of building elements made of wood to differ in the face of negative factors. This necessitates impregnation applications focused on specific performances in some buildings instead of general-purpose impregnation processes extending wood's service life against various influences.

Fire, which results from out-of-control combustion, is a disaster that can lead to loss of life and property if precautions are not taken. Fires that have occurred in the world, from past to present, especially in historical settlements or structures, have caused significant losses in the universal architectural heritage and caused the continuity of architectural culture to be interrupted. Against fire in wooden structures, Structural solutions such as taking construction measures, providing sufficient cross-section, and designing heat-resistant element combination details can be used (Kılıç, 2011; Şimşek, 2020). In addition to the mentioned precautions, applications such as protecting wood and extending the durability period by reducing the combustion rate of the material can also be carried out (Akıncıtürk & Perker, 2003). In this sense, impregnation research and applications focusing on the combustion properties of wood is gaining importance.

There are various experimental studies on impregnating wood in Turkey-based literature. However, in the relevant literature, holistic research that can guide and help architects select impregnated wood based on combustion performance has yet to be found. In this context, this study aims to analyze experimental research on the subject and to present a holistic scheme as a guide for impregnation applications that enable improvement of the combustion properties of wood.

## 2. WOOD IN ARCHITECTURE

Wood is used in architecture; production methods can be handled in two ways: natural and engineered. As a result of the processes of cutting trees, drying them, shaping and sizing them as required by the element to be used in the structure, the material used in architecture is called natural wood (Kartal, 2015). Natural wood can generally be applied as structural elements, cladding, joinery, and interior architectural elements in architectural structures (Öztürk, 2024) (Figure 1, 2, 3, 4).

Figure 1. Structural wood in architecture (Izba) (Ancient wooden Russian hut in winter, 2024)

Figure 2. Use of wood on the facade (Fidan, 2018)

Figure 3. Use of wood in door and window (Codden, 2024)

Figure 4. Use of wood in roof and flooring (Stock, 2024)

Engineered wood used in architecture is obtained by combining wood fibers or particles with resin and other binders. Engineered wood types such as GLT (Glued Laminated Timber), LVL (Laminated Veneer Lumber), CLT (Cross Laminated Timber), OSB (Oriented Strand Board), MDF (Medium Density Fiberboard), Plywood can be used for various purposes in architecture. The discovery of engineered wood made using smaller diameter tree trunks and other industrial waste possible. Engineered wood can be produced in a more resistant and homogeneous structure compared to natural wood, and it finds a wide range of uses in architecture due to the variety of shapes and sizes it offers (Çolak & Değirmentepe, 2020; Demir & Aydın, 2016).

Engineered wood is generally applied as a structural element, cladding, panel, or interior architectural element in architectural structures. Engineered wood is frequently preferred for floor and ceiling claddings, wall panels, or interior architectural elements in indoor spaces of architectural buildings. In addition, engineered wood in architecture can be used as facade cladding, roof, and floor cladding, etc. (Coşkun & Yardımlı, 2022) (Figure 5, 6).

Figure 5. GLT beam and plywood ceiling cladding - LeMay Museum, Tacoma / ABD (LeMay Museum / LARGE Architecture, 2024)

Figure 6. CLT facade - OMM, Eskişehir / Türkiye (Menezes, 2019)

## 3. THERMAL PROPERTIES AND COMBUSTION BEHAVIOR OF WOOD

Natural wood has low thermal conductivity because it contains air due to the heat-resistant properties 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 (Perker, 2004).

The low thermal conductivity of natural wood delays the outer surface temperature of the wood from reaching the inner parts of the wood in the event of a possible combustion. This feature is considered an advantage for wood in case of fire (Özgünler et al., 2002).

On the other hand, natural wood expands when exposed to heat and contracts when cooled. However, these expansion and contraction rates are pretty small in wood compared to other materials. This feature is interpreted as an advantage in preserving the structure's integrity in case of fire, as it causes the volume of the wood to expand very little in case of fire (Anonymous, 1980; Örs & Keskin, 2001).

If the natural wood comes into contact with an element at a high temperature, decomposition occurs in the cellulose and hemicellulose molecules, and the material is damaged. In case of fire, wood dries up to 1700C, releases CO, CO2, and water vapor up to 2700C, and ignites between 2500C and 3000C. The encounter of the released hot gases with O2 in the environment causes the combustion to continue. As long as the combustion process continues, the cross-section of the wooden element decreases. If the cross-section of the wooden element falls below the safe cross-section, the system collapses (Özgünler et al., 2002).

On the other hand, the combustion behavior of processed wood depends on the type of tree from which it is produced and the combustion behavior of other raw materials used in its production. In addition, the shape and dimensions of engineered wood also significantly affect its combustion properties. Thin and dry veneer sheets may be more susceptible to fire due to their large surface area and may catch fire quickly. However, the risks can be reduced when these boards are applied on solid wood or chipboard or turned into plywood. The surface-to-volume ratio is an important factor that determines the sensitivity of the material to fire (Göker & Ayrılmış, 2002; Peker & Atılgan, 2015).

Engineered wood can also produce various gases of a flammable nature when exposed to high temperatures. Flammable gases can cause fire to spread rapidly and endanger people's safety (Ayrılmış, 2006).

## 4. IMPREGNATION IN WOOD PROTECTION

Impregnation is the process of deeply protecting wood with various substances to increase its durability against different effects. Impregnation methods are commonly discussed under two headings. These are non-pressure methods and pressure methods. Methods that do not apply pressure include: It is classified under four headings: brushing or spraying, dipping, hot-cold bath, and soaking methods. Methods where pressure is applied are; It is discussed under four headings: full-cell method, empty-cell method, vacuum process, and oscillating pressure process (Bozkurt & Erdin, 2011; Örs & Keskin, 2001; Öztürk, 2024).

Impregnation method to be applied: It varies depending on the type of tree from which the wood is obtained, the conditions of the environment, and the place of use. Impregnation of natural wood: This is done to increase the durability of wood against external factors such as moisture, insects, fungi, and fire and to extend its life. If natural wood is to be impregnated with chemicals before being placed in its place of use, pressure-applied methods are generally preferred. In these methods, chemicals penetrate the wood. If natural wood is placed at the place of use without being impregnated with chemicals, protective substances are generally applied to the surface by brushing or spraying (Bozkurt & Erdin, 2011).

Impregnation methods used for engineered wood vary depending on the type of tree from which the wood is obtained and its intended use. The impregnation process is mainly applied to board products by either adding it to glue, chips, or fibers during the production stage or by dipping it into the board with pressure, applying it with a brush, or spraying it after production (Ayrılmış, 2006).

It is very important to protect the wood used in architecture against fire. Fire protection aims to make it difficult for wood to catch fire and prevent fire spread. Fire inhibitors should make it harder for the wood to catch fire and deteriorate, reduce the rate of charring, prevent the flame from spreading at different levels, and stop combustion when the heat source is removed (Küçükosmanoğlu, 1993). When wood is effectively impregnated with fire-retardant substances, good protection against fire can be provided (Ayrılmış, 2006; Bozkurt & Erdin, 2011; Demir & Aydın, 2016). Thanks to the impregnation of wood with various substances, the combustion time of the material during a fire can be extended, and a safe escape opportunity can be provided in case of fire (Ayrılmış, 2006).

## 5. METHOD

The material to be studied within the scope of the research consists of academic articles with experimental content based in Turkey and published in Turkish. A search was made on the "DergiPark" database to obtain the research material with the keyword "impregnation." The articles encountered as a result of the search were examined in detail, and a list of articles focusing on the effect of impregnation on the combustion behavior of wood was prepared. Ten articles in the created list constituted the study material of this research (Table 1).

Table 1. Information about the articles in the dataset

| Title of Journal | Authors, Year |
|---|---|
| Artvin Çoruh University Faculty of Forestry Journal | Atılgan & Peker, 2012 |
| Düzce Universty Journal of Forestry | Var, 2008 |
| Erciyes University Journal of The Institute of Science and Technology | Baysal, 2003 |
| Journal of Advanced Technology Sciences | Yaşar & Atar, 2017 |
| Journal of Bartın Faculty of Forestry | Özcan, 2019 |
| Kastamonu University Journal of Forestry Faculty | Yuca et al., 2014 |
| Pamukkale University Journal of Engineering Sciences | Yalınkılıç et al., 1998<br>Örs et al., 1999<br>Özen & Özçiftçi, 2001 |
| Turkish Journal of Forestry | Aslan & Özkaya, 2004 |

Within the scope of the research, first of all, a table was created containing the titles, journal names, authors, and years of the articles that constitute the study material. Then, the contents in the articles, the tree/wood type, impregnation material, and impregnation method, were analyzed and evaluated regarding the effect of impregnation on the wood's combustion properties.

## 6. RESULTS AND DISCUSSION

It was determined that the type of wood used in the studies covered within the scope of the research was in two different categories: natural wood and engineered wood. The wood used include softwood such as Scots pine, Douglas fir, red pine, Anatolian black pine, and Cedar of Lebanon. Hardwood species include oriental beech, quercus petraea, walnut, eucalyptus, black poplar, and beech (Table 2).

Table 2. Wood species used in the articles (Table 2 was prepared by the authors using the sources in Table 1)

| WOOD SPECIES | | | ARTICLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| NATURAL WOOD | SOFTWOOD | Scotch Pine | | | | ■ | | | ■ | | ■ | |
| | | Douglas Fir | ■ | | | | | | | | | |
| | HARDWOOD | Oriental Beech | | | | | | | ■ | | ■ | |
| | | Quercus Petraea | | | | | | | | | ■ | |
| | | Walnut | | | | | | | | | | ■ |
| | | Eucalyptus | | ■ | | | | | | | | |
| ENGINEERED WOOD | SOFTWOOD | Red Pine | | | | | | ■ | | | | |
| | | Scotch Pine | | | ■ | | | | | | | |
| | | Anatolian Black Pine | | | | | | ■ | | | | |
| | | Cedar of Lebanon | | | | | | ■ | | | | |
| | HARDWOOD | Black Poplar | | | | | ■ | ■ | | | | |
| | | Beech | | | | | | | | ■ | | |

It was observed that four different groups of impregnation materials were used in the studies covered within the scope of the research. Natural preservatives include colophon (pine resin), fruits of oaf tree, red pine bark, sumac leaf abd valex (acorn) extract, and alkyd resin from oil-borne preservatives. The water-borne preservatives used in the studies are ammonium sulfate (AS), ammonium tetra fluoroborate, borax (Bx), boric acid (BA), cement-borax mixture, copper azole, copper-chrome-borate (Tanalith-CBC)/(Wolmanit-CB), diammonium phosphate (DAP), Immersol-WR 2000, monoammonium phosphate (MAP), phosphoric acid (PA), polyethylene glycol (PEG-400) / (PEG-1000), potassium carbonate, pyresote (Pyr), sodium borate, sodium silicate, sodium tetraborate, Vacsol-WR, zinc chloride. Among organic solvent impregnation materials, Styrene (St), Methylmethacrylate (MMA), and Isocyanate (ISO) were used. (Table 3).

Table 3. Preservatives used in articles (Table 3 was prepared by the authors using the sources in Table 1)

| PRESERVATIVES | | ARTICLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| NATURAL | Colophon (Pine Resin) | | | | | | ■ | | | | |
| | Fruits of Oak Tree | | | | ■ | | | | | | |
| | Red Pine Bark | | | | ■ | | | | | | |
| | Sumac Leaf | | | | ■ | | | | | | |
| | Valex (Acorn) Extract | | | | ■ | | | | | | |
| OIL-BORNE | Alkyd Resin | | | | | | ■ | | | | |
| WATER-BORNE | Ammonium Sulfate | | ■ | | | | | | | | ■ |
| | Ammonium Tetrafluoroborate | | | | | | | ■ | | | |
| | Borax | ■ | ■ | | ■ | ■ | ■ | | | | ■ |
| | Boric Acid | ■ | ■ | | ■ | | ■ | | ■ | | ■ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cement-Borax Mixture | | | | | | | ■ | | | |
| | Copper Azole | | | | | | | | | ■ | |
| | Copper-Chrome-Borate | | ■ | ■ | | ■ | ■ | | | ■ | |
| | Diammonium Phosphate | | | | | | | | | | ■ |
| | Immersol-WR 2000 | | ■ | ■ | | | ■ | | | | |
| | Monoammonium Phosphate | ■ | | | | | | | | | |
| | Phosphoric Acid | ■ | | | | | | | | | |
| | Polyethylene Glycol | ■ | ■ | | | | | | | | |
| | Potassium Carbonate | | | | | ■ | | | | | |
| | Pyresote | ■ | | | | | | | | | |
| | Sodium Borate | | | ■ | | | | | | | |
| | Sodium Silicate | | | | | | | | | | ■ |
| | Sodium Tetraborate | | | ■ | | | | | | | |
| | Vacsol-WR | | ■ | | | | | | | | |
| | Zinc Chloride | | | | | | | | | | ■ |
| ORGANIC SOLVENT | Isocyanate | ■ | | | | | | | | | |
| | Methyl Methacrylate | ■ | | | | | | | | | |
| | Styrene | ■ | | | | | | | | | |

In studies on the effect of impregnation on the combustion behavior of wood, it is seen that both non-pressure and pressure methods are preferred as impregnation methods. The studies preferred brushing/spraying, and dipping methods as impregnation methods without applying pressure. Vacuum methods were used as the pressure-applied method (Table 4).

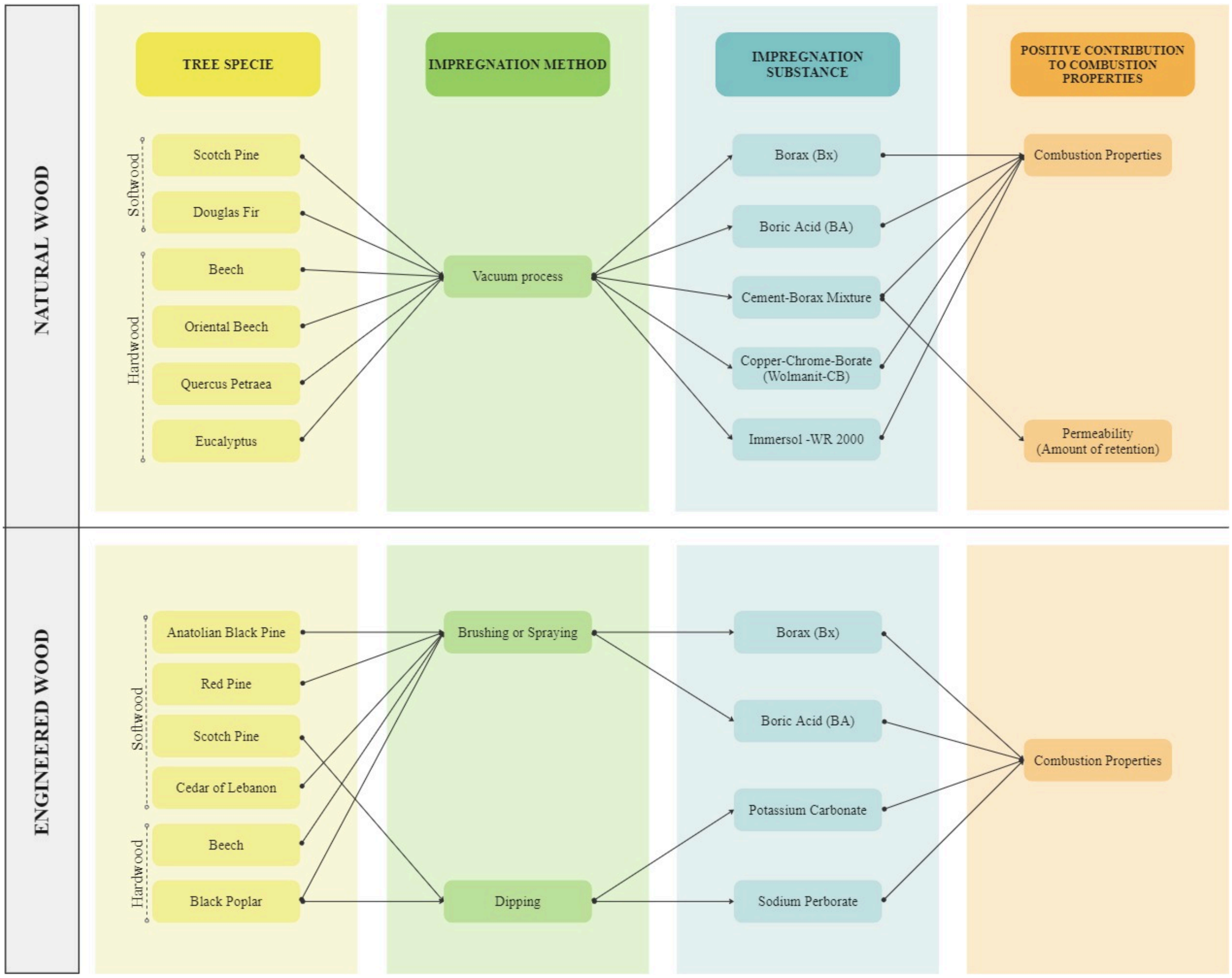
Table 4. Impregnation methods used in articles (Table 4 was prepared by the authors using the sources in Table 1)

| **IMPREGTANION METHODS** | | **ARTICLES** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **NON-PRESSURE** | Brushing or Spraying | | | | | ■ | ■ | | ■ | | |
| | Dipping | | | ■ | | ■ | | | | | ■ |
| | Hot-Cold Bath | | | | | | | | | | |
| | Soaking | | | | | | | | | | |
| **PRESSURE** | Full Cell Process | | | | | | | | | | |
| | Vacuum process | ■ | ■ | | ■ | | | ■ | | ■ | |

In studies focusing on the effect of impregnation on the combustion behavior of wood, the change in the combustion properties of wood was evaluated based on factors such as the material's combustion resistance, flammability properties, and ignition temperature. In this context, when the combustion resistance of the wood is high and its flammability is low due to the impregnation process, this is described as a positive development in terms of the combustion behavior of the material. In the studies discussed, it was determined that boron compounds (boric acid, borax) used as impregnation materials have properties that increase the combustion resistance of the material (Yalınkılıç et al., 1998; Baysal, 2003; Var, 2008; Yuca et al., 2014). It has been determined that the impregnation material named Wolmanit-CB has properties that increase the material's combustion resistance due to its boron component (Yaşar & Atar, 2017). As an impregnation agent, potassium carbonate is one of the substances that positively affects the material's combustion behavior (Aslan & Özkaya, 2004). However, it has been observed that the combustion resistance of natural tanning materials is insufficient due to the flammable components they contain, and Tanalith-CBC has high flammability properties (Baysal, 2003; Özen & Özçiftçi, 2001; Örs et al., 1999). In some of the studies focusing on the effect of impregnation on the combustion properties of wood, it has been determined that the wood type, impregnation material, and impregnation method used affect the permeability properties as well as the combustion properties of the wood. The change in permeability values that affect the effectiveness of the impregnation in wooden materials varies according to the amount of retention. Accordingly, as the amount of retention increases, its permeability, such as its impregnation efficiency, also increases. Related studies also determined that Vacsol and the cement-borax mixture had high retention rates (Örs et al., 1999; Atılgan & Peker, 2012; Öztürk, 2024).

As a result of analyzing the experimental studies included in the research, a scheme was created that holistically reveals the positive effect of impregnation on the combustion behavior of wood (Figure 7). The diagram includes research results that positively affect the combustion behavior of wood.

Figure 7. Scheme for the Positive Contribution of Impregnation to the Combustion Behavior of Wood (Figure 7 was prepared by the authors using the sources in Table 1)




When the findings obtained within the scope of the research are compared based on natural wood samples, It is observed that impregnation materials such as borax, boric acid, cement-borax mixture, copper-chrome-borate (Wolmanit-CB), and Immersol WR 2000 used with the vacuum process method have a positive effect on the combustion behavior of natural wood. The specified method and impregnation materials are natural softwood species such as Scotch Pine and Douglas Fir. It is understood that it is effective on natural hardwood species: Beech, Oriental Beech, Quercus Petraea, and Eucalyptus.

When the findings are compared based on engineered wood samples, it is seen that impregnation substances such as borax and boric acid, used with the brushing or spraying method, and potassium carbonate and sodium perborate, used with the dipping method, have a positive effect on the combustion behavior of engineered wood. It is understood that substances such as borax and boric acid used together with the brushing or spraying method are effective on engineered wood samples, especially Anatolian black pine, red pine, Scotch pine, cedar of Lebanon, which are softwood species, and beech-based engineered wood samples, which are hardwood species. It is observed that impregnation materials such as potassium carbonate and sodium perborate used together with the dipping method are effective on black poplar-based engineered wood samples from hardwood species.

## 7. CONCLUSION

Within the scope of the research, ten articles written in Turkish, obtained from the DergiPark database, and focusing on the effect of impregnation on the combustion behavior of wood was systematically analyzed. Contents of the articles within the scope of analysis: tree/wood type, impregnation material, impregnation method, and the effect of the impregnation process on the combustion properties of the wood are discussed.

In some studies, focusing on the effect of impregnation on the combustion behavior of wood, the treatment was carried out on natural and engineered wooden samples. In experimental studies conducted on natural wood samples, it has been determined that natural, water-borne, or organic solvent impregnation materials are used as impregnation materials. In studies that conducted experimental research on engineered wood samples, it was observed that natural, oil-borne, or water-borne preservatives were used as impregnation materials.

In experimental studies conducted on natural wood samples, it was determined that both pressure and non-pressure methods were used as impregnation methods. In the studies conducted on engineered wood samples, it was seen that only vacuum methods were used as an impregnation method among the methods that do not apply pressure.

When the findings obtained from the research are evaluated for use in architecture, it is seen that borax, boric acid, and cement-borax were used with the vacuum process method to improve the combustion behavior of Scotch Pine, Douglas Fir, Beech, Oriental Beech, Quercus Petraea, which are natural wood species that are likely to be used in architectural structures. Impregnation materials such as mixture and copper-chrome-borate come to the fore. In order to improve the fire behavior of engineered wood that can be used in architecture, impregnation materials such as borax or boric acid are noteworthy, especially for softwood species such as Anatolian black pine, red pine, Scotch pine, and cedar of Lebanon-based products, along with the brushing or spraying method. For black poplar-based products, it can be concluded that impregnation materials such as potassium carbonate, sodium perborate, and the dipping method are beneficial.

As a result of the research, a scheme was created that holistically reveals the positive contribution of impregnation to the burning behavior of wood. It is believed that architects can use the created scheme as a rational selection aid in the selection of impregnated wood.

Conducting new research on the combustion behavior of different types of wood that can be used in architectural structures and not covered in current research will contribute to the widespread use of wood in architecture. On the other hand, it is thought that studies of the different performances expected from wood to be used in architecture, together with its combustion behavior, will make valuable contributions to the use of wood in architecture.

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