

Abstract

The construction sector is transitioning to sustainable materials that combine energy efficiency with reduced environmental impact to achieve high performance and reduce the carbon footprint, in line with the Sustainable Development Goals (SDGs) of the 2030 Agenda. In this context, wood, a renewable and recyclable material characterized by a hierarchical porous structure, is configured as an engineerable platform for the development of highly engineered functional composites. Among these, Transparent Wood (TW), with its modular optical properties and easily functionalized nanostructure, opens up new perspectives for its application in sustainable construction, for example, in smart buildings with high energy savings. In this PhD thesis, developed as part of the PNRR NODES (Digital and Sustainable North West) project, the engineering of TW for building applications is studied, with the aim of improving its process sustainability and industrial transferability.

Chapter 1 introduces the theoretical and strategic framework of research: the role of the Sustainable Development Goals (SDGs) in European and national contexts is discussed. The thesis is, in fact, part of the PNRR NODES (Digital and Sustainable North West) project and falls under Spoke 4 – *Digital Innovation Toward Sustainable Mountain*. The research program is aligned with the objectives presented in the Spoke, which include: i) the enhancement of resources by using wood for the creation of multifunctional transparent composites; ii) the enhancement of energy efficiency through the design of wood based components to be integrated in e.g. into photovoltaic devices; iii) the improvement of durability, overcoming the natural degradation of wood through chemical and physical processes. Part of the chapter is dedicated to a critical review of the state of the art, with particular attention to the research gaps to be addressed to transition this product from the laboratory to industry. The steps to be taken in terms of chemical sustainability of processes, polymer consumption, industrial scalability, and control

of optical properties are mainly taken into account, as well as the definition of the thesis objectives, oriented towards rapid and sustainable production.

To achieve this goal, the work has been divided into three main objectives that will be presented in chapters 2, 3, and 4.

Chapter 2 is dedicated to objective 1, which focuses on developing a new whitening process derived from traditional treatments presented in the literature, but faster, more sustainable, and more efficient. The developed process allows for the production of mechanically stable bleached wood templates, with the possibility of recovering and reusing reagents until exhaustion, thereby reducing overall chemical consumption and process time and minimizing energy use. This work led to the publication of a scientific paper and the filing of a patent.

Chapter 3 is dedicated to objective 2, focusing on the development of TW, by impregnation of the bleached wood with suitable polymers. The Chapter mainly focuses on optimizing the polymer impregnation step to reduce resin consumption and studying its effect on optical properties through a Design of Experiments (DOE)-guided approach. This approach is used in particular to evaluate the potential tuning of light scattering by varying process parameters: the residual pressure and resin/wood ratio. Two thermocurable resins based on bisphenol A, crosslinkable at room temperature, were studied: one completely synthetic with UV-absorber and one partially biobased without UV-filter. The stability of both optical and structural properties was evaluated before and after 1 year of accelerated UV-Visible exposition in Solarbox. The results of this part of the study led to a publication currently unpublished.

Chapter 4, developed during the research period at the Royal Institute of Technology (KTH, Stockholm) and dedicated to objective 3, mainly focused on further improving the environmental sustainability of the whole process. In fact, it focuses on the use of a temperature-curable natural acrylic resin, derived from limonene (poly-limonene acrylate (PLIMA)), to obtain TW composites. This study allowed to evaluate the use of a lignin-rich white wood template, infiltrated with a completely biobased polymer matrix, to obtain high photostability values for future photovoltaic applications, which will be developed in collaboration with Uppsala University. Although the integration and evaluation of TWs' performance in photovoltaic devices are not presented in this thesis, the research establishes the basis for using TWs as an active substrate in perovskite solar cells synthesized at

low temperatures (150°C). The thesis is structured as a collection of articles and supplementary experimental sections and chapters. Chapter 5 concludes with a critical analysis of the results obtained and future perspectives. Overall, the work proposes transparent wood as an innovative and engineered material through the sustainable optimization of processes and the targeted control of properties, with a view to real industrial transferability.