JOURNAL OF BALKAN ARCHITECTURE

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Scientific Research Paper

DOI: https://doi.org//10.69648/UHCK8365

Journal of Balkan Architecture (JBA), 2025; 2(1): 19-27

jba.ibupress.com

Online ISSN: 2955-2524

Application :11.03.2025

Revision :31.03.2025

Acceptance :28.04.2025

Publication :16.05.2025

Murtezi, E., & Miloshevska-Janakieska, M. (2025). Integrating polymers in sustainable architecture with circular wood polymer composites for façade applications. Journal of Balkan Architecture, 2(1), 19-27. https://doi.org//10.69648/UHCK8365

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BALKAN JOURNALS

Integrating Polymers in Sustainable Architecture With Circular Wood Polymer Composites for Façade Applications

Eljesa Murtezi and Marija M. Janakieska

Abstract

The interest in using wood as a façade cladding material in contemporary architecture is constantly increasing due to its aesthetic, biophilic, and sustainable qualities. However, wood as a raw material faces several challenges, especially when used in external applications. By integrating polymers into the wood composition, these limitations can be addressed. Moreover, these new products can enhance circularity since they can be made of wood flour from the production process's waste.

This study explores the development of new products - Circular Wood Polymer Composites (CWPCs) that could be used as sustainable façade cladding materials. By combining wood flour, a by-product of furniture manufacturing, with polymers such as polystyrene (PSt), polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), and biopolymers, the mechanical, chemical, and physical properties of wood can be significantly enhanced, and the disadvantages can be overcome. Their durability, resistance to environmental degradation, and potential for the circular economy are highlighted, with a focus on their use in sustainable architecture, especially in façade applications. The process for creating WPCs with different ratios of wood flour is covered, as well as how well they perform in tests of weathering, aging, swelling, durability, and decay resistance. The results highlight WPCs' potential for innovative architecture and sustainable building.

Keywords: circular wood polymer composites, sustainable architecture, façade materials, polymers, circular economy

Introduction

Wood as a construction material was used intensively in the past for both structural and non-structural elements, due to its availability and ease of use. This led to its organic implementation in Macedonian vernacular architecture (Miloshevska Janakieska et al., 2024). Figure 1 shows examples of houses from the 19th century where wood was used as part of the building structure, in walls, slabs, roofs, stairs, but also as a decorative element on the facade.

Figure 1

Wood application in vernacular architecture in Macedonia – Houses in Ohrid and Krushevo

The interest in using wood continued in the contemporary Macedonian architecture, mostly as a decorative material and rarely as structural material. Designers and architects are motivated to use wood in the interior and exterior architectural application due to the beautiful aesthetic, natural texture, warmth tones and biophilic components. Figure 2 shows the wood application in the Summer Scene City Park in Skopje City Park, built in 2022.

Unfortunately, raw wood is not suitable for use as an external material since it is not resistant to atmospheric influences and pests. Disadvantages such as durability, maintenance requirements, higher maintenance cost, sustainability concerns, and color and texture changes are only some of the concerns regarding external wood application. Figure 3 shows damage in the wood façade decoration on a residential building in Skopje due to severe climatic conditions.

Figure 2

Wood application in the Summer Scene City Park, Skopje, built in 2022

Figure 3

Damage to the wood façade decoration in a residential building in Skopje

To overcome the disadvantages of wood, new products based on wood with improved characteristics are introduced to the market. Those products are called Engineered Wood Products – EWPs (Kitek Kuzman et al., 2018). Specifically, by combining wood with polymers, the negative sides of the wood being used externally would be solved. The proposed materials are called Circular Wood Polymer Composites – CWPCs, since they are made out of wood flour obtained as a by-product in furniture manufacturing, combined with polymers.

Composite materials known as wood plastic composites (WPCs) combine thermoplastic polymers with wood flour or fibers. These materials offer the aesthetic appeal of wood while enhancing durability and resistance to environmental factors. The properties of WPCs are greatly influenced by the addition of different synthetic and biopolymers, which makes them appropriate for a variety of uses in the furniture, automotive, and construction industries, as well as façade systems in sustainable architecture.

The selection of polymers used in WPCs influences their recyclability, water resistance, and mechanical strength. They are compatible with wood fibers and can impart certain properties like improved mechanical performance, weather resistance, and thermal stability. Therefore, polystyrene (PSt), polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP) are widely used. Furthermore, biopolymers are attracting interest due to their potential for producing WPCs that are completely sustainable.

This study aims to explore how these materials can retain the advantages of wood, such as its natural aesthetic, while overcoming its disadvantages, particularly its susceptibility to atmospheric influences. By enhancing durability, these materials can be effectively used for exterior building decoration, contributing to circular economy and promoting sustainability.

Literature Review

Numerous studies and books examine the disadvantages of wood as a construction material, highlighting issues such as susceptibility to moisture and decay, vulnerability to insect infestation, and limitations in fire resistance and structural stability. Franzini et al. (2018) explore the key factors that influence wood durability in construction, emphasizing the challenges of exterior wood applications and discussing methods for improvement through proper material selection and treatment. To address some of these challenges, the application of engineered wood products (EWPs) has become popular in sustainable architecture. EWPs are explored by Miloshevska Janakieska et al. (2024), highlighting their properties and application, including wood-plastic composites (WPCs) in modern construction.

In addition, the sustainability aspects of wood in construction have also been examined. For example, Cho et al. (2019) investigate the impact of wood interior remodeling on indoor air quality (IAQ) in welfare facilities. Their findings suggest that wood remodeling can improve IAQ, supporting public health, particularly for vulnerable populations. Moreover, the role of digitalization in architecture, especially related to wood and wooden structures, is analyzed by Kitek Kuzman and Zbašnik-Senegačnik (2018). They show how digital tools are improving the design, manufacturing, and sustainability in contemporary architecture with timber.

Furthermore, the potential of wood-plastic composites (WPCs) in construction has been the focus of various studies. Gardner et al. (2015) provide a detailed overview of WPCs, covering their manufacturing processes, such as extrusion, injection molding, and compression molding, and exploring newer methods like additive manufacturing. They also examine the challenges and advancements in polymer selection, particularly the use of polyethylene and polyvinyl chloride to prevent thermal degradation of wood fillers. Complementing this, Ayana et al. (2024) offer a comprehensive analysis of WPCs, discussing their formulation, manufacturing technologies, and mechanical and thermal properties, along with interphase modifications and advanced characterization techniques. Ramesh et al. (2022) also review the processing techniques, properties, and applications of wood-based polymer composites, shedding light on their environmental and performance benefits as well as the challenges in their development.

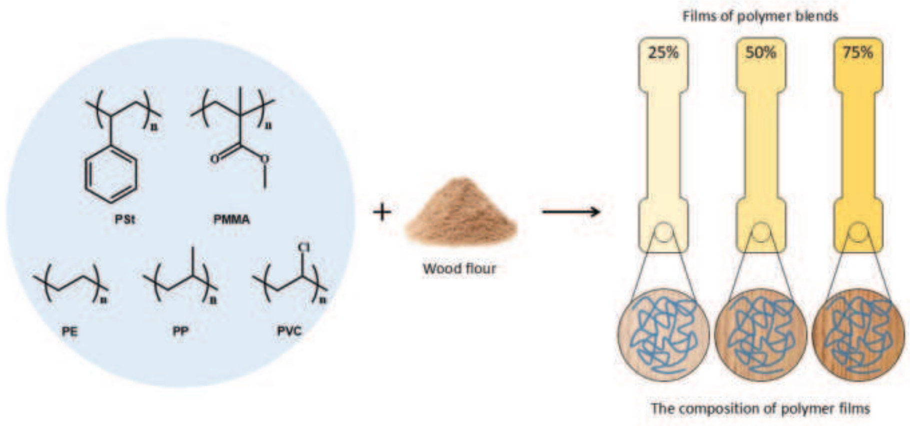
The literature reveals a growing interest in researching wood-based materials, especially in the context of sustainability. However, there remains a need for more region-specific information. To address this gap, the authors are analyzing the theoretical performance of CWPCs, building on the existing body of knowledge.

Methodology

WPCs are synthesized through molding, blending, or extrusion processes, incorporating different proportions of wood flour (WF) with thermoplastics. Procedures like drying and sieving wood flour to eliminate moisture and contaminants are part of the standard methodology. The next step is polymer selection and blending, which involves using extrusion to combine the selected polymer with wood flour at various weight ratios (for example, 25%, 50%, and 75% wood content). The blended mixture is then melted and extruded into the required shapes, like films or profiles, in the compounding and extrusion step. In order to increase weathering resistance, the extruded WPC is cooled, cut to the appropriate size for the application, and treated with optional coatings or UV stabilizers.

Scheme 1

Structural formulas of the selected polymers to be incorporated in WPC. WPCs are synthesized through molding, blending, or extrusion processes for film production, in proportion with wood flour. On the right-hand side, the composition of polymer films is shown with the corresponding percentage of wood flour. The blue curved line represents one or more combinations of polymers from the blue circle.



A variety of testing techniques are used to assess the mechanical and environmental performance of WPCs, including weathering tests (UV exposure, temperature cycling) to ascertain long-term stability. Ageing effect studies, swelling properties (where water absorption tests are performed to measure dimensional changes upon exposure to moisture) and durability tests are crucial to assess resistance to mechanical wear and load-bearing capacity of WPC's. In order to evaluate the biological durability using the fungal and microbial degradation tests, decay resistance studies are also valuable and significant. Last but not least, important methods for characterizing the performance of WPCs are fire resistance testing and exposure to real or simulated environmental conditions (heat, UV, and rain) to examine surface deterioration and color retention.

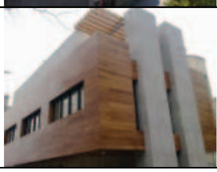
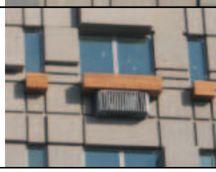
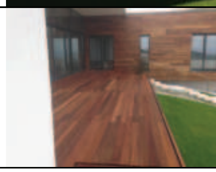
Discussion

In this context, polymer selection is defined by the properties of the polymer itself, which are ascertained as explained below. As a result, polystyrene (PSt) has limited flexibility but enhances surface quality and dimensional stability. Polymethyl Methacrylate (PMMA) is appropriate for façade applications because it guarantees transparency and increases UV resistance, while polyethylene (PE) offers high flexibility and moisture resistance, extending the lifespan of WPC, and Polyvinyl chloride (PVC) offers superior fire resistance and durability, making it perfect for outdoor use. Tensile strength and resistance to chemical deterioration are increased by the proper use of polypropylene (PP). Therefore, it's crucial to have in mind biopolymers like polylactic acid (PLA) and polyhydroxyalkanoates (PHA), which improve biodegradability and lessen environmental impact while contributing to environmentally friendly WPC solutions.

Table 1 shows data and photos on exterior wood applications in three buildings in Skopje. The percentage of wood on the façade range from 5-50%, depending on the architectural design of the façade. The wooden elements are combined with clear simple white or gray façade surfaces, for sophisticated appearance and emphasis of the wood. Wood can be used for small details, as presented in the residential building, or on larger surfaces, as presented in the residential houses in Table 1.

Table 1

Buildings with exterior wood application in three buildings in Skopje

Type of building	Residential House	Residential Building	Residential House
Location	Skopje	Skopje	Skopje
Photo 1			
Photo 2			
Photo 3			
% of wood used on the façade	40%	5%	50%

Source: https://www.geo-ing.com

The integration of CWPCs as façade cladding materials aligns with key principles of sustainability, particularly in terms of material circularity, resource efficiency, and reduction of the environmental impact. Firstly, CWPCs contribute to environmental sustainability, by minimizing the waste and using the by-product from the furniture manufacturing. Moreover, the improved characteristics of the wood contribute to lower maintenance and prolonged lifespan, reducing the need for frequent replacement. Secondly, with these materials the economic sustainability is improved, through reducing maintenance and replacement costs. Lastly, social and aesthetic sustainability is enhanced, through visual and biophilic qualities of the CWPCs, as well as user well-being. By integrating these sustainability principles CWPCs present an alternative to traditional façade materials, stressing both performance challenges and environmental responsibilities in contemporary architecture. The application of WPCs in façade systems aligns with the principles of circular economy and sustainable architecture. The ability to recycle WPCs contributes to waste reduction and sustainability, while improved insulation qualities lower building energy consumption. Improved architectural appeal is another benefit of customizable textures and designs. Long-term performance in challenging environments is guaranteed by high durability.

Conclusion

Wood plastic composites offer a sustainable and versatile solution for contemporary architecture, particularly in façade applications. The performance of polymers is greatly influenced by their choice, and advanced testing methods confirm their suitability for long-term use. In this regard, the integration of biopolymers further enhances their eco-friendly potential, making WPCs a promising material for the future of green construction.

Finally, the interest in wood as a building material is constantly increasing in Macedonian architecture, driven by its sustainability, biophilic design, aesthetic appeal, and cultural significance. Moreover, these new WPCs have led to overcoming the natural disadvantages of wood, such as susceptibility to moisture, decay, and maintenance challenges. These innovative materials offer enhanced durability and weather resistance while preserving the warmth and natural beauty of wood, making them a practical and sustainable solution for modern architectural applications in Macedonia.

References

Ayana, K. D., Ha, C.-S., & Ali, A. Y. (2024). Comprehensive overview of wood polymer composite: Formulation and technology, properties, interphase modification, and characterization. Sustainable Materials and Technologies, 40, e00983. https://doi.org/10.1016/j.susmat.2024.e00983

Franzini, F., Toivonen, R., & Toppinen, A. (2018). Why not wood? Benefits and barriers of wood as a multistory construction material: Perceptions of municipal civil servants from Finland. Buildings, 8(11), 159. https://doi.org/10.3390/buildings8110159

Gardner, D. J., Han, Y., & Wang, L. (2015). Wood–plastic composite technology. Current Forestry Reports, 1(3), 139–150. https://doi.org/10.1007/s40725-015-0016-6

Geo Ing. (n.d.). Drveni fasadi i proizvodi [Wooden facades and products]. Retrieved February 7, 2025, from https://www.geo-ing.com

Kitek Kuzman, M., & Zbašnik-Senegačnik, M. (2018). Digitalization process in architecture: Wood and wood constructions. [Journal Name if available], 06, 60–67. https://doi.org/10.15292/IU-CG.2018.06.060-067

Kitek Kuzman, M., Klarić, S., Barčić, A. P., Vlosky, R. P., Janakieska, M. M., & Grošelj, P. (2018). Architect perceptions of engineered wood products: An exploratory study of selected countries in Central and Southeast Europe. Construction and Building Materials, 179, 360–370. https://doi.org/10.1016/j.conbuildmat.2018.05.164

Mi Cho, H., Hun Park, J., Lee, J., Wi, S., Yang, S., Yeol Yun, B., & Kim, S. (2019). A field study on the indoor air quality of wooden welfare facilities in Korea. IOP Conference Series: Materials Science and Engineering, 609. https://doi.org/10.1088/1757-899X/609/1/012045

Miloshevska Janakieska, M., Kitek Kuzman, M., & Sandberg, D. (2024). The use of engineered wood products in sustainable building construction in Macedonia. WoodEMA Proceedings of Scientific Papers: Green Deal Initiatives, Sustainable Management, Market Demands, and New Production Perspectives in the Forestry-Based Sector, Sofia, Bulgaria, May 15–17, 2024.

Miloshevska Janakieska, M., Kitek Kuzman, M., & Sandberg, D. (2024). Wood reimagined: Sustainable architecture with engineered wood products (1st ed.). Balkan University Press. https://doi.org/10.69648/XCTO6554

Ramesh, M., Rajeshkumar, L., Sasikala, G., Balaji, D., Saravanakumar, A., Bhuvaneswari, V., & Bhoopathi, R. (2022). A critical review on wood-based polymer composites: Processing, properties, and prospects. Polymers, 14(3), 589. https://doi.org/10.3390/polym14030589