Harnessing biogenic carbon in construction: A pathway to Sustainable Decarbonization

Ar. Anusha T C

Architect, Urban Designer, Assistant professor, SJBSAP

Email ID-
anusha.tc05@gmail.com

Anusha T C is an architect with a specialization in Urban Design, she is deeply inclined towards sustainable urbanism, green building practices, and environmentally responsive design. Her academic and research interests focus on integrating sustainability into urban planning and architecture, aiming to foster resilient, inclusive, and future-ready cities. Through teaching and research, she advocates for design solutions that harmonize built environments with ecological priorities.

Abstract

Biogenic carbon, obtained from organic materials such as plants and bio-based construction materials, plays a crucial role in sustainable construction and decarbonization efforts. The construction industry is one of the most important industrial sectors to emit global GHG, due to the use of cement and steel, among other materials, significantly increasing the carbon footprint. Biogenic carbon provides a new frontier for innovation in sustainable construction through the carbon sequestration potential in timber, bamboo, hemp, and other crop residues. Biogenic materials can significantly reduce emissions in the built environment by storing carbon, lowering embodied emissions, and following circular economy principles. This paper presents a synthesis of current research, case studies, and technical data to provide a conceptual framework for understanding and applying biogenic carbon in sustainable construction.

Keywords
Biogenic Carbon, Carbon Sequestration, Life Cycle Assessment, Embodied Carbon

1.Introduction:

The construction industry is responsible for a significant share of global greenhouse gas (GHG) emissions, contributing approximately 39% of total CO_2 emissions when both operational and embodied carbon are considered. Operational carbon includes emissions generated during the use of buildings, such as those from heating, cooling, and lighting, while embodied carbon encompasses emissions from the extraction, processing, transportation, and installation of construction materials, as well as emissions from construction activities themselves. In response to the sector's growing environmental impact, there has been a shift towards sustainable construction practices aimed at decarbonization. Among these, the incorporation of biogenic carbon presents a promising solution. Biogenic carbon is carbon that is absorbed and stored by living organisms, primarily plants, during their growth cycle.

STHALA/ ISSN 2582-9491

When biogenic materials like timber, hempcrete, straw bales, and bamboo are used in construction, they can act as carbon sinks—capturing atmospheric CO_2 and storing it for the duration of the building's life span. This not only reduces the net carbon emissions of construction projects but also aligns with circular economy principles and regenerative design philosophies that aim to restore and enhance natural ecosystems.

2. Understanding Biogenic Carbon

Biogenic carbon originates from the natural carbon cycle. Plants absorb CO_2 from the atmosphere during photosynthesis, storing it in their biomass. When these materials are harvested and used in construction, they retain the sequestered carbon, preventing its release into the atmosphere. The key benefits of biogenic carbon include:

- **Carbon Sequestration:** Biogenic materials act as carbon sinks by storing CO_2 absorbed during plant growth. For example, a wooden beam used in a building continues to store the carbon that the tree captured during its lifetime. This sequestration can last for decades or even centuries, depending on the durability and use of the material.

  In construction, using biogenic materials like mass timber (e.g., cross-laminated timber) or agricultural byproducts (e.g., straw or hempcrete) can significantly reduce the embodied carbon of a building. Embodied carbon refers to the CO_2 emissions associated with the production, transportation, and installation of building materials.

  By keeping carbon locked away, biogenic materials prevent it from contributing to atmospheric CO_2 levels, effectively reducing the greenhouse effect. This is particularly impactful when compared to materials like concrete and steel, which release significant CO_2 during production.

- **Renewability:** Biogenic materials are derived from renewable resources, such as forests, crops, or other plant-based systems, which can be regrown over time. Sustainable forestry and agriculture practices ensure that new plants can be cultivated to replace those harvested, maintaining a continuous cycle of carbon absorption and storage.

  For example, fast-growing species like bamboo or certain types of timber can be harvested and replenished within a relatively short timeframe (years to decades), unlike fossil-based materials, which take millions of years to form and are finite in supply.

  The renewability of biogenic materials supports long-term sustainability, as it reduces dependence on non-renewable resources and aligns with circular economy principles, where materials are reused, recycled, or naturally regenerated.

- **Lower Carbon Footprint:** The production and processing of biogenic materials generally require less energy compared to conventional construction materials like concrete, steel, or aluminium. For instance, cement production (a key component of concrete) is highly energy-intensive and accounts for approximately 8% of global CO_2 emissions, largely due to the high temperatures required in kilns and chemical reactions during production.

STHALA/ ISSN 2582-9491

In contrast, biogenic materials like timber require minimal processing beyond cutting, drying, and shaping. Even when additional treatments (e.g., for durability or fire resistance) are applied, the energy demand is typically lower than that of fossil-based materials.

Additionally, the transportation of biogenic materials can have a lower carbon footprint if sourced locally or from sustainably managed forests, further reducing emissions associated with logistics.

3.Biogenic Carbon in Construction Materials

Bio-based construction materials are gaining importance due to their ability to reduce greenhouse gas emissions and sequester atmospheric carbon. These materials not only minimize embodied carbon but also offer renewable alternatives to conventional building resources. Key bio-based materials include:

3.1. Timber

Timber is one of the most established biogenic materials in construction, acting both as a structural element and a carbon sink. Through photosynthesis, trees absorb atmospheric carbon dioxide (CO_2), which becomes stored in the wood. This stored carbon remains locked in the material for as long as the timber is in use. Engineered wood products—such as cross-laminated timber (CLT), laminated veneer lumber (LVL), and glue-laminated timber (Glulam)—enhance the structural capabilities of timber and enable its use in multi-storey buildings.

Carbon Sequestration: One cubic meter of wood stores approximately 0.9 tonnes of CO_2. For example, a typical CLT panel used in mid-rise construction (approximately 10 m^3 per floor) can sequester around 9 tonnes of CO_2 per floor.
For comparison, 1 ton of cement production emits approximately 0.9 tonnes of CO_2, while steel emits about 1.85 tons of CO_2 per ton produced. Thus, replacing steel or concrete elements with timber can significantly reduce embodied emissions.

- **Embodied Carbon Savings:**

A study by the *Carbon Leadership Forum* found that timber-based buildings can reduce embodied carbon by 20–60% compared to concrete or steel structures, depending on design and sourcing.

For instance, a 6-storey timber-framed building can result in a net carbon benefit of over 700 tonnes of CO_2 when compared to an equivalent concrete building.

Energy Use and Emissions:

Timber requires less energy to process:

- Embodied energy for timber is around 3–7 MJ/kg,
- **Concrete:** 0.8–1.2 MJ/kg, but used in higher volumes,
- **Steel:** 20–35 MJ/kg. Thus, the overall lifecycle energy demand of timber-based construction is significantly lower.

3.2. Bamboo

Bamboo is a rapidly renewable biogenic material that has gained traction in sustainable construction due to its fast growth rate, high strength properties, and excellent carbon sequestration potential. As a grass rather than a tree, bamboo matures in 3–5 years, making it significantly more renewable than timber. It is widely used in flooring, panelling,

STHALA/ ISSN 2582-9491

formwork, and increasingly in load-bearing structures, especially in regions where it is naturally abundant.

- **Carbon Sequestration:** Bamboo can sequester up to 0.35–0.45 tonnes of CO_2 per m^3, depending on the species and harvesting conditions. On average, 1 hectare of bamboo forest can absorb up to 12 tonnes of CO_2 per year, which is 30–35% more efficient in CO_2 absorption than many fast-growing tree species.
- **Rapid Regrowth:** Unlike trees, bamboo does not require replanting after harvest. Its rhizome root system allows it to regrow naturally, reaching full maturity in 3–5 years, compared to 20–80 years for timber species like spruce or oak. This contributes to higher yields and more frequent harvesting cycles with a lower land-use impact.
- **Mechanical Properties:**

  Tensile strength: up to 370 MPa, which exceeds that of mild steel (~250 MPa) on a per weight basis.

  Compressive strength: typically ranges from 40–100 MPa, making it suitable for lightweight structural applications.

  Density: varies between 600–800 kg/m^3, making it both light and strong.
- **Embodied Energy and Emissions:**

Embodied energy is around 5–10 MJ/kg, lower than steel and comparable to engineered timber.

When treated and processed responsibly, bamboo-based panels or composites can achieve up to 40% reduction in embodied carbon compared to conventional concrete elements.

3.3. Hempcrete

Hempcrete is a bio-composite material made by mixing the woody core of the hemp plant (hemp hurds or shiv) with a lime-based binder and water. It is used primarily as a non-load-bearing infill in wall systems, offering excellent insulation and moisture-regulating properties. As a plant-based material combined with lime—which reabsorbs carbon dioxide during curing—hempcrete can be considered carbon-negative over its lifecycle.

- **Carbon Sequestration & Emissions:** Hempcrete can sequester approximately 110 kg of CO_2 per m^3 over its lifecycle. This includes:

  22–30 kg CO_2/m^3 absorbed during hemp plant growth,

  Additional ~80–100 kg CO_2/m^3 reabsorbed by lime during carbonation. Depending on production and transportation methods, net sequestration can range between 80–130 kg CO_2/m^3, making hempcrete carbon-negative under proper conditions.
- **Thermal Efficiency:**

  Thermal conductivity: around 0.05–0.07 W/m·K, which provides good insulation compared to concrete (≈ 1.7 W/m·K).R-value: A 30 cm thick hempcrete wall provides an R-value of ~2.5–3.5 $m^2·K/W$, depending on density and binder ratios. This results in reduced energy demand for heating and cooling, contributing further to operational carbon savings.

- **Material Properties:**
    - Density: ~275–400 kg/m³ (lightweight compared to concrete at ~2400 kg/m³)
    - Compressive strength: ~0.3–1 MPa (not suitable for load-bearing)
    - Moisture regulation: Naturally hygroscopic—can absorb and release moisture without compromising insulation.
- **Embodied Energy**:
    - Hempcrete has a low embodied energy of ~30–60 MJ/m³, compared to over 1,000 MJ/m³ for concrete, contributing significantly to life cycle energy savings.

3.4. Straw Bale Construction

Straw bale construction utilizes compacted bales of straw—an abundant agricultural byproduct—as wall infill or insulation in sustainable buildings. This method not only diverts agricultural waste from landfills or burning (which emits CO_2 and pollutants) but also serves as an effective means of storing biogenic carbon. When properly designed and sealed, straw bale walls are highly durable, fire-resistant, and provide excellent thermal performance.

- **Carbon Sequestration:** Straw contains approximately 1.3–1.5 kg of CO_2 per kg of dry mass. A typical 400 mm thick straw bale wall (for a 100 m² area) uses around 2,000–2,500 kg of straw, which can sequester 2.6–3.75 tonnes of CO_2.

  Net sequestration (after accounting for minimal processing) ranges from 120–150 kg CO_2/m³ of straw bale material.

  If sourced locally and untreated, straw bale construction can be net-carbon-negative.

- **Thermal Efficiency:**

  R-value: ~ R-7 to R-9 per 400 mm wall, which is 2–3 times higher than conventional stud walls with fiberglass insulation.

  Thermal conductivity: ranges between 0.045–0.065 W/m·K, providing strong resistance to heat flow and improving building energy efficiency.

- **Material Properties:**

  Density: ~90–150 kg/m³ (very lightweight)

  Compressive strength: ~100–300 kPa when plastered, sufficient for low-rise structures

  Moisture performance: Breathable yet capable of maintaining insulation performance if kept dry with proper plaster finishes

- **Embodied Energy:**

  Straw bales have an extremely low embodied energy: ~15–30 MJ/m³, among the lowest of all construction materials.

Their use can reduce overall building embodied energy by up to 60–70% compared to concrete or brick-based insulation systems.

STHALA/ ISSN 2582-9491

4. The Role of Biogenic Carbon in Decarbonization

The use of biogenic carbon in building is a key step toward the development of a low-carbon and ultimately net-zero built environment. Biogenic carbon is carbon that is captured from the air by living organisms, mainly plants, through the process of photosynthesis and locked away in organic products like wood, hemp, bamboo, and straw. When deployed in construction, these materials function not just as structural or insulating elements but also as carbon storage devices. The strategic incorporation of these materials aids decarbonization through a variety of mechanisms.

4.1 Reduction of Embodied Carbon

Embodied carbon is the total greenhouse gas (GHG) emissions generated in the lifecycle of building materials from extraction, production, and transportation to installation, maintenance, and end-of-life disposal. In conventional construction, materials like steel, aluminium, and Portland cement have a high embodied carbon since they are manufactured through energy-intensive processes and fossil fuels.

Biobased materials like mass timber (e.g., cross-laminated timber or CLT), straw bales, and bio-based insulation (e.g., cellulose, hempcrete) have considerable embodied carbon reductions. This is largely due to:

• Their growth stage absorbs CO_2 from the air.

• Their processing is less energy-intensive, usually depending on mechanical instead of thermal or chemical conversions.

• They are regionally sourced in most areas, which reduces transportation emissions.

Quantitative Insight: According to studies, substituting traditional concrete and steel with biogenic materials in a mid-rise building can reduce embodied carbon by 30–70%. For example, CLT can store approximately 1.8 metric tons of CO_2 per cubic meter, effectively offsetting emissions elsewhere in the construction process.

4.2 Carbon Sequestration and Storage

As discussed earlier, biogenic materials lock in atmospheric CO_2 absorbed during growth, enabling long-term sequestration throughout a building's lifespan, taking it out of the carbon cycle temporarily. This lock-in of carbon is quantifiable and can be added to Life Cycle Assessment (LCA) models. The more extended the lifespan of the building, the longer the carbon is locked up. Furthermore:

• Longlived, adaptable buildings enhance the carbon sequestration performance.

•Mass timberconstruction offers structural str ength equivalent to steel and concrete, enabling taller wood buildings that s tore more carbon.

Example: A typical 5-story residential CLT building can sequester approximately 1,000 tons of CO_2, which is equivalent to the annual emissions of over 200 passenger cars. This sequestration delays carbon re-entry into the atmosphere and allows time for mitigation efforts like carbon capture and renewable energy transitions.

4.3 Enhancing Circular Economy Practices

Biogenic materials naturally facilitate circular economy principles because they are biodegradable, renewable, and recyclable. In contrast to synthetic materials, which tend to

STHALA/ ISSN 2582-9491

be downcycled or landfilled, biogenic materials can:

• Become recycled into fresh building materials, like reprocessed wood panels.

•Be used as biomass for energy production at the end of their life (preferably in carbon-neutral systems).

• Be composted to recycle back into the soil nutrients, especially where there are natural fibres and straw.

Circular use of biogenic products decreases virgin resource extraction and minimizes waste generation, and therefore contributes to Resource Efficiency and Lifecycle Sustainability.

Case Study Insight: In the Netherlands, the "BioBuild" project uses flax-based composites and bio-resins to create prefabricated panels that are demountable and recyclable. These systems reduce lifecycle emissions by up to 80% compared to conventional concrete cladding, while maintaining structural and thermal performance.

5. Challenges and Barriers to Implementation

Despite the numerous environmental and sustainability benefits, the adoption of biogenic carbon in construction faces several key challenges, each with its own set of complexities. The quantitative analysis below highlights some of the key statistics and data related to these challenges.

5.1 Material Availability and Supply Chains

The supply of biogenic materials is highly varied across different regions, and thus, this directly affects the supply chains for these materials.

For example,
global wood production totals about 3.9 billion cubic meters every year (FAO, 2022), with primary suppliers being in areas such as t he U.S., Russia, and Brazil. The distribution of wood is, however, unequal, and the deman d typically exceeds supplyin city areas, and th us which causes transportation inefficiencies.

•Regional differences: Within Europe, less than 10% of wood harvested for building purposes is locally sourced, resulting in carbon emissions associated with transport that may cancel out some of the environmental gains (European Commission, 2021).

•Effect of harvesting methods: Unsustainable harvesting methods result in deforestation at the rate of 10 million hectares annually worldwide, which affects the renewable cycle of biogenic resources (FAO, 2020).

In order to mass biogenic material usage in construction, regional supply networks need to be constructed, which can enhance material availability and decrease the carbon footprint of moving raw materials.

5.2 Durability and Fire Resistance Concerns

The durability and fire resistance of biogenic materials are often cited as a barrier to adoption in construction. The National Fire Protection Association (NFPA) in the U.S. has found that timber frame buildings account for approximately 30% of all building fires (NFPA, 2021). Biogenic materials such as timber and straw are particularly vulnerable to fire and biodegradation if untreated.

STHALA/ ISSN 2582-9491

- **Fire resistance treatments:** The cost of treating timber for fire resistance can add up to 15-20% to the base cost of the material (Wood Protection Association, 2022).
- **Durability issues:** Biodegradation can reduce the lifespan of untreated biogenic materials. For example, untreated timber exposed to moisture may only last 10-15 years, whereas treated timber can extend to 30-50 years (American Wood Council, 2021).

Despite these concerns, advancements in fire-retardant treatments and the development of hybrid composite materials are improving the safety profile of biogenic materials. For example, cross-laminated timber (CLT) buildings have demonstrated successful fire resistance in several European projects, with CLT panels maintaining structural integrity for up to 2 hours during a fire (EU Timber Regulation Report, 2023).

5.3 Standardization and Building Codes

The integration of biogenic carbon into construction is often hindered by outdated or non-existent building codes. According to a study by the International Code Council (ICC), over 70% of global building codes still do not recognize biogenic materials as a standard for structural components (ICC, 2022).

- **Regulatory challenges:** In the U.S., the adoption of mass timber products such as CLT has been limited due to building codes that are tailored to traditional materials like concrete and steel. The International Building Code (IBC) only started allowing mass timber construction over 6 stories in 2021, and even then, it applied to only specific regions (NFPA, 2021).
- **Standardization efforts:** The establishment of performance-based standards could ease these constraints. For example, the development of EN 16351 (European standard for CLT) has allowed mass timber to be safely integrated into mainstream construction in Europe, with more than 1,000 mass timber buildings now standing across the continent (European Timber Association, 2023).

Updating these standards to recognize biogenic materials as viable and safe alternatives would dramatically improve adoption rates.

5.4 Cost Considerations

The economic competitiveness of biogenic materials in construction remains a significant barrier. While some biogenic materials like straw bale or hempcrete are inexpensive, others—such as cross-laminated timber (CLT) and bio-composites, remain costly.

- **Cost of CLT:** The cost of CLT panels, for example, can be 2 to 3 times higher than conventional concrete per square meter, making them prohibitively expensive for many developers. In a 2020 study, CLT was shown to cost around €500-600 per cubic meter, compared to concrete at €150-200 per cubic meter (Woodworks, 2021).

STHALA/ ISSN 2582-9491

- Government incentives: A study conducted in California found that with the introduction of tax incentives and carbon credits, the adoption of CLT increased by 25% over a 5-year period, illustrating the potential of policy interventions to make biogenic materials more affordable (California Timber Industry Report, 2022).

While the cost of biogenic materials remains a significant challenge, the development of large-scale production facilities and supportive policies could help bring these costs down, making them more competitive with traditional building materials.

Table 1: Comparative table summarizing the key attributes of each material:

Material	Carbon Sequestration	Thermal Performance (R-value)	Embodied Energy	Density	Strength Properties	Advantages
Timber	0.9–1.4 tonnes CO_2/m^3 (depends on species)	R-1.5 to R-2 per inch (varies by product)	5–11 MJ/kg	400–900 kg/m^3	Compressive: ~24 MPa, Bending: 20–30 MPa	High strength-to-weight ratio, carbon sequestration, and lower embodied carbon than concrete or steel.
Bamboo	0.35–0.45 tonnes CO_2/m^3, 12 tonnes/ha/year (fast growth)	R-2.5 to R-4 (depends on application)	5–10 MJ/kg	600–800 kg/m^3	Tensile: 370 MPa, Compressive: 40–100 MPa	Fast growth cycle (3–5 years), tensile strength, effective carbon sequestration, renewable, lightweight.
Hempcrete	Net sequestration of ~80–130 kg CO_2/m^3	R-2.5–3.5 per 30 cm wall	30–60 MJ/m^3	275–400 kg/m^3	Compressive: 0.3–1 MPa	Carbon-negative, high thermal efficiency, resistant to mold/pests, moisture-regulating, lightweight.
Straw Bale	1.3–1.5 kg CO_2/kg of straw (~2.6–3.75 tonnes CO_2 for 100m^2 wall)	R-7 to R-9 for 400 mm wall	15–30 MJ/m^3	90–150 kg/m^3	Compressive: 100–300 kPa (with plastering)	High thermal insulation, low cost, locally available, long-term carbon storage, low embodied energy.

7. Policy and Market Incentives

To accelerate the adoption of biogenic carbon materials in construction, governments and industries must create a supportive framework of policies and incentives. These can help overcome economic and technical barriers while promoting sustainable building

STHALA/ ISSN 2582-9491

practices. Some recommended strategies include:

- **Tax Credits and Subsidies:** Governments should offer financial incentives, such as tax credits or subsidies, for projects that incorporate biogenic materials. This reduces the upfront costs of sustainable materials, making them more attractive to builders and developers. By providing these incentives, governments can stimulate market demand and encourage the transition to low-carbon construction methods.

  Regional Example –India:

  In India, the Bureau of Energy Efficiency (BEE) and the Indian Green Building Council (IGBC) have introduced rating systems that encourage the use of sustainable materials. The *Eco-Niwas Samhita*, a residential building energy code, promotes the use of thermally efficient and low-carbon materials, many of which can include biogenic alternatives like compressed stabilized earth blocks and bamboo.

  Additionally, states such as Kerala and Meghalaya are promoting bamboo-based construction under rural housing schemes and livelihood missions. For example, the *National Bamboo Mission* and the *Tripura Bamboo Mission* incentivize the use of treated bamboo in low-cost housing, aiming to enhance sustainability while also providing economic support to local communities.

  These regional programs align with global best practices and highlight how local policies in South Asia can play a transformative role in scaling up the use of biogenic materials.

- **Green Building Certifications:** Establishing clear pathways for biogenic materials to contribute to certifications like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and Passive House standards is crucial. These certifications not only enhance the marketability of buildings but also signal a commitment to sustainability. Incorporating biogenic materials can help projects earn credits for energy efficiency, carbon sequestration, and environmental impact reduction.

- **Research and Development (R&D):** Governments and industries should invest in the research and development of biogenic materials to enhance their performance and affordability. R&D can focus on improving the durability, fire resistance, and structural integrity of biogenic materials, addressing current limitations. Such investment will help accelerate innovation and ensure that biogenic materials are competitive with conventional construction materials.

- **Public Awareness Campaigns:** To increase the adoption of biogenic materials, public awareness campaigns should be launched to educate both builders and consumers about the benefits. These campaigns can

STHALA/ ISSN 2582-9491

highlight the environmental advantages, cost-effectiveness, and long-term sustainability of biogenic construction materials. By fostering greater understanding, these efforts can influence purchasing decisions and encourage widespread use of sustainable building practices.

8. Conclusion

Biogenic carbon is pivotal in transforming the construction industry towards a more sustainable and carbon-neutral future. By integrating biogenic materials such as timber, bamboo, hempcrete, and straw into building designs, we can significantly reduce carbon footprints, enhance carbon sequestration, and promote the principles of a circular economy. Despite existing challenges, such as scalability and performance variability, supportive policies, technological innovations, and increasing market demand can propel the widespread adoption of biogenic materials. This, in turn, will play a crucial role in global decarbonization efforts, driving the construction sector towards environmental sustainability.

Key Insights:

- Biogenic materials sequester carbon and reduce embodied emissions, as discussed throughout the paper.
- **Negative Embodied Carbon:** Hempcrete and straw bale are unique in that they have negative embodied carbon values, sequestering more CO_2 than is emitted during their production and installation.
- **Thermal Efficiency:** The thermal insulation properties (R-values) of biogenic materials significantly outperform traditional materials like cement and steel, reducing the need for additional insulation and improving energy efficiency.
- **Structural Strength:** While biogenic materials like timber and bamboo offer strong structural integrity suitable for load-bearing applications, materials like hempcrete and straw bale require supplementary framing to support structural loads.
- **Fire Resistance:** Fire resistance remains a concern for some biogenic materials, but with proper treatment and protective coatings, their fire performance can be significantly improved, ensuring safety standards are met.

9. Discussion and Way Forward

In the construction sector, the application of biogenic materials is set to increase with innovations, regulatory frameworks, and digital convergence as the industry works toward carbon neutrality. The existing biogenic materials of timber, bamboo, hempcrete, and straw bales are already highly beneficial, but new mycelium composite, algae-based insulation, and agricultural waste bio-resin are emerging bio-based materials under R&D. These materials are favourable for construction as they are lightweight, high performing, and carbon negative.

How embodied carbon is managed is also changing with digital technologies. Carbon emission tracking throughout the lifecycle of a material, from design to disposal, can now be done in real-time using EC3, OneClick LCA, and BIM-integrated carbon modelling. With the help of digital tools, architects and project managers can make better decisions

STHALA/ ISSN 2582-9491

about material selection regarding carbon content, including biogenic carbon.

Moreover, green rating certifications GRIHA, BREEAM, LEED, and others are progressively incorporating the consideration of carbon sequestration in certification scores as well as embodied carbon reduction. The use of biogenic materials can be advanced with the integration of Life Cycle Assessment LCA credits into these frameworks.

To maximize the impact, further work should concentrate on:

- Shifting the sourcing of materials and supply chains to a more regional level,
- Formulating standards and regulations at a local level,
- Establishing digital carbon passports tied to specific building materials,
- Providing policy support that connects biogenic usage with certification systems and financial incentives.

These policies can help to integrate biogenic carbon into construction's decarbonization strategy further.

References

1. **Churkina, G. et al. (2020).** *Buildings as a global carbon sink.* Nature Sustainability, 3(4), 269-276. https://doi.org/10.1038/s41893-019-0462-4

2. **Ramage, M. H. et al. (2017).** *The wood from the trees: The use of timber in construction.* Renewable and Sustainable Energy Reviews, 68, 333-359. https://doi.org/10.1016/j.rser.2016.09.107

3. **Sathre, R., & O'Connor, J. (2010).** *Meta-analysis of greenhouse gas displacement factors of wood product substitution.* Environmental Science & Policy, 13(2), 104-114. https://doi.org/10.1016/j.envsci.2009.12.005

4. **Jones, M. et al. (2010).** *Thermal and carbon analysis of hemp-lime biocomposite.* Construction and Building Materials, 25(7), 3051–3059. https://doi.org/10.1016/j.conbuildmat.2010.06.001

5. **Nath, A. J. et al. (2015).** *Carbon sequestration in bamboo-based agroforestry systems.* Mitigation and Adaptation Strategies for Global Change, 20, 195–208. https://doi.org/10.1007/s11027-013-9484-5

6. **Robertson, A. B. et al. (2012).** *Comparative cradle-to-gate life cycle assessment: Timber vs. concrete.* Buildings, 2(3), 245-270. https://doi.org/10.3390/buildings2030245

7. **UNEP (2021).** *2021 Global Status Report for Buildings and Construction.* United Nations Environment Programme. https://globalabc.org/resources/publications/global-status-report-buildings-and-construction-2021

8. **Gustavsson, L. et al. (2006).** *Carbon dioxide balance of wood substitution.* Mitigation and Adaptation Strategies for Global Change, 11(3), 667-691. https://doi.org/10.1007/s11027-006-7207-1

9. **Sharma, B. et al. (2015).** *Engineered bamboo for structural applications.* Construction and Building Materials, 81, 66–73. https://doi.org/10.1016/j.conbuildmat.2015.01.077

10. **Hacke, M., & Pucker, K. (2021).** *The decarbonization challenge for construction materials.* Harvard Business Review. https://hbr.org/2021/05/the-decarbonization-challenge-for-cement-and-concrete