CHAPTER 1

An introductory overview of bio-based construction materials

Fernando Pacheco-Torgal
C-TAC Research Centre, University of Minho, Guimarães, Portugal

1.1 Sustainability challenges, resource scarcity and the bioeconomy's path forward

In a world grappling with limited resources exacerbated by unsustainable lifestyles and a burgeoning population, the urgency to transition towards sustainable modes of production and consumption is undeniable. Yet, differing viewpoints emerge on the achievability of this transition. While some, such as Stoknes and Rockström (2018), express pessimism, contending that current approaches are insufficient in aligning with the ecological capacities of our planet, others, like Randers et al. (2018), acknowledge the formidable challenge, suggesting that meeting all Sustainable Development Goals by 2030, or even by 2050, may prove elusive A groundbreaking study conducted by researchers at the University of Cambridge expands upon the seminal work of "The Limits to Growth," offering fresh perspectives on the global risk of mass mortality stemming from food insecurity. Drawing on a refined depiction of World3's "runaway global warming" scenario, projecting temperature increases of approximately 8–12 °C, the study reveals alarming trends. It forecasts a precipitous decline in food production and highlights the unequal distribution of consequences, with an estimated 6 billion lives at risk of perishing due to starvation by the year 2100 (Richards et al., 2023) In the absence of immediate breakthroughs, incremental improvements serve as the only viable short-term remedy for the issue at hand. To sustain economic activity, institutions such as UNEP, the World Bank, and the European Commission advocate for the adoption of green economy and green growth principles. These approaches aim to achieve more with less, fostering enhanced human well-being and social equity. Recent years have seen a surge in demand for natural, bio, or biotech-derived products in industrial settings due to

Advances in Bio-Based Materials for Construction and Energy Efficiency
https://doi.org/10.1016/B978-0-443-32800-8.00008-1

Copyright © 2025 Elsevier Ltd.
All rights are reserved, including
those for text and data mining,
AI training, and similar technologies.

concerns about environmental impact, challenges in waste management, and the depletion of non-renewable resources. In 2002, the EU initiated its Strategy on Biotechnology (EU, 2002), followed by a significant milestone in 2012 when the European Commission introduced the world's premier bioeconomy strategy and action plan. The bioeconomy is defined as an economic framework where the fundamental components for materials, chemicals, and energy are sourced from renewable biological resources. For a deeper exploration, see Schanes et al. (2019). The bioeconomy encompasses all sectors and systems dependent on biological resources, including animals, plants, microorganisms, and derived biomass, which includes organic waste, along with their functions and principles. As per the new strategy, the bioeconomy is poised to bolster and modernize the EU industrial base by fostering the development of new value chains and implementing greener, more cost-effective industrial processes. Global demand for bio-based products is on the rise, with EU demand projected to reach a market value of 50 billion euros and help create one million new jobs by 2030. Ramcilovic-Suominen and Pülzl (2018) argue that the EU uses sustainable development as a marketing tool to promote its bioeconomy strategy, focusing on biotechnology, eco-efficiency, competitiveness, innovation, and economic output, while neglecting broader sustainability goals. This mirrors other national and regional bioeconomy policies that also prioritize biotechnology and resource efficiency but lack clarity on achieving true sustainability, particularly in environmental and social dimensions like biodiversity, equity, and social justice. The European Green Deal, launched by the European Commission in December 2019, is a comprehensive policy package aimed at addressing climate change and ensuring a "just and inclusive" transition. This initiative seeks to transition the EU towards a low-carbon, sustainable growth model that prioritizes food and energy security, biodiversity, and effective natural resource management, with the bioeconomy playing a crucial role. Pianta and Lucchese (2020) argue that Europe urgently needs to embark on a sustainable path, which requires the European Green Deal (EGD) to be integrated with a more ambitious industrial policy and a unified vision of future challenges. This approach involves expanding policy space at both European and national levels and introducing new, effective public intervention tools. Key elements include recognizing the substantial investment required, linking credit availability to structural change, understanding that market-based solutions alone cannot solve environmental problems, ensuring that public authorities lead economic

transformation, and closely aligning the green transition with democratic processes. D'Amato and Korhonen (2021) compared the green, circular, and bioeconomy models for their potential to achieve global net sustainability, emphasizing the need for an economy grounded in renewable and biodiversity-friendly processes that meet economic and social requirements for all people, now and in the future. They caution that without considering global net sustainability, implementing these models individually or jointly can result in unintended negative effects such as problem displacement, cascade effects, and rebound effects, which may undermine the effectiveness of sustainability efforts. Ronzon et al. (2022) demonstrated that the bioeconomy has maintained its relative importance within the overall EU27 economy. Agriculture and the food industry have been key drivers of this transition in primary and industrial bioeconomy sectors due to their significant impact on labor productivity. Four Northern Member States (MS) have modernized their bioeconomy activities and implemented structural changes, indicating a successful transition. However, other Northern and Western EU MS are still in the early stages of this transition, and it remains largely elusive in Eastern and Central Europe. Firoiu et al. (2023) emphasized the importance of bioeconomy statistics for evidence-based policymaking, particularly during the transition to a sustainable, carbon-free economy. Using data from 2015 and 2020, the researchers found that Western European countries consistently outperformed the Baltics and Central and Eastern Europe. However, the Baltic and Eastern European countries showed significant growth potential, with rates over 20% higher than the EU average, indicating the need for targeted strategies. Belgium and Denmark were highlighted as role models due to their superior performance in bioeconomy advancements.

1.2 The promise of biobased materials towards a sustainable construction industry

Although the future of humanity remains shadowed by serious environmental challenges, the construction industry is certain to continue growing due to an increasing world population, projected to reach 11 billion by 2100. In this context, the use of bio-based construction materials is crucial for reducing the industry's environmental footprint. While bio-based materials like timeber have long been used, particularly for structural purposes, they have struggled to compete with the superior performance of steel and reinforced concrete in the construction of increasingly taller skyscrapers.

However, the imperative of sustainable development in recent years is changing this dynamic, and the scientific community is actively contributing to the revival and advancement of bio-based materials. Initiatives like the COST Action FP1303 on the performance of bio-based building materials, which ran from October 2013 to October 2017, have significantly contributed to the field. Among its achievements was the publication of an up-to-date review of the status of various bio-based materials and the factors influencing their in-service performance (Jones & Brischke, 2017). Other studies have also highlighted the increasing importance of bio-based materials. For instance, Pittau et al. (2018) demonstrated that storing carbon in fast-growing biogenic materials is much more efficient than in timber elements. Further, Pittau et al. (2019) examined the use of bio-based construction products for renovating existing facades, concluding that fast-growing bio-based materials have a higher potential to act as carbon sinks compared to timber. Approximately 15% of the total ordinary Portland cement (OPC) concrete production—the most widely used construction material on Earth—contains chemical admixtures to modify its properties in both fresh and hardened states. These superplasticizers, based on synthetic polymers such as melamine, naphthalene condensates, or polycarboxylate copolymers, improve workability, strength, and durability. However, these admixtures are derived from the fossil fuel industry, which is responsible for significant environmental disasters, including the BP Deepwater Horizon oil spill that released approximately 780 million liters of crude oil into the Gulf of Mexico. As oil exploration ventures into deeper, stormier, and icier seas, the associated risks escalate, underscoring the need for new biodegradable polymers derived from renewable sources. Examples of bio-based admixtures used in concrete include lignosulfonate, starch, chitosan, pine root extract, protein hydrolysates, and vegetable oils. However, investigations into the use of biopolymers in ordinary Portland cement (OPC) remain limited; of the 10,000 Scopus-referenced journal papers on OPC published since 2000, less than 1% explore biopolymer applications. Carbon fiber reinforced polymers (CFRP) represent a widely recognized technological solution for structural strengthening in civil engineering applications. Nevertheless, their expense and high environmental footprint are significant concerns raised by some authors. Ghorbel et al. (2021) confirmed that bio-sourced flax fiber-reinforced polymer is a promising material for confining recycled aggregate concretes, providing consistent strength and strain enhancements. Sain et al. (2021) synthesized formaldehyde-free bioresin adhesives from lignin and tannin, which were obtained from softwood bark. Another important polymer widely used by the construction industry is

polyurethane that is used in thermal insulation. In the last years however many investigators have dedicated to the development of biobased polyurethanes. Andersons et al. (2020) developed rigid high-density polyurethane foams using polyols derived from renewable tall oil fatty acids for use as structural thermal break materials. de Oliveira et al. (2022) studied castor oil-based polyurethane reinforced with açaí waste as an alternative for eco-efficient building insulation. The nanotechnological advancements of the past decade have paved the way for the development of new and improved biopolymer-based materials. Research on cellulose nanocrystals—cellulose elements with at least one dimension in the 1–100 nm range—represents a significant and recent nanotech field that promises eco-efficient, high-performance materials. As the most abundant organic polymer on Earth, cellulose—producing about 1.5 trillion tons annually—is renewable, biodegradable, and carbon neutral, with the potential for industrial-scale, low-cost processing, making it a green biotech source for future building materials. Cellulose aerogel is another promising application for developing high-performance thermal insulator building materials. These insulators, with thermal conductivity lower than 0.020 W/m K, outperform current petroleum-based insulation materials like expanded polystyrene (EPS) and extruded polystyrene (XPS), which have values around 0.03–0.06 W/m K. The use of high-performance thermal insulation is critical for reducing heat losses in buildings, thereby increasing energy efficiency. Additionally, as non-flammable materials, aerogels do not release toxic fumes under fire conditions, unlike current insulation materials like EPS and XPS, providing a significant safety advantage. Sen et al. (2022) showed that Cellulose aerogels demonstrate high thermal stability and fire retardance, with mechanical strength improved through the incorporation of inorganic materials. However, challenges in commercialization persist, and future research aims to enhance properties like moisture repellence and cost-effectiveness by using industrial waste materials for large-scale production. Petrescu et al. (2021) provided insights into the steps necessary for biocomposites to become ready-to-use products in the construction industry, specifically in structural roles. Their study addresses the development and adoption of these materials through two key concepts: technology readiness level and roadmapping. This approach is illustrated with a case study on "liquid wood." The study resulted in a customized roadmap, highlighting a predominantly non-technical viewpoint regarding the material. It also identifies potential adoption and diffusion challenges for "liquid wood" and offers further recommendations to address these issues. A review by Boros and Tőzsér (2023) of 977 publications, revealing a yearly increase

in relevant papers, with most belonging to the engineering discipline. The literature thoroughly evaluates a wide range of plant-based building materials, which are primarily used to enhance the mechanical properties of conventional materials. Many of these plant-based materials are also tested as substitutes for traditional ones. Table 1.1 shows the most assessed plant-based materials and their use in the construction industry in the studied literature.

Table 1.1 The most assessed plant-based materials and their use in the construction industry in the studied literature (Boros & Tőzsér, 2023).

Building material/ procedure	Plant-based material	Products created after plant-based material use
Cement production	Agricultural palm waste	Cement composites
	Mixed plant-based agricultural waste	Biocomposites as reinforcers, plasticizers, and insulators
	Rice and reed fiber	Reinforced cementitious panels and biocomposites with increased compressive strength
	Hemp fiber	Cement-based mortar with increased compressive and flexural strength
	Sugarcane bagasse ash	Cement-based products with increased compressive strength
Concrete production	Palm kernel shell	Lightweight concrete aggregate
	Mixed plant fibers	Reinforced concrete
	Coconut fiber	High-strength reinforced concrete with increased compressive and bending strength
	Biofilm with microorganisms	Concrete with increased bioreceptivity
	Hemp	Concrete with reinforced internal structure and increased self-healing ability
	Bamboo fiber	Agent treating concrete cracks, high-performance concrete with decreased shrinkage
	Juta fiber	Reinforced concrete
	Pineapple leaf fiber	Reinforced concrete
	Flax fiber	Reinforced concrete with increased compressive strength
	Granulated cork	Concrete and mortar with increased insulating property
	Tobacco waste	Lightweight concrete
	Resins from different origin	Translucent concrete

Table 1.1 The most assessed plant-based materials and their use in the construction industry in the studied literature—cont'd

Building material/ procedure	Plant-based material	Products created after plant-based material use
Brick production	Building waste materials with mycelium	Bio-composite mycelium bricks
Wood-based products	Delignified, succinylated birch wood	Transparent wood
	Chitosan	Wooden surfaces with increased flame resistance
	Fungal melanin, linseed, and tree tea oil	Wooden materials with increased antibacterial effects and water resistance
	Peanut husk	Green composite panels with increased flame resistance
Sealing and insulation materials	Nanocellulose	Performance improvement of tannin-based foams
	Various plant species	Bio-green insulation panels
	Coconut fiber	Insulation ceiling board, fibrous thermal insulation
	Peat	Thermal insulation material
	Sawdust	Green insulation panels
	Arch, pine, spruce, fir, and oak tree bark resins	Insulation panels
	Beet-pulp fiber with potato starch	Biopolymer composites with increased insulation property
	Almond skin	Sound absorber materials
Other	Spent coffee grounds	Mortar with increased technical and sustainability performance

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Le et al. (2023) reviewed 97 articles with the aim of categorizing case studies, examining the state-of-the-art in sustainability assessments, and highlighting the pros and cons of circular bio-based building materials. The results indicate that material scale is the most researched aspect, with environmental analysis—primarily using life cycle assessment—being the most frequently studied, followed by economic analysis. Research on social impact is still in its early stages. Regarding the pros and cons, circular

bio-based building materials generally outperform traditional materials in reducing initial production costs and mitigating environmental impacts, particularly in terms of climate change and abiotic resource use. However, some bio-based materials perform worse in categories such as eutrophication and land use, and may not be economically viable when considering the entire life cycle. Dams et al. (2023) evaluated the barriers faced by bio-based materials in scaling up production and breaking into mainstream construction. This evaluation was conducted through semi-structured interviews with senior professionals experienced in bio-based construction, focusing on core categories such as finance, knowledge, and policy. The challenges identified include difficulties in scaling up production for manufacturers of emerging materials, inconsistencies in life cycle assessments, issues with material certification and accreditation, vested interests within the construction industry, and concerns regarding initial costs, product availability, and knowledge. Potential solutions for promoting the upscaling of bio-based construction include increasing the number of case studies, enacting positive legislation, fostering regional economic regeneration, emphasizing the wellness agenda, ensuring long-term economic sustainability, and engaging with established construction companies. Sutkowska et al. (2024) explored existing natural material prefabrication technologies, examining their capabilities and assessing their suitability for single-family housing in Central and Eastern Europe. A bibliometric analysis of 949 research articles from the Web of Science (WOS) and Scopus databases revealed a substantial increase in publications, rising from 29 in 2015 to 175 in 2023, with 17 already in 2024 (and counting). This trend underscores the growing emphasis on practical applications and technological progress in the field. Their article provides a comprehensive assessment of bio-based materials in the construction sector, focusing on advancements to promote a lower carbon footprint. Chen et al. (2024) conducted a comprehensive review of building biomaterials, examining relevant policies and performing life cycle assessments through various case studies. Their findings highlight the substantial potential of bio-based materials to mitigate over 320,000 tons of carbon dioxide emissions by 2050. These materials also offer significant benefits, such as reducing water absorption by 40%, decreasing energy consumption by almost 10%. Biomaterials in construction face challenges in technological advancements, economic viability, and regulatory adherence, compounded by a lack of harmonized standards and durability issues due to bioerosion. Supportive policies have spurred innovation, though they sometimes impose constraints, and dynamic policy adaptation has accelerated

progress in the industry. Careful material selection, stringent production controls, robust maintenance practices, and the development of relevant codes and guidelines are essential to mitigate health and safety risks associated with biomaterials. The introductory chapter highlights the urgent need for sustainability within the construction sector, given the pressing challenges of resource scarcity and environmental degradation. Embracing bio-based materials and eco-efficient practices emerges as a promising strategy to address these issues. Through interdisciplinary collaboration and innovation, the construction industry can lead the way towards a more sustainable and resilient built environment. Nonetheless, persistent challenges in commercialization, standardization, and scalability underscore the necessity for coordinated efforts across academia, industry, and policy spheres. This chapter sets the foundation for further exploration into the practical applications and implications of bio-based construction materials, offering insights into both the opportunities and obstacles in achieving sustainability goals.

1.3 Outline of the book

This book provides an updated state-of-the-art review on Bio-Based Materials and Biotechnologies for Eco-Efficient Construction covering bio-based materials and biotechnologies for infrastructure applications, for building energy efficiency and other applications.

The first part of the book concerns bio-based materials and biotechnologies for infrastructure applications (Chapters 2–13).

Chapter 2 presents the performance properties of asphalt mixtures composed with bio materials used as bio extenders, considering a percentage of fossil binder replacement greater than 20%.

Chapter 3, reviews cellulose nanofibers and cellulose nanocrystals employed in the construction sector as a stabilizer for manufacturing bituminous emulsions and Pickering emulsion systems stabilized by nanocellulose to be used as templates to create nanocomposite foams.

Chapter 4 examines the availability and physical and chemical properties of various biomass aggregates and ash from plant wastes, highlighting their impact on the usability, mechanical and environmental performance of concrete, including aspects such as lightweight, insulation, sustainability, and cost effectiveness. It discusses the benefits and challenges of using biomass materials in concrete and emphasizes the importance of effective pre-treatment processes.

Chapter 5 provides an overview of the production process of rice husk ash (RHA) and its application in developing activators for geopolymer production. It also discusses the properties of geopolymer binders created with synthesized activators from RHA, emphasizing their sustainability characteristics.

Chapter 6 classifies agricultural wastes used in geopolymers into three categories: agricultural waste ash, agricultural fiber, and agricultural aggregate. It provides a comprehensive review of the literature to showcase the latest research on geopolymers incorporating agricultural waste and aims to serve as a reference for future studies and applications.

Chapter 7 explores biomineralization processes, environmental conditions, bacterial species, protection and stimulation methods, nutrient mediums, and the fundamental characteristics and engineering applications of bacterial concrete. It also reviews bio-fibers as innovative additives for reinforcement and crack control, covering their sources, mechanical properties, durability, applications, challenges, and opportunities.

Chapter 8 discusses three main aspects of the fire behavior of bio-based concrete: fire reaction, fire resistance, and smoldering fire. Fire reaction explains how the material directly contributes to fire development. Fire resistance indicates the structure's ability to protect occupants in adjacent rooms from fire impact for a certain duration. Smoldering fire refers to the slow, flameless combustion often observed in insulating materials.

Chapter 9 presents the physicochemical and mechanical properties of flax fibers and their water absorption kinetics. It discusses the mixing issues of cementitious composites and the influence of flax fibers on their fresh properties, including workability, hydration, and setting. The flexural and compressive behavior of the composites is then analyzed. Finally, the chapter outlines the main methods for enhancing the performance of flax fiber cementitious composites.

Chapter 10 presents experimental insights on enhancing Normal Strength Concrete (NSC) using *Opuntia ficus-indica* mucilage (Ofim) as a replacement for mixing water. It compares the plastic and hardened-state properties of Ofim and chemical admixture modified concrete with conventional mixes. Durability properties and micro-characterization of mucilage-modified mixes are also discussed. The chapter concludes with a comparative Environmental Life Cycle Assessment (E-LCA) to evaluate the resource efficiency and environmental impacts of Ofim-modified versus conventional concrete.

Chapter 11 reviews the performance of nanocellulose-modified cementitious composites, addressing key aspects such as workability, setting time, hydration characteristics, pore structures, and mechanical properties (compressive, flexural, tensile, and fracture behavior). It provides recommendations for enhancing performance and durability through modifications to the cement matrix and nanocellulose fibers. The chapter concludes by discussing future trends, highlighting the increasing significance and potential of nanocellulose as a sustainable and eco-friendly reinforcement material for cement-based applications.

Chapter 12 explores the development of green bio-composite mortars by reusing spent coffee grounds (SCG), an agri-food residue, in line with the Circular Economy approach. The chapter covers manufacturing procedures, technological characterization, and potential construction applications, considering technical norms, Minimum Environmental Criteria certification, and the European Green Deal's goals for zero-energy buildings. It also discusses technological implementations like plastering solutions, prototype preparation, and real-world application in a construction site.

Chapter 13 includes the result of original work concerning the environmental assessment, in terms of Life Cycle Assessment (LCA) of a novel material for infill walls for buildings envelopes, obtained from urban agricultural (UA) wastes derived from a tomato crop harvested in a building rooftop greenhouse.

Biobased materials and biotechnologies for building energy efficiency are the subject of Part II (Chapters 14–22).

Chapter 14 reviews the current state of conventional thermal insulation materials and delves into the mechanisms and classifications of emerging aerogel-based thermal insulations. It covers the fabrication techniques of flexible nanocellulose aerogel materials, including atmospheric pressure drying, supercritical drying, and freeze drying. Additionally, it discusses functional modifications, such as hydrophobic treatment and mechanical optimization, along with application strategies, challenges, and emerging trends in thermal insulation research.

Chapter 15 focuses on manufacturing insulating panels composed of 70% hemp shiv and recycled cardboard fibers to reduce energy consumption in buildings. To enhance durability, moisture and fire resistance, and protection against fungi, an organic coating and citric acid as a crosslinking agent are applied. The thermal insulation properties were assessed.

Chapter 16 This chapter delves into the thermal performance, energy efficiency, sustainability, challenges, and future research directions of hemp clay walls in sustainable building practices. Made from hemp fibers, clay, and natural additives, these walls provide outstanding thermal insulation, moisture regulation, and environmental benefits. The discussion includes considerations on technical constraints, regulatory hurdles, economic factors, and market acceptance challenges.

Chapter 17 investigates the thermal performance of mortar reinforced with various agricultural wastes, including hemp, jute, sunflower fibers, straw fibers, rice husk ash, and olive solid ash. It highlights the sustainability and potential of underutilized agricultural waste as an alternative construction material. The chapter focuses on the thermal conductivity, thermal insulation properties, and related characteristics of mortars incorporating these wastes, providing a detailed analysis of how each type of waste enhances the thermal performance of the mortar.

Chapter 18 evaluates the thermal performance of a building in Meknes, Morocco, with walls insulated using hemp wool and hemp concrete-filled bricks. Using TRNSYS software, it examines the effects of thermal inertia, ventilation, and double glazing on heating and cooling needs. It also assesses economic and environmental impacts, including costs, energy savings, payback periods, and greenhouse gas emissions.

Chapter 19 explores using locally sourced natural fibers as an alternative to conventional insulators. Algae from southern Chile (Luga and Sargazo) were evaluated for thermal and physical properties, such as thermal conductivity, density, thermal stability, and morphology.

Chapter 20 experimentally evaluated the hygrothermal and energy performance of a building envelope using a phase change material-hygroscopic material (PCM-HM) wall. Various wall configurations were tested to analyze the effects of the hygroscopic material (HM), the phase change material (PCM), and the placement of the PCM.

Chapter 21 This chapter introduces a bio-based PCM dry-assembled wooden panel designed for sustainable and energy-efficient buildings. The panel consists of cork panels on a 2 cm OSB layer, supported by wooden laths that create internal air gaps for flexible sheets containing Bio-PCMs.

Chapter 22 closes Part II with a review on the adaptability and low-maintenance potential of photobioreactor (PBR) façades, emphasizing their role in climate change mitigation. The system is designed to be low-consumption and simple, with minimal need for specialized support. Using Scenedesmus microalgae, the study presents a comprehensive methodology

for monitoring and optimizing growth conditions by tracking parameters like dissolved oxygen, temperature, pH, and visual indicators, aiming to develop a protocol for system autonomy.

References

Andersons, J., Kirpluks, M., Cabulis, P., Kalnins, K., & Cabulis, U. (2020). Bio-based rigid high-density polyurethane foams as a structural thermal break material. *Construction and Building Materials*, *260*, 120471.

Boros, A., & Tőzsér, D. (2023). The emerging role of plant-based building materials in the construction industry—A bibliometric analysis. *Resources*, *12*(10), 124.

Chen, L., Zhang, Y., Chen, Z., Dong, Y., Jiang, Y., Hua, J., … Yap, P. S. (2024). Biomaterials technology and policies in the building sector: A review. *Environmental Chemistry Letters*, *22*(2), 715–750.

D'Amato, D., & Korhonen, J. (2021). Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework. *Ecological Economics*, *188*, 107143.

Dams, B., Maskell, D., Shea, A., Allen, S., Cascione, V., & Walker, P. (2023). Upscaling bio-based construction: Challenges and opportunities. *Building Research and Information*, *51*(7), 764–782.

de Oliveira, B. P., Balieiro, L. C., Maia, L. S., Zanini, N. C., Teixeira, E. J., da Conceição, M. O., … Mulinari, D. R. (2022). Eco-friendly polyurethane foams based on castor polyol reinforced with açaí residues for building insulation. *Journal of Material Cycles and Waste Management*, *24*(2), 553–568.

EU. (2002). *European Commission. Life sciences and biotechnology, a strategy for Europe. Communication from the Commission to the European Parliament, the council, the Economic and Social Committee and the Committee of the Regions*. Brussels: European Commission.

Firoiu, D., Ionescu, G. H., Cojocaru, T. M., Niculescu, M., Cimpoeru, M. N., & Călin, O. A. (2023). Progress of EU member states regarding the bioeconomy and biomass producing and converting sectors. *Sustainability*, *15*(19), 14128.

Ghorbel, E., Limaiem, M., & Wardeh, G. (2021). Mechanical performance of bio-based FRP-confined recycled aggregate concrete under uniaxial compression. *Materials*, *14*(7), 1778.

Jones, D., & Brischke, C. (2017). *Performance of bio-based building materials*. Woodhead Publishing.

Le, D. L., Salomone, R., & Nguyen, Q. T. (2023). Circular bio-based building materials: A literature review of case studies and sustainability assessment methods. *Building and Environment*, *244*, 110774.

Petrescu, T. C., Voordijk, J. T., & Mihai, P. (2021). Developing a TRL-oriented roadmap for the adoption of biocomposite materials in the construction industry. *Frontiers of Engineering Management*, *10*, 223–236.

Pianta, M., & Lucchese, M. (2020). Rethinking the European Green Deal: An industrial policy for a just transition in Europe. *Review of Radical Political Economics*, *52*(4), 633–641.

Pittau, F., Krause, F., Lumia, G., & Habert, G. (2018). Fast-growing bio-based materials as an opportunity for storing carbon in exterior walls. *Building and Environment*, *129*, 117–129.

Pittau, F., Lumia, G., Heeren, N., Iannaccone, G., & Habert, G. (2019). Retrofit as a carbon sink: The carbon storage potentials of the EU housing stock. *Journal of Cleaner Production*, *214*, 365–376.

Ramcilovic-Suominen, S., & Pülzl, H. (2018). Sustainable development—A 'selling point' of the emerging EU bioeconomy policy framework? *Journal of Cleaner Production*, *172*, 4170–4180.

Randers, J., Rockstrøm, J., Stoknes, P. E., Goluke, U., Collste, D., & Cornell, S. (2018). Achieving the 17 sustainable development goals within 9 planetary boundaries. *EarthArXiv*, *2*. October.

Richards, C. E., Gauch, H. L., & Allwood, J. M. (2023). International risk of food insecurity and mass mortality in a runaway global warming scenario. *Futures*, *150*, 103173.

Ronzon, T., Iost, S., & Philippidis, G. (2022). Has the European Union entered a bioeconomy transition? Combining an output-based approach with a shift-share analysis. *Environment, Development and Sustainability*, *24*(6), 8195–8217.

Sain, S., Matsakas, L., Rova, U., Christakopoulos, P., Öman, T., & Skrifvars, M. (2021). Spruce bark-extracted lignin and tannin-based bioresin-adhesives: Effect of curing temperatures on the thermal properties of the resins. *Molecules*, *26*(12), 3523.

Schanes, K., Jäger, J., & Drummond, P. (2019). Three scenario narratives for a resource-efficient and low-carbon Europe in 2050. *Ecological Economics*, *155*, 70–79.

Sen, S., Singh, A., Bera, C., Roy, S., & Kailasam, K. (2022). Recent developments in biomass derived cellulose aerogel materials for thermal insulation application: A review. *Cellulose*, *29*(9), 4805–4833.

Stoknes, P. E., & Rockström, J. (2018). Redefining green growth within planetary boundaries. *Energy Research & Social Science*, *44*, 41–49.

Sutkowska, M., Stefańska, A., Vaverkova, M. D., Dixit, S., & Thakur, A. (2024). Recent advances in prefabrication techniques for biobased materials towards a low-carbon future: From modules to sustainability. *Journal of Building Engineering*, *91*, 109558.